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Exploring the potential of Mushroom powder (*Agaricus bisporus*) on sausage production and quality parameters

Exploración del potencial del polvo de champiñón (*Agaricus bisporus*) en la producción de embutidos y parámetros de calidad

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ABSTRACT

This study aimed to develop an innovative version of traditional Turkish fermented sausages enriched with dietary fiber. For this purpose, cultivated mushroom powder (*Agaricus bisporus*) was incorporated into sausage formulations at different concentrations (5%, 8%, and 10%), and its effects on quality characteristics were evaluated during storage (0, 7, 14, 21, and 28 days). The influence of mushroom powder on physicochemical, microbiological, textural, and sensory properties was investigated. The results revealed significant differences among experimental groups in terms of dry matter, color, fat, protein, dietary fiber, thiobarbituric acid reactive substances, and texture ($P<0.05$). No significant changes were observed in pH or residual nitrite levels ($P>0.05$). Microbiological evaluation indicated significant variations in lactic acid bacteria counts on days 1, 4, 7, and 21 ($P<0.05$), whereas no significant differences were detected on days 0, 14, and 28 ($P>0.05$). In sensory analysis, color did not differ significantly among storage days ($P>0.05$); however, significant differences were observed among treatments ($P<0.05$), with the control group receiving the highest color scores, particularly on day 7. Regarding flavor, the Sausage with 5% mushroom powder addition group showed significant differences between day 7 and the other storage days ($P<0.05$). The highest flavor score was recorded for Sausage with 5% mushroom powder addition on day 7, while Sausage with 10% mushroom powder addition consistently exhibited the lowest scores throughout storage. On the seventh day of storage, sausages containing 5% mushroom powder received more favorable scores for flavor, texture, and overall acceptability compared to the control group; however, only the flavor parameter was statistically significant ($P<0.05$). Overall, supplementation with mushroom powder improved lipid oxidation stability and color attributes while enhancing dietary fiber content. These findings suggest that Agaricus bisporus powder can be effectively used to improve the quality and nutritional value of fermented sausages during storage.

Key words: *Agaricus bisporus;* dietary fiber; fermented sausage; mushroom powder

RESUMEN

Este estudio tuvo como objetivo desarrollar una versión innovadora de salchichas turcas fermentadas tradicionales enriquecidas con fibra dietética. Para este propósito, se incorporó polvo de *Agaricus bisporus,* un hongo cultivado, en formulaciones de salchichas en diferentes concentraciones (5 %, 8 % y 10 %), y se evaluaron sus efectos sobre las características de calidad durante el almacenamiento (0, 7, 14, 21 y 28 días). Se examinó la influencia del polvo de hongo en las propiedades fisicoquímicas, microbiológicas, texturales y sensoriales. Los resultados mostraron diferencias significativas entre los grupos experimentales en cuanto a materia seca, color, grasa, proteína, fibra dietética, Sustancias Reactivas al Ácido Tiobarbitúrico y textura ($P<0,05$). No se observaron cambios significativos en el pH ni en el nitrito residual ($P>0,05$). La evaluación microbiológica indicó variaciones significativas en los recuentos de bacterias de ácido láctico en los días 1, 4, 7 y 21 ($P<0,05$), pero no en los días 0, 14 y 28 ($P>0,05$). En el análisis sensorial, el color no mostró diferencias significativas entre los días de almacenamiento ($P>0,05$); sin embargo, el grupo control presentó diferencias significativas en comparación con los demás tratamientos ($P<0,05$), alcanzando las puntuaciones más altas, especialmente en el día 7. En términos de sabor, el grupo de las salchichas con un 5 % de adición de polvo de champiñones. mostró diferencias significativas entre el día 7 y los demás días de almacenamiento ($P<0,05$). La puntuación más alta se registró en las salchichas con un 5 % de adición de polvo de champiñones en el día 7, mientras que en las salchichas con un 10 % de adición de polvo de champiñones presentaron los valores más bajos durante todo el almacenamiento. En el séptimo día de almacenamiento, el grupo de salchichas que contenía 5 % de polvo de champiñones recibió puntuaciones más positivas en términos de sabor, textura y aceptabilidad general en comparación con el grupo de control, pero solo el parámetro de sabor fue estadísticamente significativo ($P<0,05$). En general, la suplementación con polvo de hongo mejoró la estabilidad de la oxidación de lípidos y los atributos de color, al mismo tiempo que mejoró el contenido de fibra dietética. Estos hallazgos sugieren que el polvo de *Agaricus bisporus* se puede utilizar para mejorar la calidad y el valor nutricional de las salchichas fermentadas durante el almacenamiento.

Palabras clave: *Agaricus bisporus;* fibra dietética; embutido fermentado; polvo de hongo

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INTRODUCTION

Meat is composed of animal tissues such as muscle, fat, and connective tissue. It is an important source of animal protein and fat in the nutrition of humans and other living creatures. In addition to containing high-quality protein, it provides essential nutrients, including B vitamins and minerals such as iron, which are vital for human health [1].

Meat is a source of both saturated and unsaturated fatty acids, mainly palmitic, oleic, and linoleic acids [2]. Recently, the consumption of processed meat products has been increasing, driven by factors such as taste, price, and health, microbiological, and chemical safety concerns. Modern consumers are increasingly opting for products that are natural, minimally processed, and easy to use [3].

Meat products such as sausages, hot dogs, salami, sausages, and hamburgers are considered excellent sources of high-quality protein, fat, and minerals [4]. Among these, sausages are a widely consumed product valued for their high protein and energy content [5].

Various production techniques exist, including dry, soft, heat-treated, and fermented. Fermented sausages are obtained by pretreating raw materials and then stimulating the growth of specific microorganisms under controlled conditions [6]. These microorganisms break down polysaccharides, lipids, and proteins, contributing to the development of the final product's distinctive aroma, taste, and texture. Recent developments in the food sector emphasize the use of natural additives in sausage production, aiming to meet consumer expectations while addressing food safety and health concerns [6, 7].

In this context, mushrooms have gained interest as functional ingredients in meat products. Early efforts focused on adding fresh mushrooms to meat-based foods to provide plant-based alternatives. For example, ground *Pleurotus sajor caju* mushrooms have been tested as a substitute in chicken and beef patties [8, 9].

Mushrooms are nutrient-rich and offer favorable fatty acid profiles, characterized by high protein and polysaccharide content, low fat levels, and a higher proportion of monounsaturated and polyunsaturated fatty acids. They are also important sources of phenolic compounds, vitamins, and essential minerals [10].

Among them, Agaricus species, commonly called "wild mushrooms," include both edible and toxic varieties. The white button mushroom, *Agaricus bisporus* , is the most widely consumed species due to its nutritional value and availability [11].

Studies have shown that the dried stems of *A. bisporus* contain between 38.3% and 48.9% carbohydrates, between 17.7% and 23.3% fiber, between 7.77% and 11.00% ash, and between 2.53% and 3.92% fat [12]. Rich in amino acids, these fruits provide all nine essential amino acids needed by humans [13] and are an excellent source of vitamins A, B, C, and D, as well as antioxidants and polyphenols with potential health benefits against cardiovascular and metabolic diseases [14, 15].

The incorporation of mushroom powder into traditional fermented meat products, such as sausage, is considered promising for improving their nutritional and functional qualities [16, 17]. Mushrooms contribute antioxidant and antimicrobial activities, which could improve product stability and safety [18].

This study investigates the effects of adding *A. bisporus* mushroom powder to fermented Turkish sausages on their microbiological, physicochemical, textural, and sensory properties. Using higher supplementation levels (with concentrations rarely exceeding 5%) than those commonly used in previous studies (5, 8, and 10%), this research provides a more comprehensive assessment of the role of mushroom powder in sausage production. Given the limited scientific data available on this topic, this study aims to contribute to both industrial and academic research and to offer insights into how mushroom powder can improve the quality, safety, and consumer acceptance of fermented sausages in terms of microbiological and sensory properties.

MATERIALS AND METHODS

Collection and powdering of mushroom samples

In the present study, mushrooms were washed and sliced to obtain *A. bisporus* mushroom powder. The mushrooms were oven-dried. The drying process was carried out at 80°C for 3 to 5 hours (h) (Wartmann WM–2206–DH, Türkiye). Subsequently, the dried mushrooms were ground into powder using a mechanical grinder (Sinbo, SCM–2934, Türkiye). The steps required for processing *A. bisporus* samples into mushroom powder are numbered 1 to 5 and are shown in FIG. 1.

FIGURE 1. Production process of *Agaricus bisporus* powder: (1) fresh mushroom selection; (2) slicing; (3) drying; (4) dehydrated slices; (5) milling to obtain fine powder

Preparation of experimental sausage samples

In fermented sausage production, minced meat and fat components obtained from 3–year-old Simmental carcasses were prepared and mixed with the spices, curing salt, ascorbic acid, sugar, and mushroom powder additive specified in the formulation at the determined ratios. A mixture of *Lactobacillus sakei* (B2 SafePro®, CHR-Hansen, Hørsholm, Denmark) and *Staphylococcus carnosus* (BFL-T03, CHR-Hansen, Hørsholm, Denmark) was used as the commercial starter culture in production. After the addition of the starter culture, the mixture was homogenized and allowed to rest under appropriate conditions, re-minced, stuffed into casings, and subsequently transferred to the fermentation (ripening) stage.

Fermentation was carried out in controlled ripening chambers with an air velocity of 1–1.5 m·s^{-1} for a total of 6–7 days (d) under gradually decreasing temperature and relative humidity conditions. Specifically, during d 0–2, samples were maintained at 24°C and 95% relative humidity; on d 3 at 22°C and 90% relative humidity; on d 4 at 20°C and 85% relative humidity; on d 5 at 18°C and 80% relative humidity; and on d 6–7 at 16°C and 75% relative humidity. Following fermentation, the samples were stored at 4°C under 40–50% relative humidity. Physicochemical and microbiological analyses were conducted on storage d 0, 7, 14, 21, and 28. In addition to the control group, three experimental groups were created with mushroom powder addition rates of 5%, 8%, and 10%. The supplements used in fermented sausage production and the applied addition rates are presented in FIG. 2.

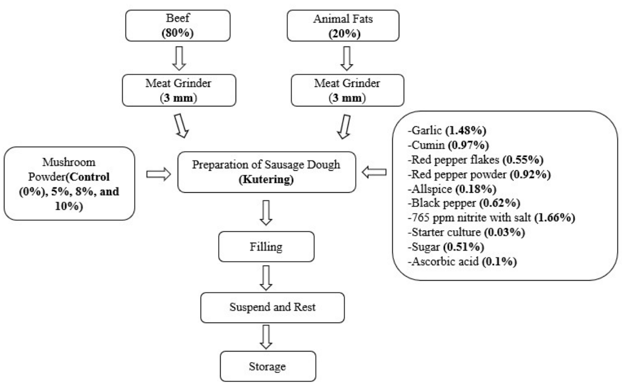

FIGURE 2. Flowcharts of the sausage manufacturing process

Physicochemical analyses

Ten grams of experimental sausage samples were weighed, homogenized with 90 mL of distilled water, and measured using a HORIBA (LAQUA, PH210–K, Japan) pH meter [19]. Dry matter values were calculated according to Association of Official Analytical Chemists (AOAC), 1990 [20]. The Soxhlet method was used to determine the fat content of the experimental sausage samples. The percentage of fat in the samples was calculated according to AOAC 2000 [21].

The protein content of experimental sausage samples was accurately determined using the Dumas method with a Gerhardt DUMATHERM® N PRO, C. Gerhardt GmbH & Co. KG (Germany) device [22]. Thiobarbituric acid reactive substances (TBARS) value was determined spectrophotometrically using the modified version of the methods reported by Tarladgis *et al.* and Jin *et al.* [23, 24].

The dietary fiber content of the experimental sausage samples was determined according to AOAC Method No. 985.29 [25]. Residual nitrite was analyzed using HPLC/DAD (Agilent, 1100series, USA) with a PRP-X100 column (5 µm, 150 × 4.6 mm) at a flow rate of 2 mL·min^{-1}. The results were calculated from a nitrite standard curve and expressed as mg·kg^{-1} [26]. The color intensity of the experimental sausage samples was measured using a colorimeter (CR–400 Minolta Co, Osaka, Japan). Three color parameters (L*, a*, b*) were measured with the device [27].

Texture profile analysis

For texture profile analysis (TPA), experimental sausage samples were cut into 1.5 cm thick slices using a sharp knife. Texture analyses of the cylindrical sausages were performed using a texture analyzer (Stable Micro Systems TA, HD Plus Connect Texture Analyzer, England). Springiness, hardness, adhesiveness, resilience, and chewiness parameters were calculated from the data recorded by the device [28].

Microbiological Analyses

Microbiological analyses were conducted on storage d 0, 7, 14, and 28. In addition, to monitor early-stage microbial changes during storage, analyses were also performed on d 1 and 4. Sausage samples (25 g) were placed in sterile stomacher bags and homogenized with 225 mL of buffered peptone water for 2 min. Serial dilutions were prepared from the resulting homogenate and appropriate dilutions were inoculated by the spread or pour plate method. Total mesophilic aerobic bacteria count was assessed on Plate Count Agar (PCA; Merck 1.05463, Darmstadt, Germany) after incubation at 30°C for 24–48 h. *L. sakei* counts were determined on Man Rogosa Sharpe Agar (MRS; Oxoid CM361, Basingstoke, UK) following incubation at 30°C for 48–72 h under anaerobic conditions generated using an Anaerocult/Anaerogen system in an anaerobic jar. *S. carnosus* counts were assessed on Baird Parker Agar (BPA; Merck 050118, Germany) after incubation at 37°C for 24 h. Coliform and Enterobacteriaceae counts were carried out on Violet Red Bile Agar (VRBA; Merck 1.10275) and Violet Red Bile Dextrose Agar (VRBD; Merck 1.10275, Germany) by the pour plate method, respectively, with 24 h incubation at 37°C [29].

Yeast and mold counts were determined on Potato Dextrose Agar (PDA; Difco, B13, USA) after 5–7 d of incubation at 25°C [29, 30]. *Salmonella* spp. isolation was carried out according to the ISO 6579:2002 standard, and *Escherichia coli* enumeration was carried out on Tryptone Bile X-Glucuronide Agar (TBX; Merck 1.16122, Germany) according to the ISO standard [31].

Sensory evaluation

Sensory evaluation of the sausages was carried out at predetermined storage intervals by a trained panel of 10 academics and graduate students from the Department of Food Hygiene and Technology at Burdur Mehmet Akif Ersoy University, who are experienced in conducting routine sensory analyses. Before sensory evaluation, sausage samples were cooked in a pan for 2 min per side, for a total of 4 min. Color, odor, taste, texture, and overall acceptability were assessed using a 9–point hedonic scale (1 = dislike extremely; 9 = like extremely) to determine the degree of liking. Panelists evaluated the samples individually under controlled conditions [32].

Statistical Analyses

Data obtained from the current study were analyzed using SPSS software (Version 23.0, IBM Corp., Armonk, NY, USA). One-way analysis of variance (ANOVA) was performed to determine significant differences between groups. When significant differences were observed, means were compared using the Tukey post-hoc test. The data are expressed in the tables as Arithmetic Mean ± Standard Deviation ($\bar{X} \pm SD$), with a level of error of 0.05.

RESULTS AND DISCUSSION

The changes in physicochemical (pH, dry matter, fat, protein, TBARS, dietary fiber, and residual nitrite) results for the experimental samples are presented in TABLE I.

TABLE I
Physicochemical analysis results of experimental sausage samples

Parameters	Storage period (Days)	Physicochemical Analysis			
		Groups ($\bar{X} \pm SD$)			
		Control	**SMP5**	**SMP8**	**SMP10**
pH	0	5.89 ± 0.10^{aA}	5.90 ± 0.07^{aA}	5.93 ± 0.05^{aA}	6.06 ± 0.04^{aA}
	7**	4.70 ± 0.01^{bC}	4.68 ± 0.00^{bC}	4.82 ± 0.00^{aBC}	4.62 ± 0.01^{cC}
	14**	4.68 ± 0.01^{cC}	4.78 ± 0.00^{abBC}	4.77 ± 0.00^{abBC}	4.89 ± 0.01^{aB}
	21	4.90 ± 0.08^{aB}	4.93 ± 0.12^{aB}	4.72 ± 0.06^{aC}	4.81 ± 0.02^{aB}
	28**	4.73 ± 0.04^{bBC}	4.81 ± 0.01^{abBC}	4.88 ± 0.04^{aB}	4.91 ± 0.05^{aB}
Dry matter (%)	0**	55.85 ± 0.54^{cE}	56.42 ± 0.26^{cE}	57.44 ± 0.05^{bE}	59.57 ± 0.47^{aE}
	7**	63.78 ± 0.74^{bD}	65.36 ± 0.47^{abD}	65.03 ± 1.10^{abD}	66.77 ± 0.55^{aD}
	14**	67.14 ± 0.06^{cC}	67.70 ± 0.17^{bC}	67.98 ± 0.22^{bC}	70.67 ± 0.24^{aC}
	21**	69.98 ± 0.44^{cB}	71.70 ± 0.39^{bB}	72.32 ± 0.10^{bB}	75.79 ± 0.60^{aB}
	28**	73.11 ± 0.32^{cA}	75.35 ± 0.38^{bA}	76.21 ± 0.87^{bA}	79.93 ± 0.52^{aA}
Fat (%)	0**	33.65 ± 0.19^{aD}	28.91 ± 0.05^{bD}	24.55 ± 0.46^{cC}	22.08 ± 0.02^{dD}
	7**	34.27 ± 0.85^{aD}	33.78 ± 0.15^{aB}	27.61 ± 0.18^{bB}	26.12 ± 0.20^{cC}
	14**	35.64 ± 0.35^{aC}	32.71 ± 0.10^{bC}	27.51 ± 0.49^{cB}	26.95 ± 0.12^{cB}
	21**	36.85 ± 0.17^{aB}	34.13 ± 0.54^{bB}	27.96 ± 0.16^{cB}	26.78 ± 0.13^{dB}
	28**	38.13 ± 0.04^{aA}	36.44 ± 0.64^{bA}	30.25 ± 0.46^{cA}	29.24 ± 0.06^{cA}
Protein	0**	15.66 ± 0.06^{dE}	18.49 ± 0.04^{cD}	22.00 ± 0.73^{bD}	26.62 ± 0.03^{aD}
	7**	21.59 ± 0.05^{cD}	22.02 ± 0.13^{cC}	23.22 ± 0.31^{bD}	27.11 ± 0.46^{aD}
	14**	24.08 ± 0.46^{cC}	26.38 ± 0.34^{bB}	27.81 ± 0.14^{aC}	28.63 ± 0.33^{aC}
	21**	24.99 ± 0.25^{dB}	27.83 ± 0.02^{cA}	29.23 ± 0.61^{bB}	31.55 ± 0.47^{aB}
	28**	26.31 ± 0.14^{dA}	28.24 ± 0.34^{cA}	30.64 ± 0.21^{bA}	32.87 ± 0.21^{aA}
TBARS (μmol MDA·kg^{-1})	0**	2.46 ± 0.05^{aA}	1.95 ± 0.14^{bB}	2.14 ± 0.07^{bB}	2.10 ± 0.10^{bC}
	7*	2.82 ± 0.10^{aA}	2.05 ± 0.08^{cB}	2.59 ± 0.22^{bAB}	2.53 ± 0.06^{bB}
	14**	2.75 ± 0.14^{aA}	2.31 ± 0.18^{bA}	2.50 ± 0.02^{abB}	2.72 ± 0.06^{aAB}
	21	2.67 ± 0.10^{aA}	2.34 ± 0.12^{aA}	2.40 ± 0.20^{aAB}	2.45 ± 0.25^{aB}
	28**	2.59 ± 0.19^{abA}	2.39 ± 0.12^{bA}	2.80 ± 0.36^{aA}	3.12 ± 0.05^{aA}
Dietary fiber (%)	0**	0.48 ± 0.01^{cB}	0.52 ± 0.005^{bA}	0.54 ± 0.01^{bD}	0.66 ± 0.02^{aB}
	7**	0.50 ± 0.02^{cA}	0.47 ± 0.006^{cC}	0.65 ± 0.01^{bB}	0.75 ± 0.01^{aA}
	14**	0.52 ± 0.01^{cA}	0.43 ± 0.005^{dD}	0.68 ± 0.01^{bA}	0.74 ± 0.02^{aA}
	21**	0.47 ± 0.02^{bB}	0.45 ± 0.005^{bC}	0.69 ± 0.01^{aA}	0.70 ± 0.01^{aAB}
	28**	0.47 ± 0.01^{dB}	0.54 ± 0.007^{cA}	0.62 ± 0.01^{bC}	0.67 ± 0.01^{aB}
Residual Nitrite (mg·kg^{-1})	0	10.89 ± 1.00^{aA}	11.03 ± 0.99^{aA}	10.92 ± 1.00^{aA}	10.47 ± 1.00^{aA}
	7	9.17 ± 1.01^{aAB}	9.98 ± 1.00^{aAB}	9.97 ± 1.00^{aAB}	9.93 ± 1.00^{aAB}
	14	8.75 ± 1.00^{aAB}	9.71 ± 1.05^{aAB}	8.71 ± 1.09^{aABC}	7.72 ± 0.99^{aBC}
	21	7.97 ± 1.00^{aB}	8.43 ± 1.00^{aB}	7.29 ± 1.00^{aBC}	7.12 ± 1.00^{aC}
	28	7.04 ± 1.00^{aB}	7.99 ± 1.08^{aB}	6.79 ± 1.00^{aC}	7.32 ± 1.03^{aBC}

Different lowercase letters (a-e) within the same row indicate significant differences among treatment groups, and different uppercase letters (A-E) within the same column indicate significant differences among storage times. Asterisks indicate levels of statistical significance (*P<0.05; **P<0.01). Control: Sausage without mushroom powder, SMP5: Sausage with 5% mushroom powder addition, SMP8: Sausage with 8% mushroom powder addition, SMP10: Sausage with 10% mushroom powder addition; $\bar{X} \pm SD$: Mean ± Standard deviation. Days 0 and 7 are the fermentation stage. MDA: Malondialdehyde

The pH value in fermented sausages should be below 5.4 [33]. In our experimental samples, the pH value dropped below this limit starting from the 7th day of ripening (TABLE I). Gençcelep and Zorba [34] and Stefanello [35] reported the increasing effect of mushroom powder addition on pH and the decrease in pH during storage. Similarly, in study, the pH value decreased during storage and increased as the mushroom concentration increased. Gençcelep and Zorba [34] reported that the decrease in pH during fermentation was primarily associated with organic acid production by lactic acid bacteria, whereas the subsequent increase observed during storage was attributed to protein degradation and the formation of basic nitrogenous compounds, including biogenic amines. In agreement with these findings, the decrease in pH observed in the present study during storage may be related to ongoing lactic acid production." was added to the rest of this sentence.

In study, dry matter values increased both during storage and as the mushroom concentration increased. The dry matter findings for our samples are shown in TABLE I. One study examined the dry matter content of sausages by adding different amounts (0.5, 1, and 2%) of mushroom powder (*A. bisporus*) at different storage times (0, 3, 6, 9, and 12 d) and reported that dry matter values increased throughout the storage period. The increase in mushroom concentration is thought to be related to the increased dry matter content of higher mushroom powder ratios [34].

According to the meat products circular, fermented sausages should have a maximum fat content of 40% [36]. This ratio ranged from 22.08% to 38.13% in experimental sausage samples. While an increase in fat content was observed during storage, a general decrease in fat content was observed with increasing mushroom powder concentration (TABLE I).

Similarly, it has been reported that the fat content of sausages in which different amounts of *Pleurotus sajor-caju* mushroom powder (0–6%) were added instead of chicken meat decreased depending on the concentration [37]. Özünlü and Ergezer [38], also reported that adding different amounts of dried *Pleurotus ostreatus* to beef salami reduced the fat content. Furthermore, a study in which sun mushrooms were added to pork sausages found an increase in fat content during storage [35]. These findings are consistent with the results of the present study.

The fruiting bodies of edible mushrooms generally contain between 19% and 35% protein [39]. The protein value in sausages should be at least 16% [33]. According to our findings, the protein value ranged from 15.66% to 32.87%. When the protein values were examined, a general increase in protein values was observed as the mushroom concentration increased on all storage days. The findings of the protein values are shown in TABLE I.

In a study conducted by Stefanello *et al.* [35], they added 0, 1, 2, and 4% sun mushroom to pork sausages and examined them on different days (0, 7, 14, 21, 28, and 35) over a 35–d period. They found that protein values increased with increasing mushroom concentration. In another study, mushroom powder was added to beef patties at different concentrations (0, 4, 8, and 12%), and the physical and chemical properties were examined on different storage days (d 0, 2, 4, and 6). Protein values were reported to increase with increasing mushroom concentration [40].

Another study examined the effect of adding shiitake (*Lentinula edodes*) mushroom powder at 1% and 4% levels to chicken nuggets on protein values, and showed that the nuggets with mushroom powder had increased protein content compared to standard nuggets [41]. These studies are consistent with the findings of our current study.

Dietary fiber contributes to product quality by improving textural properties in meat products and is generally used to reduce fat content [42]. Dietary fiber content in the sausage samples varied significantly among treatments. SMP10 consistently exhibited the highest values throughout the 28–d storage period, whereas SMP8 showed a slight but significant decrease on d 28. Minor fluctuations were observed in the control and SMP5 groups during storage. The reduction observed in SMP8 after an initial increase may be attributed to moisture loss, enzymatic interactions, or structural modifications of mushroom fibers within the meat matrix.

These findings suggest that moderate levels of mushroom addition may be more sensitive to prolonged storage conditions, while higher inclusion levels contribute to improved fiber stability. Dietary fiber results obtained in experimental sausage samples are presented in TABLE I. It has been reported that the amount of dietary fiber in chicken patties containing *P. sajor-caju* increased with increasing mushroom content [9].

Similarly, the amount of dietary fiber was reported to increase significantly with the addition of 1% and 4% *Lentinula edodes* (shiitake) powder to chicken nuggets [41]. These results are consistent with existing findings indicating that dietary fiber content increases with increasing mushroom powder concentration.

Lipid oxidation leads to the formation of compounds such as hydroperoxides, aldehydes, and ketones as a result of the reaction of polyunsaturated fatty acids with oxygen, leading to deterioration in taste, odor, and nutritional value in meat products [43, 44]. In this study, the highest TBARS value was determined in the SMP10 group on d 28 (3.12 ± 0.05 μmol MDA·kg^{-1}), and the lowest value was determined in the SMP5 group on d 0 (1.95 ± 0.14 μmol MDA·kg^{-1}).

Although mushroom powder is known to contain antioxidant compounds, a pronounced and sustained antioxidant effect was not observed throughout storage. While SMP5 exhibited lower TBARS values at the initial stages, higher inclusion levels (SMP8 and SMP10) showed increased lipid oxidation by d 28. This may be related to the limited stability of phenolic compounds during processing and storage or the variable effectiveness of natural antioxidants in meat systems, as previously reported in meat products [44]. The addition of mushroom powder decreased TBARS values compared to the control group (TABLE I).

The literature also provides evidence that the addition of mushroom powder to meat products may have an effect on lipid oxidation in meat products. It has been reported that the addition of *Volvariella volvacea* reduced peroxide values up to 4%, which may be due to the antioxidant effect of polysaccharides and polyphenols [45, 46]. It has also been reported that malondialdehyde levels decreased in chicken sausages with *Flammulina velutipes* powder added [47]. It has been reported that TBARS values increased during storage in beef patties containing *A. bisporus* and *P. ostreatus*, but a partial antioxidant effect was observed, especially at levels of 2.5–5% [48].

It was observed that residual nitrite values in experimental sausage samples decreased during the storage period. However, when residual nitrite values measurements on 0, 7, 14, 21 and 28 d were compared, the differences between the groups were found to be statistically insignificant ($P>0.05$). Findings in the literature on the effects of mushroom powder addition on nitrite content and oxidative stability in meat products are varied. Ghobadi *et al*. [49], reported that oxidative stability and sensory properties were improved when 1% *Ganoderma lucidum* mushroom powder was used in different sausage formulations or when combined with mushroom powder to reduce nitrite levels.

Similarly, Özünlü and Ergezer [38] reported that adding varying amounts of dried oyster mushrooms to beef salami increased residual nitrite content, but this value decreased as storage progressed. In the present study, mushroom powder addition had no significant effect on residual nitrite levels. However, residual nitrite content decreased progressively with extended storage time, which is consistent with the findings of Özünlü and Ergezer [38].

Color stands out as a decisive quality parameter in consumer perception and purchasing decisions. Currently, L*, a*, and b* are widely used as objective color parameters. Of these values, L* represents brightness, a* represents redness, and b* represents yellowness [50]. The red color in meat products is primarily associated with the myoglobin pigment. Processing methods, additives, and storage conditions influence color, and the a* value, in particular, is considered an objective indicator of red color quality. Sodium nitrate interacts with myoglobin to form nitrosomoglobin, which increases the stability of the red color and contributes to the visual appeal of the product and consumer preference [51, 52]. In the present study, L*, a*, and b* values decreased in sausage samples prepared with the addition of mushroom powder compared to the control group. Data on color parameters are presented in TABLE II.

There are numerous studies in the literature on the effects of mushroom powder addition on the color parameters of meat products. Gençcelep [53], reported that the L*, a*, and b* values in sausages with different levels of *A. bisporus* added during storage decreased significantly ($P<0.05$) with mushroom concentration and storage time. Similarly, Chockchaisawasdee *et al.* [54], found a decrease in L* values, a general decrease in a* and b* values, and only a statistically insignificant increase in the 90/10 group ($P>0.05$) when adding increasing amounts of oyster mushroom/rice supplement to pork sausages. Özünlü and Ergezer [38], also stated that adding *P. ostreatus* at different concentrations to beef salami reduced brightness (L*), redness (a*), and yellowness (b*) values depending on both the mushroom amount and storage time. A similar trend was reported by Jo *et al.* [47], who found that adding dried *F. velutipes* to chicken sausages significantly reduced the L* value, but there was no significant difference in the a* and b* values between the control and supplemented groups.

Texture is an important quality parameter that determines consumer acceptance in meat and meat products. Textural properties are affected by factors such as the gelation capacity of myofibrillar proteins, temperature, drying, maturation, and high pressure [55]. In this study, it was observed that hardness values decreased with increasing mushroom powder concentration, and this decrease was particularly pronounced in the SMP10 group. Hardness generally increased during storage ($P<0.05$). Chewiness

TABLE II
Color analysis results of experimental sausage samples

Parameters	Storage period (Days)	Color Analysis			
		Groups ($\bar{X}$ ± SD)			
		Control	SMP5	SMP8	SMP10
L*	0	49.58 ± 0.86^{aC}	42.32 ± 0.83^{cC}	40.17 ± 0.85^{cC}	44.59 ± 0.76^{bBC}
	7	50.61 ± 0.73^{bC}	46.09 ± 0.92^{cAB}	54.59 ± 0.86^{aA}	42.57 ± 0.83^{dCD}
	14	53.97 ± 0.85^{aB}	45.55 ± 0.76^{cB}	47.14 ± 0.73^{bcB}	47.82 ± 0.92^{bA}
	21	54.69 ± 0.86^{aB}	47.76 ± 0.86^{bAB}	45.76 ± 0.85^{bB}	41.61 ± 0.76^{cD}
	28	58.35 ± 0.74^{aA}	47.86 ± 0.92^{bA}	46.89 ± 0.70^{bcB}	44.89 ± 0.71^{cB}
a*	0	11.62 ± 0.92^{aA}	7.67 ± 0.80^{bA}	7.11 ± 0.79^{bB}	7.15 ± 0.88^{bA}
	7	13.25 ± 0.80^{aA}	9.95 ± 0.86^{bA}	10.14 ± 0.98^{bA}	8.42 ± 0.74^{bA}
	14	13.35 ± 0.93^{aA}	8.94 ± 0.80^{bA}	9.96 ± 0.79^{bA}	7.59 ± 0.88^{cA}
	21	12.54 ± 0.80^{aA}	8.25 ± 0.95^{bA}	8.26 ± 0.91^{bAB}	7.67 ± 0.73^{bA}
	28	13.27 ± 0.67^{aA}	8.50 ± 1.04^{bA}	7.31 ± 0.77^{bB}	8.87 ± 0.89^{bA}
b*	0	14.71 ± 0.84^{aA}	8.68 ± 0.73^{bA}	6.06 ± 0.67^{cB}	9.17 ± 01.02^{bA}
	7	12.39 ± 0.78^{aBC}	8.29 ± 0.67^{bA}	10.05 ± 0.83^{bA}	8.57 ± 0.76^{bA}
	14	9.75 ± 0.92^{aD}	8.51 ± 0.87^{aA}	10.03 ± 0.91^{aA}	6.14 ± 0.73^{bB}
	21	11.38 ± 0.67^{aCD}	6.34 ± 0.86^{bB}	7.43 ± 0.91^{bB}	7.18 ± 0.73^{bAB}
	28	14.17 ± 0.86^{aAB}	6.24 ± 0.86^{cB}	8.26 ± 0.93^{bAB}	9.33 ± 0.87^{bA}

Different lowercase letters (a-e) within the same row indicate significant differences among treatment groups, and different uppercase letters (A-E) within the same column indicate significant differences among storage times. Control: Sausage without mushroom powder, SMP5: Sausage with 5% mushroom powder addition, SMP8: Sausage with 8% mushroom powder addition, SMP10: Sausage with 10% mushroom powder addition; $\bar{X}$ ± SD: Mean ± Standard deviation. Days 0 and 7 are the fermentation stage decreased with increasing mushroom concentration, increasing until the 14th d of storage and then declining. Regarding springiness, the control group exhibited higher values than the mushroom-treated groups on d 0. However, no significant differences were observed between the control and treatment groups on d 7 and 14 ($P>0.05$). An increase in springiness was observed particularly in the SMP8 group during the later stages of storage (d 21 and 28). Nevertheless, mushroom powder addition did not result in a consistent or statistically significant increase in springiness across all treatments. Data on the texture profile are presented in TABLE III.

The effects of mushroom powder addition on the textural properties of meat products vary in the literature. In Cantonese sausages supplemented with *V. volvacea* (1–4%), no significant change in springiness was observed, while slight decreases in hardness, adhesiveness, and chewiness were reported [45]. Partial replacement of fat and salt in beef patties with *A. bisporus* and *P. ostreatus* powders (2.5% and 5%) during cold storage resulted in a decrease in springiness and consistency [46].

Similarly, Gizatova *et al.* [56] reported that the addition of oyster mushrooms reduced the toughness and improved chewiness of pork chops. Furthermore, in sausage formulations where winter mushroom powder (0–2%) was used as a phosphate substitute, a trend towards a decrease in hardness and chewiness was observed, although no significant difference was observed in the values of hardness and chewiness due to the higher dietary fiber content [57].

Because of their rich nutrient content, meat and meat products provide an ideal environment for microbial growth. It has been reported that coliform group microorganisms should not be present in high numbers in fermented sausage [58, 59]. According to the Turkish "Microbiological Criteria" regulation, acceptable limits for meat and meat products are as follows: total mesophilic aerobic bacteria (TMAB) count of 10^6–10^7 cfu /g (6–7 $\log_{10}$ cfu·g^{-1}), molds and yeasts not exceeding 10^3 cfu·g^{-1} or mL (3 $\log_{10}$ cfu·g^{-1}), and complete absence of *Salmonella* spp. and *E. coli* (0/25 g or mL). No upper limit is specified for starter cultures such as *S. carnosus* and *L. sakei* [36, 58, 59, 60].

TABLE III
Texture profile analysis results of experimental sausage samples

Parameters	Storage period (Days)	Texture Analysis — Groups ($\bar{X} \pm SD$) Control	SMP5	SMP8	SMP10
Hardness	0**	163.24 ± 5.03^{aD}	105.89 ± 3.01^{bC}	110.47 ± 8.09^{bC}	96.83 ± 14.66^{bAB}
	7**	180.90 ± 5.85^{aCD}	159.71 ± 8.59^{bD}	121.89 ± 5.84^{cC}	87.63 ± 1.34^{dB}
	14**	269.18 ± 21.4^{aBC}	240.50 ± 35.50^{aB}	229.38 ± 18.56^{aB}	101.01 ± 1.67^{bAB}
	21**	331.58 ± 15.4^{aAB}	273.42 ± 1.71^{bB}	263.99 ± 13.33^{bA}	105.63 ± 4.34^{cAB}
	28**	396.20 ± 64.33^{aA}	343.16 ± 2.47^{bA}	285.86 ± 5.17^{cA}	113.33 ± 6.53^{dA}
Adhesiveness	0	−2.46 ± 0.09^{aB}	−2.51 ± 0.05^{aA}	−3.31 ± 0.67^{aA}	−3.09 ± 0.30^{aA}
	7**	−2.78 ± 0.39^{bAB}	−2.40 ± 0.35^{bA}	−3.61 ± 0.21^{aA}	−1.57 ± 0.21^{cB}
	14**	−3.06 ± 0.12^{aA}	−2.24 ± 0.20^{bAB}	−2.74 ± 0.27^{abAB}	−2.98 ± 0.21^{aA}
	21**	−1.83 ± 0.18^{bC}	−1.23 ± 0.11^{cC}	−1.23 ± 0.12^{cC}	−3.29 ± 0.04^{aA}
	28**	−1.07 ± 0.15^{bD}	−1.38 ± 0.61^{bBC}	−1.76 ± 0.44^{bBC}	−3.04 ± 0.48^{aA}
Springiness	0**	0.94 ± 0.09^{aA}	0.69 ± 0.03^{bB}	0.70 ± 0.02^{bB}	0.73 ± 0.06^{bA}
	7	0.63 ± 0.10^{aB}	0.66 ± 0.03^{aB}	0.66 ± 0.02^{aB}	0.73 ± 0.13^{aA}
	14	0.65 ± 0.07^{aB}	0.93 ± 0.12^{aA}	0.80 ± 0.15^{aB}	0.80 ± 0.15^{aA}
	21*	0.78 ± 0.05^{bAB}	0.68 ± 0.06^{bB}	1.34 ± 0.33^{aA}	0.70 ± 0.03^{bA}
	28**	0.62 ± 0.12^{bB}	0.61 ± 0.02^{bB}	0.96 ± 0.02^{aAB}	0.69 ± 0.02^{bA}
Chewiness	0**	96.79 ± 4.51^{aBC}	76.18 ± 4.36^{bB}	46.60 ± 1.93^{cC}	42.05 ± 1.96^{cC}
	7**	80.33 ± 4.43^{aC}	70.85 ± 1.75^{aB}	55.95 ± 1.86^{bC}	50.09 ± 7.73^{bC}
	14**	254.38 ± 14.45^{aA}	144.83 ± 42.2^{bA}	216.50 ± 14.93^{aA}	94.64 ± 5.96^{bAB}
	21**	245.99 ± 32.33^{aA}	132.83 ± 10.03^{bA}	161.58 ± 21.9^{bB}	108.85 ± 8.23^{bA}
	28**	125.78 ± 1.46^{aB}	98.85 ± 3.17^{bAB}	60.86 ± 4.17^{dC}	82.63 ± 1.46^{cB}
Resilience	0**	0.25 ± 0.01^{bB}	0.26 ± 0.03^{bB}	0.28 ± 0.02^{bB}	0.36 ± 0.01^{aB}
	7**	0.25 ± 0.04^{bB}	0.27 ± 0.02^{bB}	0.38 ± 0.06^{bB}	0.64 ± 0.09^{aA}
	14	0.52 ± 0.07^{aA}	0.59 ± 0.07^{aA}	0.62 ± 0.01^{aA}	0.64 ± 0.09^{aA}
	21	0.56 ± 0.04^{aA}	0.63 ± 0.01^{aA}	0.66 ± 0.07^{aA}	0.61 ± 0.03^{aA}
	28	0.62 ± 0.03^{aA}	0.64 ± 0.03^{aA}	0.69 ± 0.01^{aA}	0.66 ± 0.02^{aA}

Different lowercase letters (a-e) within the same row indicate significant differences among treatment groups, and different uppercase letters (A-E) within the same column indicate significant differences among storage times. Asterisks indicate levels of statistical significance (*$P<0.05$; **$P<0.01$). Control: Sausage without mushroom powder, SMP5: Sausage with 5% mushroom powder addition, SMP8: Sausage with 8% mushroom powder addition, SMP10: Sausage with 10% mushroom powder addition; $\bar{X} \pm SD$: Mean ± Standard deviation. Days 0 and 7 are the fermentation stage

In study, TMAB values ranged from 5.89 to 8.42 $\log_{10}$ cfu·g^{-1}; *L. sakei* counts from 6.13 to 8.19 $\log_{10}$ cfu·g^{-1}; *S. carnosus* counts from 7.48 to 8.07 $\log_{10}$ cfu·g^{-1}; yeast counts from 2.08 to 2.88 $\log_{10}$ cfu·g^{-1}; and mold counts from 2.26 to 2.89 $\log_{10}$ cfu·g^{-1} on d 0 and 1. Molds were below detectable levels (< 10 cfu·g^{-1}) on subsequent d. Coliform group bacteria, Enterobacteriaceae, *Salmonella* spp., and *E. coli* remained below detectable levels (< 10 cfu·g^{-1}) throughout the study period. Changes in microbiological analysis values for experimental sausage samples are given in TABLE IV.

Microbiological quality is a critical parameter in fermented meat products in terms of product safety and shelf life, and similar trends have been reported in various studies in the literature. Nazlı [58], stated that the TMAB count in commercial fermented sausages ranged from 6.84 to 6.90 $\log_{10}$ cfu·g^{-1}. Gençcelep and Zorba [34], reported that the number of Enterobacteriaceae in sausages supplemented with *A. bisporus* powder at different rates (0.5, 1, and 2%) increased as the mushroom concentration increased but decreased during storage, falling below 10 $\log_{10}$ cfu·g^{-1} from the third day onwards.

TABLE IV
Microbiological analysis results of experimental sausage samples

Parameters	Storage period (Days)	Microbiological Analysis			
		Groups ($\bar{X}$ ± SD)			
		Control	SMP5	SMP8	SMP10
TMAB	0**	5.89 ± 0.07^{bC}	6.26 ± 0.08^{aE}	6.03 ± 0.04^{bE}	6.32 ± 0.09^{aE}
	1**	7.94 ± 0.02^{aB}	7.39 ± 0.05^{bD}	7.27 ± 0.06^{cD}	7.23 ± 0.03^{cD}
	4**	8.22 ± 0.10^{aA}	7.68 ± 0.08^{cC}	7.99 ± 0.15^{bA}	7.89 ± 0.09^{bBC}
	7**	8.18 ± 0.05^{abA}	8.42 ± 0.13^{aA}	7.93 ± 0.07^{cAB}	8.08 ± 0.08^{bA}
	14	7.89 ± 0.07^{aB}	7.92 ± 0.06^{aB}	7.91 ± 0.03^{aAB}	8.00 ± 0.12^{aAB}
	21**	7.94 ± 0.07^{aB}	8.02 ± 0.07^{aB}	7.53 ± 0.12^{bC}	7.66 ± 0.07^{bC}
	28**	7.89 ± 0.12^{aB}	7.45 ± 0.06^{bD}	7.76 ± 0.09^{aBC}	7.76 ± 0.12^{aBC}
Lactobacillus sakeii	0	6.13 ± 0.08^{aD}	6.29 ± 0.07^{aC}	6.34 ± 0.06^{aB}	6.82 ± 0.07^{aE}
	1**	7.73 ± 0.06^{aC}	7.76 ± 0.08^{aAB}	7.62 ± 0.03^{abA}	7.55 ± 0.06^{bCD}
	4**	7.99 ± 0.08^{aAB}	7.62 ± 0.09^{bB}	7.91 ± 0.07^{aA}	7.91 ± 0.06^{aAB}
	7**	8.19 ± 0.07^{aA}	7.81 ± 0.07^{cAB}	7.88 ± 0.09^{bcA}	8.07 ± 0.08^{abA}
	14	7.80 ± 0.08^{aBC}	7.82 ± 0.08^{aAB}	7.89 ± 0.06^{aA}	7.90 ± 0.10^{aAB}
	21**	8.02 ± 0.09^{aAB}	7.98 ± 0.09^{aA}	7.60 ± 0.09^{bA}	7.36 ± 0.09^{cD}
	28	7.71 ± 0.08^{aC}	7.66 ± 0.09^{aB}	7.56 ± 0.07^{aA}	7.74 ± 0.09^{aBC}
Staphylococcus carnosus	0**	7.54 ± 0.09^{bC}	7.52 ± 0.09^{bBC}	7.99 ± 0.09^{aA}	7.44 ± 0.09^{bC}
	1**	7.68 ± 0.10^{bB}	7.85 ± 0.11^{abA}	7.99 ± 0.08^{aA}	8.07 ± 0.09^{aA}
	4**	7.63 ± 0.09^{bB}	7.48 ± 0.09^{cC}	8.07 ± 0.09^{aA}	7.85 ± 0.09^{abAB}
	7**	7.84 ± 0.09^{aAB}	7.66 ± 0.09^{bBC}	7.52 ± 0.10^{bB}	7.91 ± 0.09^{aA}
	14**	7.50 ± 0.08^{cC}	7.72 ± 0.10^{bcAB}	7.88 ± 0.09^{abA}	8.06 ± 0.10^{aA}
	21**	7.97 ± 0.07^{aA}	7.80 ± 0.10^{aA}	7.50 ± 0.12^{bB}	7.54 ± 0.09^{bC}
	28	7.62 ± 0.12^{aB}	7.78 ± 0.10^{aAB}	7.83 ± 0.10^{aA}	7.63 ± 0.07^{aBC}
Yeast	0*	2.49 ± 0.13^{bA}	2.88 ± 0.11^{aA}	2.88 ± 0.12^{aA}	2.79 ± 0.12^{abA}
	1	2.62 ± 0.47^{aAB}	2.57 ± 0.47^{aAB}	2.21 ± 0.10^{aB}	2.58 ± 0.13^{aAB}
	4**	2.48 ± 0.12^{aAB}	2.08 ± 0.08^{bB}	2.14 ± 0.13^{bB}	2.60 ± 0.15^{aAB}
	7*	2.14 ± 0.12^{bB}	2.77 ± 0.12^{aA}	2.57 ± 0.40^{abAB}	2.30 ± 0.12^{abB}
	14	2.58 ± 0.11^{aAB}	2.40 ± 0.11^{aAB}	2.46 ± 0.11^{aAB}	2.48 ± 0.12^{aAB}
	21	2.80 ± 0.12^{aA}	2.88 ± 0.11^{aA}	2.91 ± 0.08^{aA}	2.71 ± 0.12^{aA}
	28	2.56 ± 0.12^{aAB}	2.82 ± 0.13^{aA}	2.62 ± 0.15^{aAB}	2.71 ± 0.12^{aA}
Mold	0**	2.89 ± 0.12^{aA}	2.29 ± 0.10^{cA}	2.59 ± 0.09^{bA}	2.65 ± 0.10^{abA}
	1	2.37 ± 0.11^{aB}	2.26 ± 0.17^{aA}	2.49 ± 0.09^{aA}	2.59 ± 0.10^{aA}
	4	BDL	BDL	BDL	BDL
	7	BDL	BDL	BDL	BDL
	14	BDL	BDL	BDL	BDL
	21	BDL	BDL	BDL	BDL
	28	BDL	BDL	BDL	BDL

Different lowercase letters (a-e) within the same row indicate significant differences among treatment groups, and different uppercase letters (A-E) within the same column indicate significant differences among storage times. Asterisks indicate levels of statistical significance (*P<0.05; **P<0.01). Control: Sausage without mushroom powder, SMP5: Sausage with 5% mushroom powder addition, SMP8: Sausage with 8% mushroom powder addition, SMP10: Sausage with 10% mushroom powder addition; $\bar{X}$ ± SD: Mean ± Standard deviation. Days 0 and 7 are the fermentation stage; TMAB: Total Mesophilic Aerobic Bacteria; BDL: Below Detectable Level

The same study reported that the lactic acid bacteria (LAB) count was 8.06 log_{10} cfu·g^{-1} in the control group and 7.76 log_{10} cfu·g^{-1} in the group with 1% mushroom powder added. Öksüztepe *et al*. [61], reported the average TMAB count in fermented sausage samples sold in Elâzığ as 8.75 log_{10} cfu·g^{-1}, the yeast and mold count as 3.08 log_{10} cfu·g^{-1}, and the LAB count as 8.56 log_{10} cfu·g^{-1}. Şimşek [59], reported that *Salmonella* spp., *E. coli*, and coliform bacteria growth was not observed in different sausages, while the yeast and mold level was 2.45 log_{10} cfu·mL^{-1}.

Similarly, Nagy *et al*. [62], did not detect *Salmonella* spp. in smoked sausages containing *A. bisporus* at different storage times and different ratios. These results are consistent with the absence of *Salmonella* spp. in study, indicating that the addition of mushroom powder and storage conditions did not adversely affect the microbiological quality parameters in terms of Salmonella.

The effects of a starter culture containing *Lactobacillus plantarum* and *Staphylococcus xylosus* strains isolated from traditional sausages on the microbiological quality traits of dry fermented sausages during the ripening process (d 0, 1, 3, 7, 9 and 14) were evaluated. LAB counts reached 7.98 log_{10} cfu·g^{-1}, while *Staphylococcus* counts reached 6.68 log_{10} cfu·g^{-1} and remained constant [63].

Dias *et al.* [64], reported that LAB counts ranged from 3.079 to 8.987 log_{10} cfu·g^{-1} in pork sausages. Fifty sausage samples produced by various smallholder producers in southern Brazil were examined for LAB, and most (72%) reported lactic acid bacteria counts exceeding 6 log_{10} cfu·g^{-1}, with the highest counts exceeding 8 log_{10} cfu·g^{-1} [65].

Fermented sausages were prepared by adding *Lactobacillus plantarum* and *Staphylococcus xylosus* (1:1) to improve bacterial quality. *Staphylococcus* and LAB counts were evaluated at different ripening d (0, 6, and 12). According to the study results, *Staphylococcus* values ranged from 7.64 to 7.91 log_{10} cfu·g^{-1}, while LAB values ranged from 8.59 to 8.73 log_{10} cfu·g^{-1} [66].

In sensory evaluations, when sausage samples were examined in terms of texture, all groups with added mushroom powder generally received lower scores compared to the control group. However, this decrease did not have a significant negative effect on the overall sensory acceptance of the other application groups. Specifically, on the 7th d of storage, the SMP5 group received more favorable scores than the control group in terms of flavor, texture, and overall acceptability.

However, only a statistically significant difference was observed in taste among these parameters (P<0.05). These findings indicate that the addition of mushroom powder may slightly affect sensory properties such as texture and taste, but in most cases, it does not seriously affect consumer acceptability. Changes in the sensory values of the experimental sausage samples are presented in TABLE V.

TABLE V
Sensory evaluation results of experimental sausage samples

Parameters	**Storage period (Days)**	**Sensory Evaluation Groups ($\bar{X}$ ± SD)**			
		Control	**SMP5**	**SMP8**	**SMP10**
Colour	7^{**}	8.20 ± 0.63^{aA}	5.90 ± 1.44^{bA}	6.50 ± 1.43^{abA}	6.00 ± 1.88^{bA}
	14	7.50 ± 1.17^{aA}	6.50 ± 1.35^{aA}	6.30 ± 1.63^{aA}	6.20 ± 1.68^{aA}
	21^{**}	7.80 ± 0.78^{aA}	6.60 ± 0.96^{bA}	6.20 ± 1.03^{bA}	6.00 ± 0.94^{bA}
	28^{**}	7.50 ± 0.52^{aA}	6.00 ± 1.15^{bA}	5.60 ± 0.51^{bA}	5.50 ± 0.70^{bA}
Smell	7^{*}	8.00 ± 0.66^{aA}	5.90 ± 1.44^{abA}	6.50 ± 1.84^{bA}	5.90 ± 1.52^{bA}
	14	7.10 ± 0.87^{aB}	6.50 ± 1.85^{aA}	6.60 ± 1.71^{aA}	5.90 ± 1.44^{aA}
	21^{**}	7.80 ± 0.63^{aAB}	7.10 ± 0.87^{abA}	6.70 ± 1.05^{abA}	6.10 ± 1.28^{bA}
	28^{**}	7.90 ± 0.56^{aAB}	6.40 ± 1.07^{bA}	6.10 ± 1.10^{bA}	5.70 ± 1.33^{bA}
Taste	7^{**}	7.90 ± 0.73^{bA}	8.30 ± 0.94^{aA}	6.40 ± 1.83^{bcA}	5.70 ± 1.41^{cA}
	14	7.40 ± 0.96^{aA}	6.80 ± 1.81^{aB}	6.40 ± 1.57^{aA}	5.50 ± 1.84^{aA}
	21^{**}	8.00 ± 0.81^{aA}	7.20 ± 0.78^{abAB}	6.30 ± 1.55^{bcA}	5.50 ± 1.58^{cA}
	28^{**}	7.70 ± 0.82^{aA}	7.00 ± 1.15^{abAB}	6.10 ± 1.52^{bcA}	5.40 ± 1.26^{cA}
Texture	7	6.90 ± 0.99^{aA}	7.20 ± 1.13^{aA}	6.40 ± 1.50^{aA}	6.30 ± 1.25^{aA}
	14	7.20 ± 0.76^{aA}	6.50 ± 1.17^{aA}	6.20 ± 1.37^{aA}	6.30 ± 1.54^{aA}
	21^{*}	7.70 ± 0.91^{aA}	7.20 ± 0.63^{abA}	6.80 ± 0.91^{bA}	6.50 ± 1.18^{bA}
	28	7.50 ± 0.70^{aA}	6.80 ± 1.05^{aA}	6.70 ± 0.92^{aA}	6.30 ± 1.16^{aA}
Overall Acceptability	7^{**}	7.80 ± 0.78^{aA}	7.60 ± 1.17^{abA}	6.10 ± 1.70^{bcA}	5.90 ± 1.55^{cA}
	14	7.40 ± 0.69^{aA}	6.70 ± 1.41^{aA}	6.10 ± 1.72^{aA}	5.70 ± 1.70^{aA}
	21^{**}	7.90 ± 0.87^{aA}	7.20 ± 0.78^{abA}	6.60 ± 1.26^{bA}	6.10 ± 1.19^{bA}
	28^{**}	7.80 ± 0.63^{aA}	6.90 ± 1.19^{abA}	6.40 ± 1.32^{bA}	5.60 ± 1.26^{bA}

Different lowercase letters (a-e) within the same row indicate significant differences among treatment groups, and different uppercase letters (A-E) within the same column indicate significant differences among storage times. Asterisks indicate levels of statistical significance (*P<0.05; **P<0.01). Control: Sausage without mushroom powder, SMP5: Sausage with 5% mushroom powder addition, SMP8: Sausage with 8% mushroom powder addition, SMP10: Sausage with 10% mushroom powder addition; $\bar{X}$ ± SD: Mean ± Standard deviation. Days 0 and 7 are the fermentation stage

In the literature, the effects of mushroom powder addition on the sensory properties of meat products have yielded varying results. Süfer *et al.* [67], reported that the addition of mushroom powder at increasing levels (*A. bisporus* and *P. ostreatus*; 0–30%) to meatball formulations generally negatively affected sensory properties such as color, taste, and texture, whereas the addition of 5% *P. ostreatus* provided acceptability similar to the control group. In Cantonese sausages supplemented with *V. volvacea* (1–4%), color scores were reported to decrease with increasing mushroom content, while smell and flavor scores were reported to increase [45].

Rosli and Solihah [68] reported that the addition of oyster mushrooms up to 25% did not significantly affect the sensory properties of chicken meatballs, and this level provided the highest panelist acceptance. Nayak *et al.* [69] reported that the addition of 15% *A. bisporus* extended the shelf life and increased sensory scores in fish meatballs. Similarly, *P. ostreatus* supplementation was found to improve taste and aroma scores in beef salami, but slightly decrease color scores [38].

A study conducted by Ramle *et al.* [70] reported that brown button patties had higher moisture content compared to shiitake patties. This may have positive effects on the texture and juiciness of products in sensory evaluations, as higher moisture content can contribute to better texture and juiciness profiles in meat products [71]. Tutun *et al.* [72] reported that the sensory properties of heat-treated hybrid sausage analogs varied based on the cooking technique used. They found that appearance and overall acceptability significantly influenced consumer perception. This aligns with the current findings, which suggest that changes in color parameters caused by adding mushroom powder may have impacted the overall sensory perception.

Similarly, Balıkçı *et al.* [73] demonstrated that using different mushroom flours specifically *Agaricus bisporus*, *Agaricus campestris*, and *Morchella esculenta* in meatball formulations altered several sensory parameters. Notably, higher levels of mushroom flour inclusion tended to decrease aroma and overall acceptability scores.

CONCLUSIONS

The demand for innovative and functional food products has grown rapidly, particularly in Türkiye. Rising consumer concerns about cholesterol and synthetic additives have contributed to reduced meat consumption and increased interest in alternative foods rich in dietary fiber, especially among young people and health-conscious individuals.

In conclusion, the addition of mushroom powder affected some quality parameters of the sausages. In particular, both instrumental and sensory color values were negatively influenced by mushroom powder addition. Since color is one of the most important attributes affecting consumer preference in meat products, this change may influence product perception. Textural properties were modified depending on mushroom concentration and storage time. Although no statistically significant differences were observed in overall acceptability, a decreasing tendency in flavor and general acceptance scores were observed with increasing mushroom powder levels. Therefore, while mushroom powder can be used in sausage formulation, higher concentrations may adversely affect certain quality attributes, especially color. Its application supports both product diversification and the growing consumer demand for functional, nutritionally enhanced foods.

Conflict of interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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