Black Sea Journal of Agriculture
doi: 10.47115/bsagriculture.1782045

Open Access Journal
e-ISSN: 2618 – 6578

Research Article
Volume 9 - Issue 2 : 190-202 / March 2026

USE OF HAZELNUT SKIN IN EMULSION-TYPE SAUSAGES: EFFECTS ON EMULSION STABILITY, LIPID OXIDATION AND STORAGE STABILITY

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Abstract: In this study, the quality and technological properties of sausages formulated with varying levels of hazelnut skin were evaluated. Four formulations were prepared: a control sample without hazelnut skin, and experimental samples containing 0.5%, 1.0%, and 2.0% hazelnut skin, respectively. Selected quality parameters were monitored over the storage period on days 0, 15, 30, and 60. The highest emulsion capacity (EC) and emulsion stability (ES) were observed in sausages containing 2% hazelnut skin. Hazelnut skin addition influenced pH and jelly-fat release (JFR) from the sausage matrix, with increasing concentrations resulting in lower pH values and higher JFR. Furthermore, hazelnut skin increased the protein content while reducing the fat content of the sausage samples. According to the sensory evaluation, no significant differences were found between the control and hazelnut skin-containing samples ($p>0.05$), indicating that the addition did not adversely affect sensory properties. Both treatment and storage duration had significant effects ($P<0.05$) on pH, package drip loss, conjugated diene levels, TBARS, free fatty acidity (FFA), and L*, a*, and b* color values. Over the storage period, TBARS values decreased in samples with hazelnut skin, while FFA values increased in all samples. Moreover, sausages enriched with hazelnut skin demonstrated greater oxidative stability compared to the control. These findings suggest that hazelnut skin can effectively delay oxidation in sausages without compromising their sensory quality.

Keywords: Hazelnut skin, Emulsion, Oxidation, Sausages

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Received: September 12, 2025
Accepted: January 30, 2026
Published: March 15, 2026

Cite as: Aydın Demirtaş, F. M., & Gençcelep, H. (2026). Use of hazelnut skin in emulsion-type sausages: Effects on emulsion stability, lipid oxidation and storage stability. *Black Sea Journal of Agriculture*, 9(2): 190-202.

1. Introduction

In food manufacturing facilities, substantial amounts of food waste, commonly referred to as by-products, are generated during the processing of products. The majority of this waste is either disposed of or converted into low-value products, such as animal feed, using basic or low-level technologies. Proper assessment and utilization of waste produced during food processing are crucial not only for mitigating environmental pollution but also for creating added value and diversifying product lines. Consequently, the application of such waste in the development of new products holds significant importance for human health, environmental sustainability, and the national economy (Yağcı et al., 2006).

In Türkiye, an average of 700,000 tons of hazelnuts are produced annually, resulting in approximately 350,000 tons of kernel hazelnuts. About 50% of these kernel hazelnuts are processed by roasting. Around 2.5% of roasted hazelnuts consist of hazelnut skin, leading to the generation of approximately 4,375 tons of skin waste. Raw hazelnuts are consumed with their skins, whereas roasted hazelnuts are typically sold without skins, as the skin cracks and separates from the nut during the roasting process. Only a small portion of this waste is utilized to extract the oil it contains. Hazelnut skin contains approximately 65% dietary fiber, 8% protein, and 15% fat. In addition, phenolic compounds are concentrated in hazelnut skin, making it a significant by-product of the hazelnut industry (Özdemir et al., 2014). Compared to the hazelnut kernel, hazelnut skin has been found to be a good source of bioactive compounds, and it is rich in phenolic compounds, flavonoids, and the conjugated soluble fraction of phenolic acids (Taş and Gökmen, 2015; Özyurt and Ötleş, 2018; Şahin et al., 2019; Çelik et al., 2023; Menci et al., 2023; Pfeil et al., 2024; Musati et al., 2025).

In a study conducted by Montella et al. (2013), fiber obtained from hazelnut skin was extracted using water and alkaline solution, and its compositional analyses were performed. More than thirty complex oligosaccharides, primarily composed of galacturonic acid and N-acetylgalactosamine, were characterized for the first time in this study. The oligosaccharide concentrations ranged between 16 and 34 mg per gram of extract, and the oligosaccharides isolated from this

agricultural by-product were found to be mainly hexose oligosaccharides (potentially galacto-oligosaccharides) and xyloglucans. As a result, hazelnut skins have been proposed as an abundant and low-cost source of natural oligosaccharides.

Özyurt and Ötleş (2018), the total phenolic content of hazelnut skin was analyzed using different extraction methods. As a result, the total phenolic content was determined to be 1413.32 mg GAE/g dry matter and 3072.7 mg CE/g dry matter. Shahidi et al. (2007) reported the phenolic concentration of hazelnut skin to be between 577.7 mg/g and 638 mg/g expressed as catechin equivalents, while Contini et al. (2012), using 80% aqueous ethanol, determined it to be between 680.3 mg/g and 743.5 mg/g expressed as gallic acid equivalents.

In a study conducted by Özdemir et al. (2014), the potential use of hazelnut skins as a brown-colored functional ingredient was investigated. Hazelnuts were roasted at 150 °C for 30 minutes, after which the brown hazelnut skins were separated and ground using a household grinder. The chemical composition of the ground hazelnut skin was characterized. As a result, the chemical composition of hazelnut skin was determined as follows: moisture 7.4%, total soluble dietary fiber 10%, total insoluble dietary fiber 57.7%, protein 8.2%, fat 14.5%, ash 1.7%, total phenolic content 233 mg GAE/g, and total antioxidant capacity 2.57 mmol TE/g. Subsequently, hazelnut skin oil and defatted coarse hazelnut skin powder were obtained by extraction with hexane. The fatty acid composition of hazelnut skin oil was found to be 6.8% palmitic acid, 75.2% oleic acid, and 16.2% linoleic acid. The tocopherol contents were measured as α-tocopherol 1.25 µg/g, β-tocopherol 0.85 µg/g, γ-tocopherol 1.29 µg/g, and δ-tocopherol 0.14 µg/g, with a total tocopherol content of 2.77 µg/g. According to the study's findings, the use of low-value industrial by-products as a natural coloring agent enriched with phenolic compounds and dietary fibers in functional food formulations will be facilitated. The chemical composition analysis of hazelnut skin oil indicated that this oil is very rich in tocopherol and oleic acid, making it promising for development.

Dinkçi et al. (2021) conducted a study to evaluate the potential of hazelnut skin as a functional additive in yogurt and to investigate the effects of different inclusion levels (2%, 3%, and 4%) on the physicochemical, microbiological, rheological, biochemical, and sensory properties of the final product. The results revealed that the addition of hazelnut skin significantly increased the total solids content from 16.5% to 17.7% and the fat content from 3.45% to 4.60%, while titratable acidity decreased by up to 36%. Enrichment with hazelnut skin also enhanced the viability of yogurt cultures, improved water-holding capacity (WHC), and increased the antioxidant activity of the yogurts. The most notable improvements in WHC and antioxidant levels were observed in the yogurt containing 4% hazelnut skin. Furthermore, both total phenolic content and Fe^{2+} chelating activity increased proportionally with the amount of hazelnut skin added. However, yogurts enriched with hazelnut skin exhibited lower instrumental texture measurements and apparent viscosity. Despite these drawbacks, the sensory properties of hazelnut skin-enriched yogurts remained comparable to those of the control samples, supporting their potential for consumer acceptance.

Although the processing of meat and meat products allows for the production of many functional compounds beneficial to human health, these foods are generally rich in fat and salt, but lacking in complex carbohydrates such as dietary fiber. This imbalance may lead to health risks such as cardiovascular diseases, colon cancer, diabetes, and obesity. For these reasons, increasing the daily intake of dietary fiber is recommended (Mehta et al., 2015). In addition to its nutritional benefits, dietary fiber is currently used in meat products to improve rheological properties and cooking yield, reduce formulation costs, enhance flavor, and improve texture. Meat products rich in dietary fiber are clinically better accepted than traditional meat products.

Though typically discarded as waste during processing of hazelnuts, the hazelnut pellicle has been recognized by a growing body of literature as an underutilized edible source of bioactive compounds on account of high phytochemical content of phenolic acids, proanthocyanidins (Del Rio et al., 2011) and tocopherols (Taş and Gökmen, 2015) which exert significant in vitro antioxidant activity (Alasalvar et al., 2009). Due to its high antioxidant capacity, hazelnut (*Corylus avellana L.)* skin powder has recently attracted significant attention. However, its technological properties and potential applications in other food products have not yet been fully elucidated. In this study, the effect of hazelnut skin addition on the properties of meat emulsions (emulsion capacity and stability) was investigated. Its contribution to sausage batter (amounts of separated gel and fat) and product structure was determined, and its impact on the quality characteristics of sausages during shelf life was examined. The aim was to develop fiber-enriched products and to valorize a waste by-product.

2. Materials and Methods

2.1.Materials

Meat and animal fat used in sausage production were purchased as minced meat from the Samsun market and brought to the laboratory one day prior, where they were stored at +4 °C for 24 hours. Refined corn oil (Ülker Bizim, Istanbul, Turkey) and potato starch (Migros, Istanbul) used in the model system emulsion study were obtained from a local market in Samsun. Hazelnut skin was supplied by Gürsoy (Ordu) company.The composition of the meat used in production was as follows: pH 5.97±0.01, protein 20.39±0.68%, fat 7.04±1.0%, moisture 69.41±0.9%, free fatty acids (FFA) 5.47±0.22%, and TBARS 1.44±0.34.

2.2. Sausage Production

The sausages used in this study were produced at the Meat Technology Laboratory of the Department of Food Engineering, Faculty of Engineering, Ondokuz Mayıs University. The sausage formulations used in beef 47%, animal fat 20%, potato starch 4%, ice 25% and salt (NaCl) 2%, Spice mix (white pepper, cinnamon, coriander, allspice, mustard powder, garlic powder, onion powder, clove, sodium ascorbate (E301), sodium phosphate (E450), ascorbic acid (E300), and spice extracts) 2% and Nitrite ($NaNO_2$) 150 ppm. Sausages groups were Control (No hazelnut skin), M1 (0.5% hazelnut skin), M2 (1% hazelnut skin) and M3 (2% hazelnut skin).

The sausage batter was prepared using a laboratory-type cutter (MADO Typ MTK 662, Dornhan/Schwarzwald). Minced meat, brought to the laboratory one day prior and stored at +4 °C, was chopped at high speed in the cutter for 30 seconds. After the beef, half of the ice was added and chopping continued for another 20 seconds. Subsequently, starch, spice mix, the remaining ice, animal fat, salt (NaCl), and nitrite ($NaNO_2$) were added in sequence and mixed at low speed for 100 seconds to obtain the sausage batter. Care was taken to ensure that the temperature did not exceed 12 °C during the cutting process. The prepared sausage batters were filled into sausage casings (Fibrous cellulose casing, 30 mm diameter, Kalle Nalo. Wursthüllen, Wiesbaden, Germany) using a laboratory-type piston filler (MADO Typ MTK 591, Dornhan/Schwarzwald) in amounts of approximately 100-150 g, and sealed with a clip machine (MADO Typ MTK 591, Dornhan/Schwarzwald). After filling, the sausages were cooked in a hot water bath at 90 °C for 30 minutes. Following heat treatment, the sausages were rapidly cooled with cold water, removed from their casings, vacuum-packed, and stored at +4 °C for 60 days.

2.3. Preparation of Suspension

Lean beef purchased from a local market was minced twice and mixed. Equal amounts of 25 g each were weighed, packaged, frozen in a deep freezer, and stored at -18 °C until use (Zorba et al., 1993). For suspension preparation, 25±0.5 g meat samples previously prepared and stored at -18 °C were homogenized without thawing using an Ultra-Turrax (IKA, Germany) at 13,000 rpm for 2 minutes with 100 mL of 0.4 M NaCl solution. For control samples, the suspension was prepared using only beef. To prepare suspensions with hazelnut skin addition, calculations were made based on the final suspension, and hazelnut skin was added at concentrations of 0.5%, 1%, 2%, 3%, 4%, 5%, and 6%. These suspensions were homogenized using Ultra-Turrax at 13,000 rpm for 2 minutes. Additionally, to prevent temperature rise during processing, suspensions were kept in the refrigerator.

2.4. Emulsion Preparation

The model system developed by Zorba et al. (1993) was modified and used for emulsion preparation. From the prepared suspension, 12.5 g was weighed and mixed with 37.5 mL of 0.4 M NaCl. Then, 50 mL of corn oil was added and homogenized at 3500 rpm for 10 seconds. While homogenization continued in the blender, oil was added to the system at a rate of 0.9–1.0 mL/s using a burette to prepare the emulsion. The endpoint of the emulsion was determined by monitoring changes in the current using copper electrodes placed in the system. Special care was taken to ensure that the temperature did not exceed 15 °C during emulsion preparation.

2.5. Emulsion Capacity (EC)

The obtained suspension mixture was placed in the model system. While homogenizing, corn oil in the burette was added to the suspension at a rate of 0.9–1.0 mL/s. The point at which the emulsion broke was determined by monitoring instantaneous changes in electrical conductivity using an ammeter. Emulsion capacity was calculated as mL oil per g protein based on the total amount of oil added (Zorba et al., 1993).

2.6. Emulsion Stability (ES)

An emulsion was prepared with 10 mL less than the total oil amount determined in the emulsion capacity test. Then, 10 g of this emulsion was weighed into test tubes and subjected to heat treatment in a water bath at 80 ± 2 °C for 30 minutes. After cooling to room temperature, the samples were centrifuged at 2000 g for 10 minutes. The separated water phase was weighed in grams, and emulsion stability was calculated using the following formula (Zorba et al., 1993; Gençcelep et al., 2017). %ES=100−(SW); SW = amount of separated water (g) × 10

2.7. Composition Analyses

The dry matter content of sausage samples was determined using the drying method. The protein content of the samples was determined based on the Kjeldahl method. The fat content of the samples was determined using the Soxhlet extraction method (AOAC, 2000). The surface color of sausages samples was determined using the Minolta Chrometer CR-300 (Japanese). The CIE L* (brightness), a* (redness), and b* (yellowness) values of the samples were obtained from six randomly selected points on the sample surface (Troncoso et al., 2009). Water activity was measured at 25 ºC using an AQUA LAB Dew Point Water Activity Meter (USA).Samples were diluted with distilled water at a ratio of 90%, then homogenized using Ultra-Turrax. The pH values were measured using a pH meter (Starter 2100, OHAUS). The pH meter was calibrated before measurement using buffer solutions of pH 4.00 and 7.00 (Landvogt, 1991).

2.8. Free Fatty Acid (FFA) Analysis

Five grams of sample was weighed into a 250 mL Erlenmeyer flask, and 50 mL of a diethyl ether:ethanol mixture (1:1, v/v) was added. The mixture was shaken for 1 minute to dissolve the fats and fatty acids, then allowed to stand for a few minutes in a dark environment. Subsequently, 3-4 drops of phenolphthalein indicator were added, and titration was performed with 0.1 N ethanolic NaOH from a burette

until a persistent pink color appeared (at least 15 seconds). The volume of NaOH used was recorded, and the free fatty acid content was calculated as oleic acid percentage (Gökalp et al., 1995).

2.9. Thiobarbituric Acid Reactive Substances (TBARS) Analysis

TBARS analysis was performed according to Lemon (1975). Ten grams of sausage sample was weighed into a beaker, and 25 mL of 20% trichloroacetic acid (TCA) solution and 20 mL of distilled water were added. The mixture was homogenized for 2 minutes using an Ultra-Turrax (10,000 rpm). The homogenate was filtered through Whatman No. 1 filter paper, and 5 mL of the filtrate was transferred into screw-cap tubes. To each tube, 5 mL of 0.02 M TBA (2-thiobarbituric acid) solution was added, the tubes were capped and shaken. Tubes were incubated in a boiling water bath at 93 °C for 30–35 minutes and then cooled under running tap water for 10 minutes. The absorbance was measured at 532 nm using a spectrophotometer against a blank. TBARS value was calculated by multiplying the absorbance by a factor of 7.8 and expressed as mg malondialdehyde (MDA) per kg of sample.

2.10. Conjugated Diene Analysis

Conjugated diene values of the produced sausage samples were determined according to Juntachote et al. (2007). For this purpose, 3 g of sausage sample was mixed with 30 mL distilled water to prepare a solution and homogenized using an Ultra-Turrax. Then, 0.5 mL of this mixture was taken and mixed with 5 mL of hexane: isopropyl alcohol (3:1) solvent, followed by centrifugation at 2000 g for 5 minutes. The absorbance of the upper phase was measured at 233 nm, and the measured absorbance was reported as the conjugated diene value.

2.11. Water Binding / Swelling Capacity (WBC/SC) of Hazelnut Skin

Determined according to the method by Lecumberri et al. (2007). Firstly, 1 g of hazelnut skin (M) was placed into a graduated cylinder and its volume (V_1) was recorded. Then, 10 mL of distilled water was added, and the mixture was shaken until a homogeneous dispersion formed. The dispersion was left to stand at 25 °C for 24 hours to allow the powder to fully absorb the water. After 24 hours, the volume of the hydrated hazelnut skin (V_2) was measured and recorded. Water binding capacity (WBC) was calculated using the formula: $WBC\ (mL/g)=V_2-V_1/M$

2.12. Oil Binding Capacity (OBC) of Hazelnut Skin

For this purpose, 1 gram of hazelnut skin (M_1), previously weighed (tare), was placed into a centrifuge tube (M), then 20 grams of oil (corn oil, density 0.9208 g/cm^3) was added. The tube was vortexed for 2 minutes and then centrifuged at 6000 g for 20 minutes at 4 °C. After centrifugation, the supernatant oil was discarded and the remaining precipitate (M_2) was weighed. Oil binding capacity was calculated using the formula: $OBC=M_2-M/M_1$ and expressed as grams of oil bound per gram of hazelnut skin sample (Gençcelep et al., 2017).

2.13. Total Antioxidant Activity of Hazelnut Skin (DPPH Radical Scavenging Method)

Total antioxidant activity was determined by measuring absorbance at 517 nm using the DPPH method (Delgado et al., 2010). The standard calibration curve was prepared using Trolox in 75% methanol containing 1% formic acid, and results were expressed as Trolox Equivalent Antioxidant Capacity (TEAC) per 100 g of dry matter.

2.14. Total Phenolic Content of Hazelnut Skin

Total phenolic content was determined by the Folin-Ciocalteu method (Lemos et al., 2012). Absorbance was measured at 750 nm using a UV-Visible spectrophotometer. The calibration curve was prepared using gallic acid standard solution. Results were expressed as gallic acid equivalents per 100 g dry matter.

2.15. Water Solubility Index (WSI) of Hazelnut Skin

1% aqueous solutions of hazelnut skin samples were prepared and subjected to shaking in a shaking water bath at a constant speed for 1 hour. This process was carried out at 10, 20, 30, 40, 50, 60, and 70 °C. The resulting mixtures were centrifuged at 4000 g for 10 minutes, and the supernatant accumulated on the surface was collected into a petri dish. The samples were dried at 105 °C for 18 hours and then weighed (S_2). The water solubility index (WSI) was calculated using the formula: $WSI\ (\%)=S_2/S_1\times100$ where S_1 is the initial sample weight (g) (Anderson et al., 1969).

2.16. Separated Gel and Fat Content Analysis (SGF)

Approximately 100 g of sausage batter was placed into glass jars measuring 75x58 mm. The jars were sealed and incubated in a 90 °C water bath for 30 minutes. After cooling to 45 °C, the gel and fat separated from the batter were withdrawn using a syringe and weighed in grams. The amount of separated gel and fat was calculated as a percentage of the initial batter weight (Bloukas and Honikel, 1992).

2.17. Sensory Analysis

A panel of 12 evaluators conducted sensory assessments of the sausage samples. Samples were presented in random order, and panelists were advised to drink water and eat bread between samples to cleanse their palate. Panelists evaluated the samples based on appearance (color), texture, flavor, off-flavor, odor, and overall acceptability. A 9-point hedonic scale was used, where 9 = excellent and 1 = extremely poor.

2.18. Package Drip Loss Analysis (PDLA)

The method used by Bloukas et al. (1997) was modified to determine the amount of drip loss inside the packaging of the sausage samples. The sausages were stored at 4 °C for 2 months. Drip loss analysis was performed on days 1, 15, 30, and 60 of storage. The weights of the sausages before and after drying, as well as the weights of the paper towels before and after absorption, were measured and recorded. This analysis was conducted on 3 packages from each group. The package drip loss was calculated using the following formulas given in equation 1 and 2:

$$X=(K_2-K_1)+(M_1-M_2)/2 \quad (1)$$

$$(\%)\ PDLA=X/\ M_1\times100 \quad (1)$$

Where: K_1: Initial weight of the paper towel, K_2: Weight of the paper towel after absorption, M_1: Weight of the sausage sample before drying;, M_2: Weight of the sausage sample after drying.

2.19. Statistical Analysis

Experiments were established and conducted according to a completely randomized design with two replications. SPSS 21.0 Windows software package was used for the statistical evaluation of the experimental data. Some analyses were performed on raw materials and non-stored sausage samples, where the storage factor was not considered. Variance analysis (ANOVA) was applied to storage parameters (pH, aw, TBARS, SYA, and color values L*, a*, b*), and Duncan's multiple range test was performed for variables found significant (SPSS, 2012).

3. Results and Discussion

3.1. Hazelnut Skin Composition Analysis

In sausage production, hazelnut skin can be utilized as a natural additive to enhance various quality attributes. Its high content of dietary fiber and antioxidants contributes to an improved nutritional profile. Additionally, it can enhance emulsion stability, improve texture, and increase oxidative stability by delaying lipid oxidation and rancidity. From an environmental perspective, the use of hazelnut skin also supports sustainability by valorizing a by-product of the food industry that would otherwise be discarded. The analysis results of the hazelnut skin used as raw material in the study are given in Table 1.

Özyurt (2013), the moisture content of dried hazelnut skin was found to be 8.26%, fat content 16.05%, dry matter content 94.3%, ash content 1.98%, and carbohydrate content 68.01%. Additionally, the total dietary fiber content was 73.47%, soluble dietary fiber 22.52%, insoluble dietary fiber 45.62%, phenolic content 1413.32 mg GAE/dry matter, total antioxidant activity 148.27 mg gallic acid/kg, and lignin content 58.53 g/100 g.

The oil content of hazelnut skins has been found to range between 23.46% and 25.37% (Şahin et al., 2019). Özyurt and Ötleş (2018) reported the oil content of hazelnut skin as 16.05%. Considering that the oil content of hazelnuts varies depending on ecological conditions and hazelnut variety, it can be assumed that the oil content of hazelnut skins is also influenced by these same factors (Şahin et al., 2019).

Commercially dried Oregon hazelnut kernels contained 3–6 g/100 g water, 14–17 g/100 g proteins, 11–16 g/100 g carbohydrates, 60–67 g/ 100 g fats, and 2.0–2.5 g/100 g ash. Cultivar type affected protein, tocopherols, and antioxidant activity, whereas crop year influenced total fat and dietary fiber. Significant levels of α-tocopherols and γ-tocopherols were measured in hazelnut skins (74–266 μg/g and 32–107 μg/g, respectively) and in hazelnut kernels (83–130 μg/g and 5–13 μg/g, respectively). Hazelnut skins are a rich source of dietary fibers (64–70 g/100g) and antioxidant phenolic compounds (122–172 mg gallic acid equivalents (GAE)/g soluble; 1–20 mg GAE/g insoluble) with growing year impacting relative concentrations in each cultivar. Hazelnut skins were rich in (+)-catechin (49–130 mg/100 g), epigallocatechin gallate (EGCG) (21–35 mg/100 g), dimeric procyanidin B2 (7–21 mg/100 g), and quercetin 3-rhamnoside (12–21 mg/100 g) (Pfeil et al., 2024).

Table 1. Composition analysis results of hazelnut skin (mean ± standard deviation)

Properties	Result
Dry Matter (%)	94.78 ± 0.02
Moisture (%)	5.22 ± 0.02
Protein (%)	6.96 ± 0.07
Ash (%)	1.97 ± 0.01
Oil (%)	16.47 ± 0.5
Carbohydrate (%)	69.38 ± 0.0
Water Solubility Index (%)	10 °C 12.77 ± 1.07
	20 °C 11.82 ± 1.02
	30 °C 15.78 ± 0.57
	40 °C 16.43 ± 0.07
	50 °C 16.75 ± 0.65
	60 °C 17.93 ± 0.13
	70 °C 20.28 ± 0.73
Water Holding Capacity (g/g)	4.74 ± 0.23
Conjugated Diene	0.040 ± 0.12
Fat Binding Capacity (g/g)	3.37 ± 0.18
SYA (%)	15.00 ± 0.90
pH	5.49 ± 0.05
Total Phenolic Content (mg GAE/g hazelnut skin)	31.83 ± 0.08
Total Antioxidant Activity (%)	45.99 ± 0.11
Brightness (L*)	30.98 ± 2.69
Redness (a*)	9.10 ± 0.77
Yellowness (b*)	17.99 ± 1.30

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Montella et al. (2013) reported in their study that hazelnut skin contained 1.30% total nitrogen, 8.01% protein, 21.2% fat, 7.67% moisture, 4.50% ash, 58.3% total dietary fiber, 3.33% soluble dietary fiber, and 52.7% insoluble dietary fiber.

In another study investigating the chemical composition of hazelnut skin, it was determined to contain 7.4% moisture, 10% total soluble dietary fiber, 57.7% total insoluble dietary fiber, 8.2% protein, 14.5% fat, 1.7% ash, 233 mg GAE/g total phenolic content, and 2.57 mmol TE/g total antioxidant capacity. The fatty acid composition of hazelnut skin oil was reported as 6.8% palmitic acid, 75.2% oleic acid, and 16.2% linoleic acid, while total tocopherol content was determined as 2.77 µg/g with α-tocopherol at 1.25 µg/g, β-tocopherol 0.85 µg/g, γ-tocopherol 1.29 µg/g, and δ-tocopherol 0.14 µg/g (Özdemir et al., 2014). Özyurt and Ötleş (2018) found that the chemical composition of hazelnut skin included 67.97% carbohydrate, 16.05% fat, 8.26% protein, 5.78% moisture, and 1.98% ash.

The basic composition analysis results we determined in hazelnut skin generally show similarity with the findings of previous researchers. Factors such as harvest time, cultivation and drying methods, season, geographical origin, environmental factors, storage and processing conditions, and hazelnut variety affect the chemical composition of hazelnut skin.

The soluble fraction of total dietary fiber affects the water solubility properties of hazelnut skin. Solubility is related to the structure of polysaccharides. The regular (insoluble) or irregular (soluble) arrangements of polysaccharides in the backbone or side chains influence their solubility. The presence of substituent groups such as COOH or $SO4^{-2}$ increases solubility. In addition, solubility is also influenced by temperature and ionic strength. Moreover, hydration properties of fibers in water increase with temperature (Elleuch et al., 2011). Insoluble fiber fractions are more sensitive to high temperatures compared to soluble fiber fractions (Burdurlu and Karadeniz, 2003). The water solubility index values of hazelnut skin increased with rising temperature. In analyses conducted at room temperature, the highest solubility was recorded at 70 °C with 20.28%. Additionally, due to the positive effect of temperature on solubility, increasing the temperature applied to hazelnut skin led to increased solubility.

Water holding capacity and fat binding capacity analyses determine the hydration properties of substances and, consequently, their functional properties. The ability of fiber matrices to absorb water reflects the hydration characteristic of dietary fiber. Fibers with strong hydration properties increase stool bulk, slow nutrient absorption rates in the intestine, and increase the viscosity of foods to which they are added. Dietary fibers with high water holding capacity can be used as functional ingredients to prevent water release and modify the viscosity and texture of formulated foods. Dietary fibers with high fat binding capacity enable the stabilization of high-fat food products and emulsions, prevent flavor migration, and reduce fat loss during cooking (Burdurlu and Karadeniz, 2003; Elleuch et al., 2011; Navarro-González et al., 2011). Water holding capacity is defined as the amount of water held by 1 gram of dry fiber under specific conditions such as temperature, wetting time, centrifugation time, and speed (Elleuch et al., 2011). In the hazelnut skin sample, water holding capacity and fat binding capacity values were determined as 4.74 and 3.37 g/g, respectively. Akşit (2018) reported water holding capacities of quince pomace at 6.41 g/g, grapefruit pomace at 13.09 g/g, and tomato pomace at 6.62 g/g. The hydration properties of dietary fibers depend on factors such as the chemical structure of polysaccharides in their composition, porosity, particle size, ionic form, pH, temperature, ionic strength, the type of ions in solution, and stresses on the fibers. Water retention of dietary fibers is closely related to the fiber source (Elleuch et al., 2011).

Fat binding capacity is defined as the amount of fat retained by fibers after mixing, incubation, and centrifugation (Elleuch et al., 2011). Akşit (2018) reported fat binding capacities of quince pomace at 2.93 g/g, grapefruit pomace at 4.11 g/g, and tomato pomace at 3.47 g/g. The fat binding ability of fibers is important in food applications. For example, their ability to absorb or bind bile acids is associated with plasma reduction and is effective in preventing fat loss during cooking. Fat binding capacity depends on factors such as the surface properties of fibers, bulk density, thickness, and the hydrophobic nature of fiber particles (Navarro-González et al., 2011). Insoluble fibers can bind fat up to five times their own weight (Burdurlu and Karadeniz, 2003). The pH of hazelnut skin was determined as 5.49, and a higher pH value in emulsion products is desirable as it relates to water holding capacity.

The free fatty acid value determined in hazelnut skin was quite high at 15.0%. During the roasting process applied in hazelnut processing, changes occur in the structure of fats present and degradation of antioxidants results in a rapid increase in free fatty acid values, reaching high levels. Raw materials containing fat to be used before production should be analytically tested and rancidity levels determined, and unsuitable raw materials should be prevented from use as they directly affect final product quality. The antioxidant content and bioavailability of antioxidants in foods can vary depending on the type of food material, harvest time and method, storage and preservation temperature, light exposure, climate, humidity, food preparation, and even individual and community consumption habits (Cornelli,

2009; Moure et al., 2001).

Antioxidants are chemicals that protect food materials and the organisms consuming them against oxidative damage caused by free radical molecules such as nitrogen species and reactive oxygen species. The most important source of antioxidant substances is plant-based foods. Natural antioxidant components in foods exhibit antioxidant effects through one or more mechanisms such as reducing agents, free radical scavengers, or singlet oxygen quenchers (Lee et al., 2004). Antioxidants neutralize free radicals in living organisms, preventing cells from damage or promoting self-renewal (Gök and Serteser, 2003).

The most important role of antioxidants in nutrition is to prevent oxidative stress formed after the metabolism of macromolecules (carbohydrates, proteins, fats) during nutrition. Therefore, consumption of nuts containing antioxidants and phenolic compounds is important in this context (Güleşci and Aygül, 2016).

The total phenolic content of hazelnut skin water extract was determined as 31.83 mg GAE/g hazelnut skin, and total antioxidant activity as 45.99%. Reviewing studies, Duraklı Velioğlu et al. (2017) found the total phenolic content of hazelnut skin to be 209.75 mg GAE/g dry matter. Contini et al. (2012) reported the highest phenolic content as 680 mg GAE/g hazelnut skin extract, while Locatelli et al. (2010) found 638 mg catechin equivalent/g extract.

Özdemir et al. (2014) reported total phenolic content and antioxidant capacity of hazelnut skin as 233.7 mg GAE/g and 2.57 mmol TE/g, respectively. Monagas et al. (2009) reported total phenolic content of methanol/HCl extracts from roasted hazelnut skin as 107 mg GAE/g.

Differences in results are thought to be related to various extraction conditions and solvents. When compared with phenolic content of other nut skins such as almond skin (22.8 mg GAE/g), peanut skin (73.9 mg GAE/g), and walnut skin (101 mg GAE/g), studies by Monagas et al. (2009) and Salcedo et al. (2010) found hazelnut skin to have considerably higher phenolic content. Similarly, the total phenolic content and antioxidant capacity of pistachio skin (116.32 mg GAE/g and 2.19 mmol TE/g, respectively) are lower than those of hazelnut skin.

Colarič et al. (2005) reported that although walnut skin contributes only 5% of fruit weight, its phenolic content is much higher than that of the kernel. According to Arcan and Yemenicioğlu (2009), removal of hazelnut skin reduces the total antioxidant activity of hazelnuts by nearly 36%. Similarly, Schmitzer et al. (2011) reported that skin removal negatively affects total phenolic content and antioxidant activity of hazelnuts.

Talcott et al. (2005) found that roasting peanuts increased antioxidant compounds by 22% due to moisture reduction, changes in phenolics and proteins caused by heat treatment, and formation of Maillard reaction products. Non-enzymatic browning reaction products are known to have antioxidant properties (Reische et al., 2002).

Various technological processes applied to fruit residues can affect fiber composition, functional properties, and microbial quality. Roasting causes browning of hazelnut skin (decrease in L* and increase in a* values). Özdemir et al. (2014) reported L*, a*, and b* values of hazelnut skin as 55.8, 8.4, and 11.1, respectively. The color values determined in the study differ from those found by other researchers, likely due to variety differences, heat treatment temperatures, and other factors.

3.2. Hazelnut Skin Emulsion Analysis

In order to determine the appropriate hazelnut skin ratios to be used in sausage production, emulsion trials were conducted in a model system with different hazelnut skin ratios. The results are presented in Table 2.

Considering that the pH of hazelnut skin is 5.49 (Table 1) and the pH of the control suspension is 6.60, it is expected that the addition of hazelnut skin would lower the pH of the suspension. The expected effect was also observed in this study. Statistically significant differences were found between the pH values of the samples depending on the hazelnut skin addition level.

The maximum amount of oil that can be emulsified by 1 g of protein is referred to as emulsion capacity (EC), and it is expressed in milliliters (Gökalp et al., 1995). The electrical conductivity (EC) values of emulsions prepared with five varying concentrations of hazelnut skin are presented in Table 2. The EC values of the emulsions were found to range between 212.70 and 238.95 mL oil/g protein.

The addition of hazelnut skin to the emulsion generally led to an increase in emulsion capacity; however, irregular fluctuations—both increases and decreases—were observed with higher addition levels. When examining the pH values of the emulsions, it was seen that the control group had a pH of 6.60, and the addition of hazelnut skin lowered the pH values of the emulsions. According to the results of Duncan's multiple comparison test, the highest emulsion capacity (238.95 mL oil/g protein) among the hazelnut skin-added emulsions was found in the sample containing 2% hazelnut skin.

3.3. Composition Analysis

After the batter was prepared, it was filled into casings as described in the methodology section, then cooked and vacuum-packaged. The composition analysis results of the sausages on day 0 of storage are presented in Table 3.

As shown in Table 3, the addition of hazelnut skin increases the protein content of sausages. As the protein content increases, the number of polypeptides that can interact during thermal processing also rises, which contributes to the formation of a more stable gel matrix. This structure has a higher capacity to retain water and fat, thereby enhancing the binding properties of the emulsion (Carballo et al., 1995). In this study, the protein and fat contents of the sausages were found to differ significantly depending on the level of hazelnut skin added ($P<0.05$). This difference is thought to result from the compositional variations in the hazelnut skin itself (Table 1).

Table 2. Selected analysis results of suspensions prepared with hazelnut skin and liquid vegetable oil (Mean ± standard deviation)

Hazelnut Skin (%)	pH	EC (mL oil/g protein)	ES (%)
Control	6.60 ± 0.01^{a}	225.31 ± 5.36^{b}	71.08 ± 2.34^{c}
1.0	6.30 ± 0.01^{b}	212.70 ± 7.75^{c}	71.35 ± 1.38^{c}
2.0	5.95 ± 0.01^{c}	238.95 ± 12.09^{a}	78.08 ± 1.63^{a}
3.0	5.90 ± 0.01^{c}	227.56 ± 5.71^{b}	74.38 ± 2.13^{b}
4.0	5.74 ± 0.01^{d}	227.55 ± 7.33^{b}	74.56 ± 1.17^{b}
6.0	5.63 ± 0.01^{d}	233.44 ± 11.76^{ab}	77.66 ± 2.29^{a}

Values with different superscript letters in the same column are significantly different (P<0.05), EC= emulsion capacity, ES= emulsion stability.

Table 3. Results of basic composition analyses of sausages (mean ± standard deviation)

Hazelnut Skin (%)	Moisture (%)	Crude Protein (%)	Crude Fat (%)
Control	59.54 ± 0.64	13.46 ± 0.42^{c}	21.93 ± 1.06^{a}
0.5	59.88 ± 1.13	14.75 ± 0.48^{b}	20.60 ± 0.32^{a}
1.0	59.18 ± 0.89	14.17 ± 0.24^{ab}	20.37 ± 0.64^{a}
2.0	58.73 ± 0.92	15.76 ± 0.58^{a}	18.37 ± 0.19^{b}

Values with different superscript letters in the same column are significantly different (P<0.05).

Table 4. Analysis results of frankfurter sausages during the storage periods

Sample type (ST)						
(Hazelnut skin %)	pH	Aw	ALP (%)	Conjugated dien	FFA (%)	TBARS (mg MA/kg)
Control	6.07±0.16^{c}	0.975±0.004^{b}	0.77±0.19^{b}	0.35±0.15^{a}	4.13±3.05^{b}	0.80±0.41^{b}
0.5	6.18±0.15^{b}	0.976±0.003^{ab}	0.87±0.23^{ab}	0.31±0.13^{ab}	6.20±3.15^{a}	0.72±0.28^{b}
1.0	6.19±0.14^{b}	0.977±0.004^{a}	0.96±0.30^{a}	0.28±0.13^{ab}	4.01±1.34^{b}	0.78±0.12^{b}
2.0	6.22±0.12^{a}	0.978±0.004^{a}	1.00±0.31^{a}	0.26±0.13^{b}	3.13±0.67^{b}	0.99±0.37^{a}
Significant	**	**	**	**	**	**
Storage Periods (days) (SP)						
0	6.32±0.01^{a}	0.973±0.002^{c}	0.59±0.12^{c}	0.20±0.12^{b}	2.86±0.79^{c}	0.92±0.19^{a}
15	6.19±0.06^{b}	0.976±0.002^{b}	0.92±0.13^{b}	0.17±0.07^{b}	3.14±0.62^{c}	0.99±0.25^{a}
30	6.18±0.13^{b}	0.976±0.001^{b}	0.94±0.11^{b}	0.38±0.06^{a}	4.83±2.27^{b}	0.53±0.23^{b}
60	5.97±0.05^{c}	0.982±0.002^{a}	1.16±0.29^{a}	0.43±0.09^{a}	6.64±3.26^{a}	0.85±0.39^{a}
Significant	**	NS	**	**	**	**
STxSP	**	NS	**	**	**	**

Values are means ± standard deviation. **p<0.01; $^{a-d}$: The difference between the values with different exponents in the same column is significant for each product types (P<0.05). ALP: Amount of leakage in the package, NS: not significant.

As shown in Table 3, the addition of hazelnut skin increases the protein content of sausages. As the protein content increases, the number of polypeptides that can interact during thermal processing also rises, which contributes to the formation of a more stable gel matrix. This structure has a higher capacity to retain water and fat, thereby enhancing the binding properties of the emulsion (Carballo et al., 1995). In this study, the protein and fat contents of the sausages were found to differ significantly depending on the level of hazelnut skin added (P<0.05). This difference is thought to result from the compositional variations in the hazelnut skin itself (Table 1).

3.4. Chemical and Oxidation Analysis

Some chemical and oxidation analysis results determined during the storage of frankfurter sausages are given in Table 4.

pH is one of the primary factors affecting the physicochemical properties of meat, such as water holding capacity, color, and cooking loss. During the storage period, the pH value changes due to reasons such as the accumulation of metabolites resulting from bacterial activity on the meat and the deamination of proteins (Seol et al., 2013). The pH values of the sausages ranged from 6.30 to 6.34 at the beginning of storage and from 5.91 to 6.04 at the end of the storage period. The pH

values of the treatment group sausages were slightly higher than those of the control group sausages (P<0.05). This is thought to be due to the high free acidity value of the hazelnut skin used in the production process. During storage, a decrease in the pH values of the samples was observed. This decrease is thought to be caused by the partial breakdown of proteins into amino acids and fats into free fatty acids, resulting in an increase in free acidity values (Table 4). Through lipid hydrolysis, the increase in free fatty acids may lead to a decrease in pH. Additionally, previous studies have reported that the decrease in pH during the storage of meat products is due to lactic acid bacteria producing lactic acid, which causes a gradual decline in pH (Viuda-Martos et al., 2010). The pH values of the sausage samples were found to be higher than those of the sausage batter (Table 4). This is attributed to the loss of buffering capacity of proteins present in the composition due to thermal processing.

Upon examining the table, it was determined that the water activity (aw) values of the sausages during storage ranged between 0.970 and 0.985. While the aw values of the control group sausages ranged from 0.970 to 0.981, the groups with added hazelnut skin had aw values ranging from 0.974 to 0.985. Compared to the control group, the addition of hazelnut skin did not cause any significant change in the aw value.

One of the common issues observed in vacuum-packed emulsified meat products is the leakage of some amount of fat and water from the product into the packaging. The extent of leakage varies depending on the size and shape of the sample inside the package, the applied processing method, storage temperature, and storage duration. Generally, products stored between 12-16 °C exhibit the lowest leakage, while leakage increases at temperatures below or above this range. However, to delay microbial activity, emulsified meat products are typically stored under vacuum packaging at +4 °C. Additionally, in emulsified meat formulations, increasing the fat-to-water ratio reduces the amount of leakage (Hensley and Hand, 1995).

As shown in Table 4, the leakage amount from the sausages into the packaging ranged from 0.516% to 0.707% on the first day of storage, while it increased to between 0.959% and 1.320% on the 60th day. The sausage group with 2% hazelnut skin addition exhibited the highest leakage values, with 0.707% on the first day and 1.320% on the last day of storage. As the amount of hazelnut skin added in sausage production increased, the leakage amount in the supplemented samples also increased compared to the control, which is attributed to the high oil content (16.47%) in the hazelnut skin that remains liquid at room temperature. An increase in conjugated dienes values was observed throughout the storage period of the sausages. When comparing the control and treatment groups, it was determined that the control group sausages had higher conjugated diene content than those with added hazelnut skin. However, the addition of hazelnut skin did not cause a statistically significant difference in the amount of conjugated dienes. This is thought to be due to oxidative deterioration occurring in the high oil content of the hazelnut skin.

As seen in Table 4, the TBARS values of the sausages were measured between 0.829 and 1.024 mg MDA/kg at the beginning of storage, and between 0.559 and 1.1496 mg MDA/kg at the end of storage. In the control group sausage samples, an increase was observed up to the 60th day of storage, whereas in the groups with hazelnut skin addition, a decrease was noted until the 30th day. This decrease is thought to result from the further breakdown of malondialdehydes into secondary products. Additionally, the lower TBARS values in some samples may be due to an increase in pH caused by microbial growth and the removal of TBARS compounds such as malondialdehyde by microorganisms (Rhee et al., 1997). Overall, as seen in Table 3.4, lipid oxidation increased during storage due to factors such as the unsaturated fat content of the raw materials, salt usage, and environmental pH.

Analysis of the results showed a linear increase in free fatty acid (FFA) values of the sausage samples depending on the storage duration, with a significant (P<0.05) rise observed in the later stages of storage. At the beginning of storage, the FFA values ranged from 1.98% to 3.62%, while on the 60th day of storage, they ranged from 3.48% to 10.05%. The highest value was observed in the sample group with 0.5% hazelnut skin addition, whereas the FFA values of the other hazelnut skin-added groups were lower compared to the control group. Although the addition of hazelnut skin initially caused an increase in FFA values, a marked slowdown was observed as the addition level increased. This effect is thought to be due to the phenolic compounds present in the structure of the hazelnut skin used in production. Furthermore, the elevated initial FFA values in the hazelnut skin-added samples are attributed to the high free fatty acid content of the hazelnut skin itself. However, the addition of 1% and 2% hazelnut skin appeared to reduce the FFA values. In conclusion, the lower levels of hazelnut skin addition were insufficient to fully express the antioxidant effects contained within the additive.

3.5. Color Analysis

Surface and cut surface color analysis results determined during the storage of frankfurter sausages are given in Table 5.

Analysis of the results on day 0 revealed that the external L* values of the sausage samples ranged between 52.19 and 58.03, while the internal L* values ranged between 55.66 and 60.50. On day 60, the external L* values were found to be between 53.86 and 59.77, and the internal L* values ranged from 54.68 to 60.33. As the amount of hazelnut skin added increased, the brightness (L*) values of the sausage samples decreased. This reduction is attributed to the low L* value of the hazelnut skin itself (30.48) (Table 5).

According to the table, the external a values on day 0

ranged from 11.40 to 15.96. The highest value on day 0 was observed in the control sample, while the lowest value belonged to the sample with 2% hazelnut skin addition. The highest external *a* value was recorded in the control group, and as the amount of hazelnut skin increased, the color values decreased, resulting in lighter red hues. This difference is attributed to the varying a* value of the hazelnut skin. Changes in the external a* values over time were statistically significant (P<0.05), with an increasing trend that enhanced the redness characteristics of the samples. The highest external a* values were found on the 60th day of storage.

Table 5. Analysis results of frankfurter sausages during the storage periods

Sample type (ST)	Surface Color			Cut Surface		
(%Hazelnut skin)	L*	a*	b*	L*	a*	b*
Control	59.28±1.13^{a}	15.51±0.80^{a}	16.60±0.49^{a}	60.18±0.61^{a}	17.40±0.28^{a}	15.49±0.32^{a}
0.5	56.57±0.99^{b}	12.64±1.21^{b}	15.65±0.43^{b}	57.97±1.17^{b}	14.55±1.13^{b}	14.83±0.87^{b}
1.0	55.20±0.56^{c}	11.90±0.63^{c}	15.07±0.68^{c}	56.11±0.97^{c}	14.06±0.94^{b}	14.71±0.34^{b}
2.0	52.77±1.27^{d}	10.82±0.84^{d}	13.90±0.23^{d}	54.93±0.79^{d}	12.92±1.32^{c}	14.55±0.39^{b}
Significant	**	**	**	**	**	**
Storage Periods (days) (SP)						
0	55.16±2.39^{b}	12.82±2.04^{ab}	15.18±1.04^{b}	57.97±2.29^{a}	15.06±1.67^{a}	14.85±0.44^{ab}
15	56.00±3.16^{a}	12.27±2.13^{b}	15.29±1.15^{ab}	57.29±2.36^{b}	14.60±2.09^{ab}	14.54±0.61^{b}
30	56.30±2.48^{a}	12.72±1.88^{ab}	15.59±1.15^{a}	57.22±1.81^{b}	15.15±1.60^{a}	15.10±0.52^{a}
60	56.36±2.34^{a}	13.07±1.93^{a}	15.16±1.11^{b}	56.71±2.35^{b}	14.13±2.31^{b}	15.08±0.80^{a}
Significant	**	**	**	**	**	**
STxSP	**	**	**	**	**	**

Values are means ± standard deviation. **P<0.01; $^{a-d}$: The difference between the values with different exponents in the same column is significant for each product types (P<0.05). NS: not significant.

Statistically significant differences were also found among the internal a* values of the samples (P<0.05). On day 0, internal a* values ranged between 13.71 and 17.57, while on day 60, they ranged from 12.23 to 17.60. Fluctuations in redness were observed over time. Comparing the internal a* values on the 60th day showed no significant differences among the samples. Generally, internal a* values were higher than external a* values, indicating that the interior surface of the sausages was redder than the exterior. This phenomenon may be due to greater oxidation on the exterior surface caused by exposure to factors such as light and heat.

In this study, the quality and technological properties of sausages produced with varying amounts of hazelnut skin were investigated. Four different formulations were prepared: control (without hazelnut skin), 0.5%, 1.0%, and 2% hazelnut skin additions. The addition of hazelnut skin affected the pH and the amount of gel and fat separated from the sausage batter (AJY, %); pH decreased while AJY increased with higher hazelnut skin levels. Protein content increased, and fat content decreased in the sausages with hazelnut skin addition.

Throughout the storage period (days 0, 15, 30, and 60), pH, water activity (aw), package leakage, conjugated dienes, TBARS, free fatty acid (FFA) values, and color analyses (L*, a*, b*) were performed on all samples. The effects of sausage formulation and storage time on pH were significant (P<0.05), with application groups showing slightly higher pH values than the control group. pH values decreased during storage.

Water activity (aw) was significantly affected only by storage time (P<0.05), increasing over time in all samples. Package leakage values were significantly influenced by both formulation and storage time (P<0.05). Leakage increased proportionally with hazelnut skin addition and continued to rise during storage, attributed to the high oil content in the hazelnut skin.

Conjugated diene values were not significantly affected by the hazelnut skin or its addition levels. According to TBARS analysis, hazelnut skin addition initially reduced lipid oxidation compared to the control; however, increasing the addition level caused TBARS values to rise, continuing through storage. The rapid oxidation of oil in the hazelnut skin indicates the need for pretreatment methods (vacuum packaging, refrigeration, heat treatment) before use. Such treatments are expected to reduce TBARS values and enhance the antioxidant effect of the additive in the final product.

Free fatty acid (FFA) values were significantly influenced by formulation and storage time (p<0.05). Control samples exhibited higher FFA values than hazelnut skin-added groups. FFA values increased linearly during storage, with the highest value observed in the 0.5% hazelnut skin group. Although the addition caused an initial rise in FFA, increased hazelnut skin levels slowed this trend, possibly due to phenolic compounds in the skin. Color parameters (L*, a*, b*) of both the surface and interior were significantly affected by formulation and storage time (P<0.05). Increasing hazelnut skin addition

darkened the color, decreasing L* values. Sensory analysis showed no statistically significant difference (P>0.05) between hazelnut skin-added samples and control, although scores for the former were slightly lower. The hazelnut skin-enhanced sausages demonstrated greater resistance to oxidation without imparting any foreign taste.

4. Conclusion

Sausages supplemented with 2% hazelnut skin exhibited significantly enhanced emulsion capacity (EC) and emulsion stability (ES), indicative of improved matrix integrity, whereas higher inclusion levels were associated with decreased pH and elevated jelly-fat release (JFR). Throughout the storage period, thiobarbituric acid reactive substances (TBARS) values declined in hazelnut skin-enriched samples, while free fatty acid (FFA) levels increased across all treatments, demonstrating superior oxidative stability relative to the control. These findings highlight the potential of hazelnut skin as a functional ingredient capable of enhancing the nutritional profiles, mitigating lipid oxidation, and valorizing a bioactive by-product, without compromising sensory attributes. Furthermore, hazelnut skin may serve as a viable alternative additive in emulsion-type meat products; however, raw materials containing oils intended for use should undergo prior analytical assessment to determine rancidity levels, thereby preventing the incorporation of unsuitable ingredients that could adversely affect final product quality.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	F.M.A.D.	H.G.
C		100
D		100
S		100
DCP	100	
DAI	40	60
L	80	20
W	50	50
CR	20	80
SR		100
PM		100
FA	50	50

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

Acknowledgments

This study was produced from the master's thesis titled "The Effect of Hazelnut Skin on The Properties of Meat Emulsions and Their Use in Sausage Production" (Thesis no: 571415) completed by Fatma Merve Aydın under the supervision of Hüseyin Gençcelep.

References

Akşit, Z. (2018). *Gıda atıklarından elde edilen bazı bitkisel liflerin emülsiyon özellikleri ve sosis üretiminde kullanımları* [Yayımlanmamış doktora tezi]. Ondokuz Mayıs Üniversitesi.

Alasalvar, C., Karamać, M., Kosińska, A., Rybarczyk, A., Shahidi, F., & Amarowicz, R. (2009). Antioxidant activity of hazelnut skin phenolics. *Journal of Agricultural and Food Chemistry, 57*(11), 4645–4650. https://doi.org/10.1021/jf900489d

Anderson, R. A. (1969). Gelatinization of corn grits by roll-and extrusion-cooking. *Cereal Science Today, 14*(1), 4–7.

AOAC. (2000). *Official methods of analysis of AOAC International* (15. baskı). AOAC International.

Arcan, I., & Yemenicioğlu, A. (2009). Antioxidant activity and phenolic content of fresh and dry nuts with or without the seed coat. *Journal of Food Composition and Analysis, 22*(3), 184–188. https://doi.org/10.1016/j.jfca.2008.10.016

Bloukas, I., & Honikel, K. O. (1992). The influence of additives on the oxidation of pork back fat and its effect on water and fat binding in finely comminuted batters. *Meat Science, 32*(1), 31–43. https://doi.org/10.1016/0309-1740(92)90015-V

Bloukas, J. G., Paneras, E. D., & Fournitzis, G. C. (1997). Sodium lactate and protective culture effects on quality characteristics and shelf-life of low-fat frankfurters produced with olive oil. *Meat Science, 45*(2), 223–238. https://doi.org/10.1016/S0309-1740(96)00108-8

Burdurlu, H. S., & Karadeniz, F. (2003). Gıdalarda diyet lifin önemi. *Gıda Mühendisliği Dergisi, 7*(15), 18–25.

Carballo, J., Mota, N., Barreto, G., & Colmenero, F. J. (1995). Binding properties and colour of bologna sausage made with varying fat levels, protein levels and cooking temperatures. *Meat Science,* 41(3), 301–313. https://doi.org/10.1016/0309-1740(95)00001-2

Çelik, Ö. F., Aktaş, N., Tugay, M. İ., & Tunçil, Y. E. (2023). Hazelnut (*Corylus avellana* L.) skin, a by-product of hazelnut industry, possesses oil with high oxidative and thermal stabilities. *International Journal of Food Science & Technology, 58*(10), 5471–5477. ht https://doi.org/10.1111/ijfs.16371

Colarič, M., Veberič, R., Solar, A., Hudina, M., & Štampar, F. (2005). Phenolic acids, syringaldehyde, and juglone in fruits of different cultivars of *Juglans regia* L. *Journal of Agricultural and Food Chemistry, 53*(16), 6390–6396. https://doi.org/10.1021/jf050721n

Contini, M., Baccelloni, S., Frangipane, M. T., Merendino, N., & Massantini, R. (2012). Increasing espresso coffee brew antioxidant capacity using phenolic extract recovered from hazelnut skin waste. *Journal of Functional Foods, 4*(1), 137–146. https://doi.org/10.1016/j.jff.2011.09.005

Cornelli, U. (2009). Antioxidant use in nutraceuticals. *Clinics in Dermatology, 27*(2), 175–194. https://doi.org/10.1016/j.clindermatol.2008.01.010

Del Rio, D., Calani, L., Dall'Asta, M., & Brighenti, F. (2011).

Polyphenolic composition of hazelnut skin. *Journal of Agricultural and Food Chemistry, 59*(18), 9935–9941. https://doi.org/10.1021/jf202449z

Delgado, T., Malheiro, R., Pereira, J. A., & Ramalhosa, E. (2010). Hazelnut (*Corylus avellana* L.) kernels as a source of antioxidants and their potential in relation to other nuts. *Industrial Crops and Products, 32*(3), 621–626. https://doi.org/10.1016/j.indcrop.2010.07.019

Dinkçi, N., Aktaş, M., Akdeniz, V., & Sirbu, A. (2021). The influence of hazelnut skin addition on quality properties and antioxidant activity of functional yogurt. *Foods*, *10*(11), Makale 2855. https://doi.org/10.3390/foods10112855

Duraklı Velioğlu, S., Güner, K. G., Velioğlu, H. M., & Çelikyurt, G. (2017). Fındık zarının fırıncılık ürünlerinde kullanımı. *Tekirdağ Ziraat Fakültesi Dergisi, 14*(3), 127–139.

Elleuch, M., Bedigian, D., Roiseux, O., Besbes, S., Blecker, C., & Attia, H. (2011). Dietary fibre and fibre-rich by-products of food processing: Characterisation, technological functionality and commercial applications: A review. *Food Chemistry, 124*(2), 411–421. h https://doi.org/10.1016/j.foodchem.2010.06.077

Gençcelep, H., Anil, M., Saricaoğlu, F. T., & Ağar, B. (2017). Farklı modifiye nişastaların et emülsiyonlarının bazı fiziksel ve tekstürel özellikleri üzerine etkileri. *Gida, 42*(6), 773–786.

Gök, V., & Serteser, A. (2003, 2–4 Ekim). *Doğal antioksidanların biyoyararlılığı*. 3. Gıda Mühendisliği Kongresi, Ankara, Türkiye.

Gökalp, H. Y., Kaya, M., Tülek, Y., & Zorba, Ö. (1995). *Et ve et ürünlerinde kalite kontrolü ve laboratuvar uygulama kılavuzu* (Yayın No: 751). Atatürk Üniversitesi Ziraat Fakültesi.

Güleşci, N., & Aygül, İ. (2016). Beslenmede yer alan antioksidan ve fenolik madde içerikli çerezler. *Gümüşhane Üniversitesi Sağlık Bilimleri Dergisi, 5*(1), 109-129.

Hensley, J. L., & Hand, L. W. (1995). Formulation and chopping temperature effects on beef frankfurters. *Journal of Food Science, 60*(1), 55–57. https://doi.org/10.1111/j.1365-2621.1995.tb05605.x

Juntachote, T., Berghofer, E., Siebenhandl, S., & Bauer, F. (2007). The effect of dried galangal powder and its ethanolic extracts on oxidative stability in cooked ground pork. *LWT - Food Science and Technology, 40*(2), 324–330. https://doi.org/10.1016/j.lwt.2005.08.008

Landvogt, A. (1991). Errors in pH measurement of meat and meat products by dilution effects. *Proceedings of the 37th International Congress of Meat Science and Technology* (pp. 1159–1162).

Lecumberri, E., Mateos, R., Izquierdo-Pulido, M., Rupérez, P., Goya, L., & Bravo, L. (2007). Dietary fibre composition, antioxidant capacity and physico-chemical properties of a fibre-rich product from cocoa (*Theobroma cacao* L.). *Food Chemistry, 104*(3), 948–954. https://doi.org/10.1016/j.foodchem.2006.12.054

Lee, J., Koo, N., & Min, D. B. (2004). Reactive oxygen species, aging, and antioxidative nutraceuticals. *Comprehensive Reviews in Food Science and Food Safety, 3*(1), 21–33. https://doi.org/10.1111/j.1541-4337.2004.tb00058.x

Lemon, D. W. (1975). *An improved TBA test for rancidity* (New Series Circular No. 51). Halifax Laboratory.

Lemos, M. R. B., Siqueira, E. M. A., Arruda, S. F., & Zambiazi, R. C. (2012). The effect of roasting on the phenolic compounds and antioxidant potential of baru nuts [*Dipteryx alata* Vog.]. *Food Research International, 48*(2), 592–597. https://doi.org/10.1016/j.foodres.2012.05.027

Locatelli, M., Travaglia, F., Coïsson, J. D., Martelli, A., Stevigny, C., & Arlorio, M. (2010). Total antioxidant activity of hazelnut skin (Nocciola Piemonte PGI): Impact of different roasting conditions. *Food Chemistry, 119*(4), 1647–1655. https://doi.org/10.1016/j.foodchem.2009.08.048

Mehta, N., Ahlawat, S. S., Sharma, D. P., & Dabur, R. S. (2015). Novel trends in development of dietary fiber rich meat products-a critical review. *Journal of Food Science and Technology, 52*(2), 633–647. https://doi.org/10.1007/s13197-013-1010-2

Menci, R., Biondi, L., Natalello, A., Lanza, M., Priolo, A., Valenti, B., & Luciano, G. (2023). Feeding hazelnut skin to lambs delays lipid oxidation in meat. *Meat Science, 202*, 109218. https://doi.org/10.1016/j.meatsci.2023.109218

Monagas, M., Garrido, I., Lebrón-Aguilar, R., Gómez-Cordovés, M. C., Rybarczyk, A., Amarowicz, R., & Bartolomé, B. (2009). Comparative flavan-3-ol profile and antioxidant capacity of roasted peanut, hazelnut, and almond skins. *Journal of Agricultural and Food Chemistry, 57*(22), 10590–10599. https://doi.org/10.1021/jf901391a

Montella, R., Coïsson, J. D., Travaglia, F., Locatelli, M., Bordiga, M., Meyrand, M., & Arlorio, M. (2013). Identification and characterisation of water and alkali soluble oligosaccharides from hazelnut skin (*Corylus avellana* L.). *Food Chemistry, 140*(4), 717–725. https://doi.org/10.1016/j.foodchem.2013.01.061

Moure, A., Cruz, J. M., Franco, D., Domínguez, J. M., Sineiro, J., Domínguez, H., & Parajó, J. C. (2001). Natural antioxidants from residual sources. *Food Chemistry, 72*(2), 145–171. https://doi.org/10.1016/S0308-8146(00)00223-5

Musati, M., Bertino, A., Cannone, M. S., Mangano, F., Luciano, G., Priolo, A., Bella, M. S., Biondi, L., Scerra, M., Mangione, G., & Natalello, A. (2025). Dietary hazelnut skin prevents lipid oxidation in lamb enriched in omega-3 polyunsaturated fatty acids. *Meat Science, 225*, 109811. https://doi.org/10.1016/j.meatsci.2025.109811

Navarro-González, I., García-Valverde, V., García-Alonso, J. V., & Periago, M. J. (2011). Chemical profile, functional and antioxidant properties of tomato peel fiber. *Food Research International, 44*(5), 1528–1535. https://doi.org/10.1016/j.foodres.2011.04.005

Özdemir, K. S., Yılmaz, C., Durmaz, G., & Gökmen, V. (2014). Hazelnut skin powder: A new brown colored functional ingredient. *Food Research International, 65*, 291–297. https://doi.org/10.1016/j.foodres.2014.01.060

Özyurt, V. H. (2013). *Comparison of ultrasonic and conventional extraction yields of phenolic compounds and dietary fiber from hazelnut skin and carob* (Master thesis, Ege University, Institute of Science).

Özyurt, V. H., & Ötleş, S. (2018). Hazelnut testa as a by-product: Nutritional composition, antioxidant activity, phenolic compound profile and dietary fiber content. *Journal of Faculty of Pharmacy of Ankara University, 42*(3), 38–57. https://doi.org/10.1501/Eczfak_0000000611

Pfeil, J. A., Zhao, Y., & McGorrin, R. J. (2024). Chemical composition, phytochemical content, and antioxidant activity of hazelnut (*Corylus avellana* L.) skins from Oregon. *LWT, 201*, 116204. https://doi.org/10.1016/j.lwt.2024.116204

Reische, D. W., Lillard, D. A., & Eitenmiller, R. R. (2002). Antioxidants. C. C. Akoh & D. B. Min (Ed.), *Food Lipids* içinde (2. ed). Marcel Dekker.

Rhee, K. S., Krahl, L. M., Lucia, L. M., & Acuff, G. R. (1997). Antioxidative/antimicrobial effects and TBARS in aerobically refrigerated beef as related to microbial growth. *Journal of Food Science, 62*(6), 1205–1210. https://doi.org/10.1111/j.1365-2621.1997.tb12245.x

Şahin, S., Kılıç, Ö., Şengül, S., & Perçin, S. (2019). Farklı illerden tedarik edilen fındık zarlarının bileşiminin ve antioksidan

aktivitesinin incelenmesi. *Ordu Üniversitesi Bilim ve Teknoloji Dergisi, 9*(1), 27–35.

Salcedo, C. L., Mishima, B. A. L., & Nazareno, M. A. (2010). Walnuts and almonds as model systems of foods constituted by oxidisable, pro-oxidant and antioxidant factors. *Food Research International, 43*(4), 1187–1197. https://doi.org/10.1016/j.foodres.2010.02.016

Schmitzer, V., Slatnar, A., Veberic, R., Stampar, F., & Solar, A. (2011). Roasting affects phenolic composition and antioxidative activity of hazelnuts (*Corylus avellana* L.). *Journal of Food Science, 76*(1), S14–S19. https://doi.org/10.1111/j.1750-3841.2010.01898.x

Seol, K. H., Joo, B. J., Kim, H. W., Chang, O. K., Ham, J. S., Oh, M. H., & Lee, M. (2013). Effect of medicinal plant extract incorporated carrageenan based films on shelf-life of chicken breast meat. *Korean Journal for Food Science of Animal Resources, 33*(1), 53–57. https://doi.org/10.5851/kosfa.2013.33.1.53

Shahidi, F., Alasalvar, C., & Liyana-Pathirana, C. M. (2007). Antioxidant phytochemicals in hazelnut kernel (*Corylus avellana* L.) and hazelnut byproducts. *Journal of Agricultural and Food Chemistry, 55*(4), 1212–1220. https://doi.org/10.1021/jf062472o

SPSS. (2012). *IBM SPSS Statistics for Windows, Version 21.0*. IBM Corp.

Talcott, S. T., Passeretti, S., Duncan, C. E., & Gorbet, D. W. (2005). Polyphenolic content and sensory properties of normal and high oleic acid peanuts. *Food Chemistry, 90*(3), 379–388. https://doi.org/10.1016/j.foodchem.2004.04.011

Taş, N. G., & Gökmen, V. (2015). Bioactive compounds in different hazelnut varieties and their skins. *Journal of Food Composition and Analysis, 43*, 203–208. https://doi.org/10.1016/j.jfca.2015.07.003

Troncoso, E., Pedreschi, F., & Zuniga, R. N. (2009). Comparative study of physical and sensory properties of pre-treated potato slices during vacuum and atmospheric frying. *LWT - Food Science and Technology, 42*(1), 187–195. https://doi.org/10.1016/j.lwt.2008.05.013

Viuda-Martos, M., Ruiz-Navajas, Y., Fernández-López, J., & Pérez-Álvarez, J. A. (2010). Effect of orange dietary fibre, oregano essential oil and packaging conditions on shelf-life of bologna sausages. *Food Control, 21*(4), 436–443. https://doi.org/10.1016/j.foodcont.2009.07.004

Yağcı, S., Altan, A., Göğüş, F., & Maskan, M. (2006). Gıda atıklarının alternatif kullanım alanları. In *Türkiye 9. Gıda Kongresi*.

Zorba, Ö., Gokalp, H. Y., Yetim, H., & Ockerman, H. W. (1993). Model system evaluations of the effects of different levels of K2HPO4, NaCl and oil temperature on emulsion stability and viscosity of fresh and frozen Turkish style meat emulsions. *Meat Science, 34*(2), 145–161. https://doi.org/10.1016/0309-1740(93)90024-C