

Original Research

Research on the Usefulness of Dried Zebda Mango by-Products for Production Raw Beef Sausage

**Ahmed Hassan Abdou^{1,2*}, Fahad Hassan Alarjani¹, Hossam Eldin Hamed Mansour³,
Hesham S. Ghazzawy⁴, Wael F. Shehata⁵, Doaa Bahaa Eldin Darwish⁶,
Azzah I. Alghamdi⁷, Saleh M. Abou-Elwafa⁸, Ahmed Abou El-Yazied⁹,
Khaled Abdelaal¹⁰**

¹Social Studies Department, College of Arts, King Faisal University, Al-Ahsa 31982, Saudi Arabia

²Hotel Studies Department, Faculty of Tourism and Hotels, Mansoura University, Mansoura 35516, Egypt

³Agribusiness and Consumer Sciences Department, College of Agricultural and Food Sciences,
King Faisal University, Al-Ahsa 31982, Saudi Arabia

⁴Date Palm Research Center of Excellence, King Faisal University, Al-Ahsa 31982, Saudi Arabia

⁵Agricultural Biotechnology Department, College of Agricultural and Food Sciences,
King Faisal University, Al-Ahsa 31982, Saudi Arabia

⁶Biology department, Faculty of science, University of Tabuk, 71491 Tabuk, Saudi Arabia

⁷Department of Biology, College of Science, Imam Abdulrahman Bin Faisal University,
P.O. Box 1982, 31441, Dammam, Saudi Arabia

⁸Department of Postharvest and Handling of Vegetable Crops, Horticulture Research Institute,
Agricultural Research Center, Giza, Egypt

⁹Department of Horticulture, Faculty of Agriculture, Ain Shams University, Cairo 11566, Egypt

¹⁰EPCRS Excellence Center, Plant Pathology and Biotechnology Lab., Faculty of Agriculture,
Kafrelsheikh University, 33516, Egypt

Received: 21 June 2023

Accepted: 25 July 2023

Abstract

Total phenolic (TPC), total flavonoid (TF), carotenoids and vitamin C contents were shown to be 4109, 2050 mg GAE/100 g, 3889, 1665 mg catechin/100 g, 3.86, 0.25 mg/100 g and 75.07, 65.76 mg/100 g D.W in MPP and MKP, respectively. The obtained bioactive compounds indicated that MPP (65%) had a higher antioxidant capacity than MKP (50%). The incorporation of mango by-product powder significantly altered the beef sausage's physico-chemical, microbiological and sensory criteria. Especially the addition of MPP at a high concentration (2%) was retarding the development of lipid oxidation and, consequently, the deterioration of quality, such as microbial and color parameters stability of beef sausage stored at 4°C for 12 days. The utilization of mango by-products as an antioxidant and antimicrobial natural preservative was investigated in beef sausage instead of synthetic preservatives, which are becoming avoided. Results showed that the higher concentration of MPP (2%) had a greater antioxidant effect than Butylated Hydroxy Toluene (BHT), which delayed lipid oxidation,

*e-mail: aabdou@kfu.edu.sa

had the lowest values of TBA, and showed great microbial and color parameter stability. So, the shelf life of beef sausage was extended for more than 12 days at T5, meanwhile, it reached only 7 days in T1 (BHT 200 ppm). The results indicated that mango by-product powder effectively inhibited microbial growth and lipid oxidation without altering refrigerated sausages' physical and sensory properties.

Keywords: mango kernel, mango peel, antioxidant, antimicrobial, sensory quality

Introduction

High-quality protein sources include either fresh or processed meat. Most meat products contain a certain amount of fats due to their importance in sensory parameters such as texture, flavor, and appearance. These sensory traits make meat products more attractive and accepted by consumers [1]. However, due to a higher susceptibility of fat to oxidative degradation, the fat may negatively affect the nutritional and sensory quality despite this advantage [2]. One of the first processed foods that man ever created was sausage. Hundreds of sausage varieties worldwide have a significant social and economic impact [3]. Dehydration, fermentation, and lipid oxidation are the main chemical changes of sausage during and after manufacture, as well as microbial changes. One of the primary methods for preventing lipid oxidation is using antioxidants, which may help manage and reduce the oxidation in meat products [4]. Because synthetic antioxidants such as butylated hydroxytoluene (BHT), butylated hydroxyanisole (BHA), propyl gallate (PG) and tert-butyl hydroquinone (TBHQ) may pose a health risk to consumers, there is a growing interest in natural antioxidants [5]. Additionally, due to their toxicity and potential for cancer, the Food and Drug Administration (FDA) restricted the use of synthetic antioxidants [6]. As a result, searches for naturally occurring compounds with antioxidant activity have also increased significantly recently. Several waste materials (by-products) are produced by processing agricultural products. There is a need to reduce or eliminate these by-products to achieve sustainable agriculture. A significant step toward preserving the environment's balance could be using by-products as natural antioxidants in the food industry. Moreover, these by-products are usually rich in phenolic compounds that could have high antioxidant activity. By-products from fruits and vegetables, such as kernels and peels, contain several compounds with antioxidant activity

Mango (*Mangifera indica* L.) is one of the largest crops produced globally. According to FAO, in 2020, the world production of mangoes, guavas and mangosteens was 5,522,933 ha, producing 54,831,104 tonnes. FAO considers mangoes, guavas and mangosteens as one category according to their production. However, Marçal and Pintado [7] reported that mango production is 75% of the previous production and harvesting area values. The peels and stones of mango are about 35-60 % of the total fruit weight and are not used in mango fruit processing. Moreover, about 15-25 million tonnes of peels and stones come annually from mango

processing. Mango peels contain phenolic compounds, some pigments such as carotenoids, fiber, and ascorbic acid that make it suitable to be natural preservation compound in meat processing [8]. Moreover, it has been reported that the chemical composition of mango peels is moisture (62-83%), carbohydrates (>70%), fat (1.6%-3.7%), protein (1.5%-6.6%), and ash (1.2%-4.2%) [7]. The most important chemical compound in mango peels is phenolic compounds that range from 14.85 to 127.6 mg/g DW, the most phenolic compound families are gallic acid, flavonoids, and xanthenes [8]. The integration of mango peels into the food industry was evaluated in several products, such as snacks [9]. Many previous works indicated the positive role of mango peels as antimicrobial compounds against many microbes [10]. However, the use of mango peel powder to preserve meat sausage was limited in previous studies. For example, Manzoor et al. [11] studied the effect of mango peel extract on chicken sausages. They found that lipid oxidation and carbonyl contents were reduced by adding mango peel extract, while the antioxidant activity of chicken sausages was increased. Mango seed kernel is the second essential by-product after the processing of mango fruits. The proportion of mango seed is about 10-25% of the total fruit weight, depending on their varieties. The mango seed kernel contains about 77% carbohydrate, 6.0 % protein, 2.0% crude fiber, 11% fat, 2.0% ash, amino acids (leucine and lysine), polyphenols, phytosterols, and tocopherols [12]. Moreover, the mango seeds showed antioxidant activity due to their role in free radical species (ROS) scavenging and reducing power [13]. Additionally, the antimicrobial effects of the seed kernel on meat such as minced beef were also recorded previously [14]. To the best of our knowledge, the effect of mango seed kernel on beef sausage was not evaluated before. Thus, the current study aimed to evaluate the phytochemical profile and antioxidant activity of the mango by-products (peels and seeds) extracts. Additionally, we aimed to compare the quality characteristics and shelf-life of beef sausage containing mango peel and kernel powders vs. BHT stored at 4°C for 12 days.

Experimental

Material and Chemicals

Minced beef meat, soy protein isolate (SPI), salt and other sausage additives were purchased from a local market in Giza, Egypt. After mango flesh processing

from the Zebda variety during the summer of 2021. Mango by-products (*Mangifera indica* L.) such as peels and seed kernel were collected from juice shops of the local market in Giza, Egypt. Thiobibatoric acid (TBA), 2, 2-diphenyl-1-picryl hydroxyl (DPPH), Butylated hydroxytoluene (BHT), Folin- Ciocalteu, Ethanol, Aluminum chloride, Gallic acid standard, and Trichloroacetic acid were purchased from Sigma Aldrich Chemical Co. St. Louis, Mo, USA.

Drying of Mango Byproducts

Peel and kernel without seed coat were separated manually before washing thoroughly under tap water. The peel and kernel were placed in the oven at 60°C for 10 hours to dry until constant weight. Then they were ground into a fine powder (smaller than 420 µm), sieved with a 40 meshes sieve, and stored at -20°C until further analysis [6].

Preparation of Dried Mango by-Products Extract

According to Luo et al. [15], the extraction was done with some modifications. The maceration technique used 1.5g mango by-product powder (peel or kernel) in 100 ml ethanol (80%), the extract was kept in the shaker (300 rpm) for 1 h. Then the extract was filtrated using filter paper (Whatman No.1). All extracts were analyzed in triplicate.

Estimation of Total Phenolic Compounds of Mango by-Products

The bioactive compounds were determined in dried Zebda mango by-products, such as mango peel powder (MPP) and mango kernel powder (MKP).

The Folin-Ciocalteu reagent method was used to estimate the total phenolic content with certain modifications. Mango peel powder (MPP) or mango kernel powder (MKP) extract solutions (0.1 mL) were combined with 1 mL of Folin Ciocalteu reagent (1:10 diluted with distilled water). After 5 minutes, 1 mL of 7.5% Na₂CO₃ solution was added. The mixture was incubated for one hour in the dark at room temperature. The absorbance was measured using a spectrophotometer at 760 nm (model UV-2401 PC, Shimadzu, Milano, Italia). The total phenolic content was calculated as mg/100g of dried peels of gallic acid equivalent.

Estimation of Total Flavonoids Content (TFC)

Scavenging Effect on DPPH Radical

The DPPH radical scavenging activity was used, according to Ali and El Said [16], to assess the antioxidant capacity %. A mixture of the extract (0.1 ml of MPP or MKP) and 3.9 mL of DPPH solution (0.0024 mg/100 methanol) was made. After being held

for 30 minutes in the dark, the absorption was detected at 517nm using a spectrophotometer. The percentage of inhibition used to represent free radical scavenging was as follows:

$$\text{Inhibition \%} = \left[\frac{A_{\text{control}} - A_{\text{sample}}}{A_{\text{control}}} \right] \times 100$$

A control and A sample are the absorbance of the control (DPPH solution) and extract, respectively.

Preparation of Beef Sausages

The sausages were prepared from minced beef meat, according to EOS-1972 [17]. In this method, the beef meat (550 g) was mixed with fat (150 g), rusk (15 g), ice water (100 ml), soy protein isolate (SPI) (100 g), salt (20 g), milk powder (15 g) and spices (30 g). The mixing was carried out in a food processor for 5 mins until a highly homogenous mixture was obtained. The mixture obtained was divided into 6 portions: control sample (C): ordinary beef sausage without mango by-products, T1: beef sausage with 200 ppm BHT, T2: beef sausage with 1% MKP, T3: beef sausage with 2% MKP, T4: beef sausage with 1% MPP and T5: beef sausage with 2% MPP. Each portion was filled into the cellulose casing with the help of a sausage stuffer. Then each sample was packed into polypropylene packages and stored at 4°C for 12 days. The samples were taken in 3 packages at 4 days intervals for physical-chemical, microbiological, and sensory analysis.

Physical-Chemical Quality of Beef Sausage

Color Characteristics

A hand-held colorimeter (model CR-400, Minolta Corp., Newburgh, NY, USA) was used to determine the color characteristics of beef sausages. The Minolta colorimeter was first calibrated using black and white plates. The parameters obtained in three replicates were L* (lightness), a* (redness), and b* (yellowness) [18].

pH Determination

The sausage sample (3 g) was homogenized in 30 mL of distilled water for 2 min. The mixture solution was filtered with two layers of cheesecloth. The filtrate was collected and used for pH determination by a pH meter (Jenway, model 3305, Dunmow, Essex, UK) after calibration with two buffer solutions (pH 4.01 and pH 7.00) [19].

Thiobibatoric Acid (TBA)

According to El-Beltagi et al. [6], thiobarbituric acid (TBA) was determined. The minced sausage sample (5 g) has been homogenized for 1 min in 20 mL of trichloroacetic acid (TCA solution 10% w/v). Then,

5 ml of the extract solution was mixed with 5 mL of the TBA reagent (0.02 M) and blended well into a glass tube. The previous mixture was set for a 20-minute in the water bath at 90°C. The absorbance was measured at 530 nm after cooling the mixture using a spectrophotometer (Unico UV-2000, USA). The TBA values were expressed as mg malondialdehyde MDA/kg beef sausage.

Microbial Quality of Beef Sausage

Psychotropic bacteria are the major group of microorganisms responsible for the spoilage of refrigerated foods [20]. Psychrotrophic bacteria were determined on PCA at 7°C for 10 days. For obtaining the final dilution (1:10), each sample was weighed (14 g) in a sterile stomacher bag and mixed with sterile saline (0.85 % NaCl, w/w). Samples were homogenized for 1 min using stomacher lab-blender 400 (Seward Medical, London). Serial dilutions were prepared using the previous diluent were made. The appropriate dilutions, 0.1ml was spread plated on PCA, and the inverted plates were incubated at 7°C for 10 days. Colonies were then counted and expressed as log10 psychrotrophic colony-forming units (log10 CFU /g).

Sensory Quality Evaluation

According to Velasco-Arango et al. [21], the sensory evaluation for raw sausage was done for color, odor and overall acceptability. Meanwhile, the taste of cooked beef sausage samples (the freshly prepared beef sausages were boiled in water) was rated only once on the initial day of the experiment. Only raw beef sausage samples were evaluated during the cold storage period by a 25-person panel from Cairo University's, Faculty of Agriculture's Department of Food Science (15 females and 10 males, ages 20 to 45 years). A 9-point hedonic scale was used for scoring (0-2 = greatly detest, 3-4 = dislike little, 5 = fair, 6-8 = like substantially, and 9 = superb). The maximum limit of rejections was 4, considered the minimum acceptable standard for consumers.

Statistical Analysis

The results of the findings were statistically analyzed by Duncan's analysis of variance (ANOVA), multiple range analyses, and using the XLSTAT software's least significant difference (LSD, 95%) test.

Results and Discussion

Phytochemicals Characterization of Mango by-Products

Mangiferin is a variety of heat-stable biologically active phytochemicals found in mangoes [15].

Mangiferin has been found in larger concentrations in the leaves, bark, kernel and fruit peel of mangoes than in the edible pulp, making it an essential secondary metabolite to protect plants and people against numerous types of biotic and abiotic stress [13]. The total phenolic content (TPC), total flavonoids content (TFC) and carotenoids content (CC) of the Zebda mango by-products (*Mangifera indica* L.) extracts, peel and kernel were shown to be 4109, 2050 mg GAE/100 g, 3889, 1665 mg CE/100 g and 3.86, 0.25 mg/100 g DW, respectively. The analysis indicated that MPP and MKP contained significant phenolics content, possibly due to high-temperature damage not being detected during the drying process. According to Abdel Magied and Ali [12], drying at air temperatures above 60°C resulted in a lower concentration of phenolic compounds due to thermal degradation. In addition, using low air-drying temperatures for an extended period, as with the solar drying method, resulted in a greater loss of phenolic content due to oxidation caused by oxygen. Therefore, 60°C was the appropriate drying air temperature for the retention of phenolic chemicals. Hung et al. [23] reported higher phenolic content for peel and kernel in the Keitt mango cultivar dried with different methods, freeze, static and forced air oven, which ranged from 4600-8500 mg GAE/100 g in MPP and 6000 and 3500 mg GAE/ 100 g in MKP, respectively. Otherwise, the current study agreed with Barreto et al. [13], who determined the phenolic content of dried Tommy Atkins mango peel, which ranged from 2513 to 4858 mg GAE/100g, meanwhile, the kernel recorded a lower concentration of phenolic compounds, 10.749 to 20,005 mg GAE/100 g. That may be due to the heating involved in the drying process affecting the total phenolics content in dried mango peel and kernel and the variety of mango cultivars. Polyphenolic compounds are the major contributors to the antioxidant properties of fruits, vegetables, whole grains and other plant-based materials. That is due to their ability to act as reducing agents, hydrogen donors, and free radical scavengers, also, they can chelate metal ions (e.g., iron), decreasing free radicals' catalytic formation. The present study analyzed mango extracts from the dried kernel (MKP) and dried peel (MPP) for their DPPH scavenging capacity%. Results showed that all the mango extracts tested showed high antioxidant activity. Scavenging ranges from 50% to 65% in MKP and MPP, respectively. It means that the higher phenolic content and more scavenging activity. These findings are in harmony with Sultana et al. [24], which showed that the MPP of mango varieties langra and chonsa had antioxidant activity ranging from 60 to 66%. Comparing different segments showed that MPP exhibited higher TFC, TPC, V.C. and antioxidant activity %. In contrast, MKP ranged from 40 to 48.1%, respectively. On average, MPP can be a beneficial by-product of the mango processing industry and a rich source of bioactive compounds.

Microbial Quality of Beef Sausage

Psychrotrophic Bacterial Count

The total psychrotrophic bacterial count in beef sausage samples is presented in Table 1. An initial count was 4.10 log₁₀ CFU /g for the control sample was noticed. The incorporation of MPK (T2 and T3) or MPP (T4 and T5) reduced the microbial load by 3 log. These results could be due to the antibacterial efficacy of mango by-products. Vega-Vega et al. [25] reported that mango peel extract (25 mg/mL of Haden variety) caused a 100 % inhibition of pathogenic bacteria growth, such as *Salmonella enterica* subsp. *enterica* serovar *Choleraesuis* ATCC 14028, *Listeria monocytogenes* ATCC 7644, *Escherichia coli* O157:H7 ATCC 43890 and *Staphylococcus aureus* ATCC 65384) and inhibition of 89.78 % against *Alternaria* with concentration 6.25 mg/mL. All treatments observed a significant gradual increase in the microbial count during storage periods. Meanwhile, the control sample was spoiled at the onset of day 4, when the microbial count reached 6.64 log₁₀ CFU/g over the maximum permissible limit (6 log₁₀ CFU/g) set by the EOS-1972 [17] for sausage.

In contrast, the treatments, T3 and T5 were still acceptable for consumption till the end of the storage period because they recorded the lowest microbial count, 4.95 and 4.89 log₁₀ CFU/g, respectively. Mokhtar and Eldeep [26] noticed a similar gradual increase in the microbial count during the storage of beef burgers at 4°C, which ranged from 5.82 to 6.79 log₁₀ CFU/g at day12 of storage. Also, they showed that the mango peel extract addition at 0.3% level recorded the lowest microbial count even after 12 days of storage time (5.82 log₁₀ CFU/g). That might be due to the antimicrobial properties of phenolic compounds in MPE, especially when the concentration of MPP (T5:2%) was increased. Lag phases were extended for 3, 4 and 5 days, followed by a gradual increase in numbers reaching the spoilage in the T1, T2, T4 and T3, respectively (Table 1). Treatment 5 (2% MPP) was the

highest in extending the lag phase to 6 days, with a shelf life of more than 12 days. Interestingly, the generation time (Table 2) of the spoilage microorganisms in the controls was around 7.88 h. Dried mango by-products increased the generation time (GT: calculated from the logarithmic phase) to 12.00, 12.80, 18.52, 16.76 and 31.19 h. The increase in GT increased the sausage microbial self-life to 7, 8, 10, and 12 in T1, T2, T3 and T4, respectively, compared to 3 days for control. Treatment 5 (T5: 2% MPP) was the superior treatment which reduced the growth rate of psychotropic and the GT to 31.19 h (T5). As a result, the sausage microbial shelf life reached >12 days compared to 3 days for the control.

Physical-Chemical Quality of Beef Sausage

pH

In the case of pH, non-significant differences (P<0.05) were recorded in the values of sausage samples with or without (control) mango by-product on the initial day. So, adding MPP or MKP did not significantly alter the beef sausage's pH (Fig. 1). The pH values of the beef sausage samples ranged from 6.19 to 6.25 in the freshly prepared sample. The results presented by the previous studies of Manzoor et al. [11] agree with the results witnessed in this study. During the storage period, the pH values of prepared beef sausage samples decreased with a slightly significant effect for those containing different concentrations of MPP or MKP. Meanwhile, the pH of the control beef sausage sample (C: no mango by-product powder) decreased after storage with little significant effect (P<0.05), which began after 4 days of storage without no pH changes till the end of storage. The slight pH reductions that occurred throughout cold storage in the sausage samples containing MPP or MKP may have been prompted by the glycogen breakdown and the production of lactic acid. This reduction in pH is a positive character befitting the retardation of microbial growth under lower pH conditions [27].

Table 1. Initial psychrotrophic counts, lag phase, generation time (GT) of the spoilage microorganisms, and shelf life of the beef sausage (with and without mango by-products) during cold storage at 4°C for 12 days.

Treatments	Initial load (log ₁₀ cfu g ⁻¹)	Lag phase (day)	GT (h)	Shelf life (days)
C	4.10	1.00	7.88	3
T1	4.00	3.00	12.00	7
T2	1.06	3.30	12.80	8
T3	1.03	5.00	18.52	12
T4	1.07	4.00	16.74	10
T5	1.02	6.00	31.19	>12

Treatment: C = control, T1 = BHT (200ppm), T2 = MKP (1%, w/w), T3 = MKP (2%, w/w), T4 = MPP (1%, w/w) and T5 = MPP (2%, w/w).

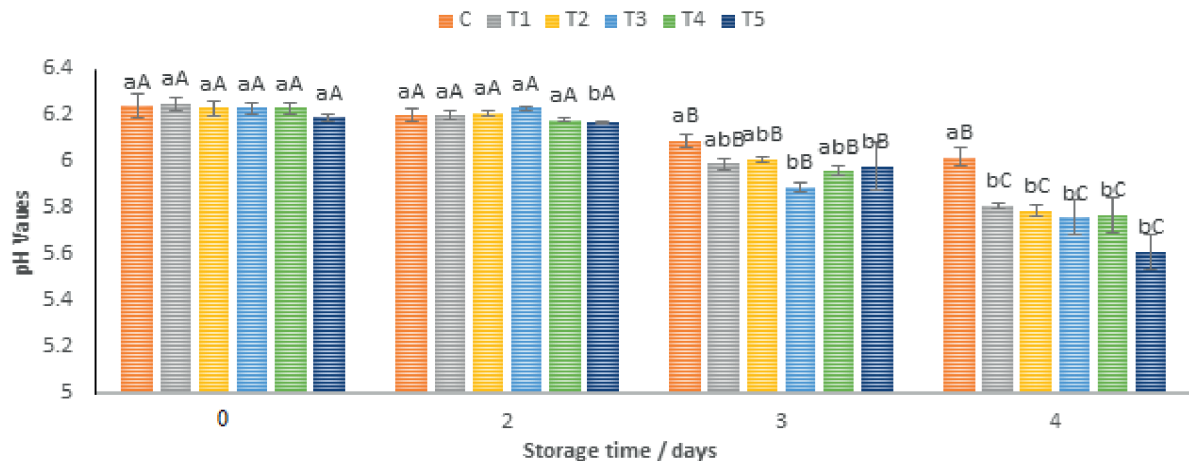


Fig. 1. pH changes of beef sausage samples (with and without mango by-products) during cold storage at 4°C for 12 days. T = treatment: C = control, T1 = BHT (200ppm), T2 = MKP (1%, w/w), T3 = MKP (2%, w/w), T4 = MPP (1%, w/w) and T5 = MPP (2%, w/w). Means (n = 3) followed by different small letters indicate significant differences (Duncan test, $p < 0.05$) between all samples in each storage period. Means (n = 3) followed by different capital letters indicate significant differences (Duncan test, $p < 0.05$) between each storage period at the same sample.

TBA

TBA levels generally increased in all of the sausage samples as the storage period progressed (Fig. 2). The TBA value is related to lipid oxidation, which is thought to be the main spillage cause in meat. The current Investigation reported that including mango by-products in all samples significantly slowed lipid oxidation compared to the control. Through the end of storage (after 12 days), the T5 recorded the lowest TBA value (0.43 mg of malondialdehyde/kg sample). Additionally, all sausage samples had low TBA values, with a significant difference ($P \leq 0.05$) between them. That shows that samples containing a high percentage of mango by-products had considerably ($P \leq 0.05$) lower levels of lipid oxidation (T3: 0.60, and T4: 0.66 mg malondialdehyde/kg). All sausage samples recorded TBA values under the maximum permissible limit (0.9 mg malondialdehyde /kg) set by the EOS-1972 [17] for sausage except control sample (C). The treatments

with no mango by-products recorded the highest TBA values at the end of storage, which reached 0.87 and 0.94 mg malondialdehyde/kg in T1 (preserved by 200 ppm BHT) and C (with no mango by-products) treatments, respectively. Therefore, the Incorporation of MPP or MKP effectively reduced TBA formation up to 36.17 and 54.26 % in T3 and T5, respectively, on 12 days of storage compared with the control sample. These results agree with the results of Manzoor et al. [11], which showed an improvement in lipid oxidative stability of refrigerated chicken sausage treated with different concentrations of mango peel extract (2%, 4% and 6%). Studies conducted by Bellucci et al. [28] on the addition of acai extract to pork patties also revealed comparable efficacy. The substantial research by Fernandes et al. [1] and Pateiro et al. [29] also agrees with our findings.

A relationship exists between delaying lipid oxidation and the preservative substance's antioxidant efficacy. Therefore, it can be said that MPP can prevent lipid oxidation more than MKP in meat products because

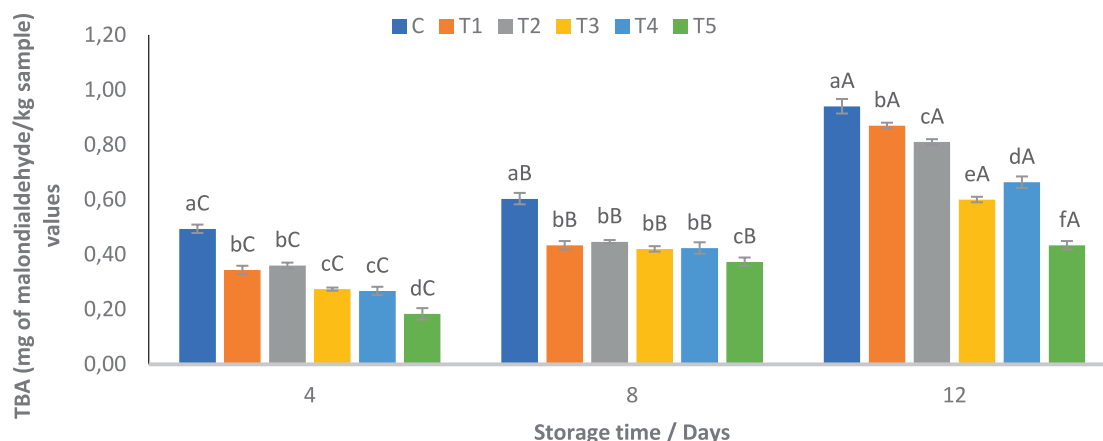


Fig. 2. TBA changes of beef sausage samples (with and without mango by-products) during cold storage at 4°C for 12 days.

of its higher bioactive compounds' contents [30]. Furthermore, the results of this study demonstrated that MPP had higher antioxidant activity (65%) than MKP (50%), which was dependent on the bioactive content of mango by-products, which appeared to include a significant amount of MPP of TPC, TF, and VC.

Color Characteristics

Color is one of the primary elements of meat and meat product quality that influences consumer acceptability [31]. The utilization of plant byproducts as antioxidants for the preservation of meats, delaying protein and lipid oxidation and limiting color deterioration during cold storage. Color parameter values of the beef sausage samples are given in Table 1. At zero time, the L^* values of all sausage samples showed relative values with no significant differences ($p < 0.05$) between them, ranging from 24.10 to 24.30. During storage, the L^* values were decreased with no significant difference in all samples except the control, which gradually decreased seton

day 4. That may be due to fat oxidation during storage, which increased in the control sample compared with other treatments. Data in Fig. 2 illustrated that during storage (12 days, 4°C), the pH values of control recorded the highest value (6.02), therefore, the L^* values decreased from 24.30 to 23.00. On the other hand, T5 recorded the lowest pH value (5.61), a higher L^* value was obtained by the end of storage, and the change was from 24.13 to 34.00.

Redness values showed great significance in all treatments from the first day. The a^* values ranged from -3.25 to 0.87, adding MPP or MKP causes that change and increases with the additional percentage. During the storage period, a gradual decrease in a^* values was noticed. A great change was recorded in the control sample (0.87 to -3.82). Meanwhile, T5 (2% MPP) also recorded a gradual decrease but without significant difference till the end of storage (-3.25 to -3.49). The same trend line was observed with b^* as a color parameter during storage without a significant difference at zero time (ranging from 13.41 to 13.81). The control

Table 2. Color changes of beef sausage samples (with and without mango by-products) during cold storage at 4°C for 12 days.

Treatments	Storage Time /days				
		0	4	8	12
C	L^*	24.30 ^{aA} ±0.06	23.87 ^{bB} ±0.06	23.53 ^{cC} ±0.05	23.00 ^{dD} ±0.10
T1		24.10 ^{aA} ±0.10	24.10 ^{aA} ±0.10	24.07 ^{abAB} ±0.06	23.97 ^{aB} ±0.06
T2		24.23 ^{aA} ±0.25	24.23 ^{aA} ±0.06	24.17 ^{aAB} ±0.06	23.73 ^{bB} ±0.06
T3		24.23 ^{aA} ±0.15	24.20 ^{aA} ±0.10	24.17 ^{aA} ±0.10	23.90 ^{abB} ±0.10
T4		24.10 ^{aA} ±0.06	24.10 ^{aA} ±0.06	24.05 ^{abAB} ±0.03	23.80 ^{abB} ±0.05
T5		24.13 ^{aA} ±0.12	24.13 ^{aA} ±0.05	24.07 ^{abAB} ±0.06	24.00 ^{aAB} ±0.10
Treatments					
C	a^*	0.87 ^{aA} ±0.06	-1.25 ^{bB} ±0.05	-1.93 ^{bC} ±0.06	-3.82 ^{dD} ±0.07
T1		0.75 ^{aA} ±0.05	-0.39 ^{aB} ±0.01	-0.70 ^{aB} ±0.51	-2.33 ^{aC} ±0.15
T2		-1.99 ^{bA} ±0.03	-2.02 ^{cAB} ±0.07	-2.38 ^{cB} ±0.03	-2.72 ^{cC} ±0.02
T3		-3.15 ^{cA} ±0.05	-3.23 ^{cAB} ±0.06	-3.47 ^{dB} ±0.03	-3.58 ^{dB} ±0.02
T4		-1.95 ^{bA} ±0.09	-2.21 ^{dB} ±0.02	-2.38 ^{cB} ±0.01	-2.57 ^{bC} ±0.02
T5		-3.25 ^{cA} ±0.05	-3.38 ^{fAB} ±0.03	-3.43 ^{dAB} ±0.02	-3.49 ^{dB} ±0.03
Treatments					
C	b^*	13.51 ^{dA} ±0.03	12.7 ^{eB} ±0.03	12.02 ^{fBC} ±0.07	11.71 ^{eC} ±0.13
T1		13.52 ^{dA} ±0.04	13.45 ^{cA} ±0.05	13.42 ^{cAB} ±0.03	13.20 ^{cB} ±0.03
T2		13.70 ^{bA} ±0.03	13.59 ^{bAB} ±0.02	13.50 ^{bAB} ±0.02	13.41 ^{bB} ±0.01
T3		13.81 ^{aA} ±0.02	13.78 ^{aA} ±0.03	13.71 ^{aAB} ±0.02	13.53 ^{aAB} ±0.03
T4		13.40 ^{cA} ±0.05	13.22 ^{dAB} ±0.05	13.12 ^{cAB} ±0.06	12.95 ^{dAB} ±0.04
T5		13.55 ^{cA} ±0.06	13.45 ^{cAB} ±0.05	13.32 ^{dAB} ±0.03	13.24 ^{cAB} ±0.04

T = treatment: C = control, T1 = BHT (200ppm), T2 = MKP (1%, w/w), T3 = MKP (2%, w/w), T4 = MPP (1%, w/w) and T5 = MPP (2%, w/w). Means followed by different small letters (within columns) and different capital letters (within rows) are significantly different ($P < 0.05$).

Table 3. Sensory quality changes of beef sausage samples (with and without mango by-products) during cold storage at 4°C for 12 days.

Treatments	Storage Time /days				
	Color	0	4	8	12
C		8.17 ^{aA} ±0.04	5.33 ^{bB} ±0.03	3.83 ^{bC} ±0.03	1.67 ^{dD} ±0.11
T1		8.00 ^{aA} ±0.06	7.50 ^{aAB} ±0.12	7.30 ^{aB} ±0.05	5.60 ^{cC} ±0.03
T2		8.00 ^{aA} ±0.21	7.00 ^{aB} ±0.06	6.91 ^{abB} ±0.06	5.50 ^{cC} ±0.04
T3		8.50 ^{aA} ±0.51	7.60 ^{aB} ±0.10	7.17 ^{aB} ±0.11	6.50 ^{bC} ±0.12
T4		8.16 ^{aA} ±0.03	7.30 ^{aB} ±0.05	7.29 ^{aB} ±0.04	6.67 ^{abC} ±0.06
T5		8.33 ^{aA} ±0.11	8.00 ^{aAB} ±0.04	7.33 ^{aB} ±0.04	7.10 ^{aB} ±0.10
Treatments					
C	Odor	8.00 ^{aA} ±0.04	5.50 ^{bB} ±0.01	3.33 ^{cC} ±0.03	1.10 ^{dD} ±0.11
T1		8.00 ^{aA} ±0.05	7.60 ^{aA} ±0.02	7.50 ^{aAB} ±0.07	5.00 ^{aC} ±0.02
T2		8.00 ^{aA} ±0.03	7.00 ^{aB} ±0.03	6.66 ^{bB} ±0.01	3.33 ^{cC} ±0.01
T3		8.31 ^{aA} ±0.01	7.00 ^{aB} ±0.03	6.83 ^{bB} ±0.02	4.33 ^{bC} ±0.04
T4		8.33 ^{aA} ±0.02	7.16 ^{aB} ±0.04	7.00 ^{abB} ±0.02	5.83 ^{aC} ±0.03
T5		8.50 ^{aA} ±0.03	7.17 ^{aB} ±0.05	7.15 ^{aB} ±0.01	6.17 ^{aC} ±0.05
Treatments					
C	Overall acceptability	8.17 ^{aA} ±0.04	4.50 ^{cB} ±0.03	4.16 ^{cC} ±0.01	2.00 ^{cD} ±0.04
T1		8.00 ^{aA} ±0.03	8.00 ^{aA} ±0.01	7.33 ^{abB} ±0.50	6.50 ^{aB} ±0.11
T2		8.16 ^{aA} ±0.02	5.00 ^{bcB} ±0.06	4.33 ^{cBC} ±0.02	4.28 ^{bC} ±0.02
T3		8.15 ^{aA} ±0.01	6.67 ^{abB} ±0.05	6.60 ^{bB} ±0.03	5.17 ^{bC} ±0.02
T4		8.10 ^{aA} ±0.07	6.83 ^{abB} ±0.01	6.80 ^{bB} ±0.02	6.51 ^{aB} ±0.03
T5		8.33 ^{aA} ±0.03	8.00 ^{aA} ±0.02	7.67 ^{aAB} ±0.04	7.00 ^{aB} ±0.05

Means followed by different small letters (within columns) and different capital letters (within rows) are significantly different ($P<0.05$).

sausage sample recorded the highest change (13.51 to 11.71) compared with other treatments, with no changes in b^* during the storage period. That may be due to the high content of phenolic compounds in mango by-products, especially in MPP, which act as antioxidants and prevent lipid oxidation that stops color deterioration [30]. By the end of storage time, all the treatments which contain mango by-products or BHT exhibited higher L^* , a^* and b^* values than the control (C), which exhibited the lowest values. Color deterioration by the end of storage could be related to the microbial load exceeding the permissible limit (6 log₁₀ CFU/g) set by the EOS-1972 [17] for sausage on the 4th in the control sample (6.64 log₁₀ CFU/g) (Table 2). The obtained results agree with El-Nashi et al. [32], who reported that adding pomegranate peels with different percentages preserves beef sausage color from deterioration during cold storage. Similar results were noticed by Bellucci et al. [28], Manzoor et al. [11] & Mokhtar and Eldeeb [26] with the addition of black rice and mango peel extract in pork, beef patties, chicken sausage and beef burger, respectively.

Sensory Quality Criteria

Sensory quality criteria such as color, odor, and overall acceptability of beef sausage samples containing different concentrations of dried mango by-products were evaluated during cold storage and the results are presented in Table 3. It could be noticed that the addition of mango by-product powder had a significant effect ($p<0.05$) on enhancing the sensory criteria of prepared beef sausage and increased their acceptability during storage. Sensory quality criteria of color, taste, odor, juiciness and overall acceptability were evaluated in cooked beef sausage for all the treatments only on the initial day and rated high scores with the addition of MPP or MKP (Data are not given). As the concentration of MPP or MKP increased, the acceptability of beef sausage increased. The results showed that all sausage samples exhibited high overall acceptability ranging between 8.10 and 8.33, with no significant difference between all treatments on the initial day of the storage (Table 3). Similar results were recorded by Mokhtar and Eldeeb [26] and Kadakadiyavar et al. [33] for

chicken nuggets and beef burgers, overall acceptability contains MPE with different concentrations. Similar scores (without a significant difference) were rated for all samples on day 4 of storage, except the control (C), which significantly decreased. The control sample reached the rejection limit (4) after 4 days of storage in all parameters. Meanwhile, the other samples were still acceptable until day 12, except T2 and T3 (Sample with 1% and 2% MKP, respectively), especially for odor which recorded 3.33 and 4.33, respectively, at day 12. Also, T2 recorded 4.28 for overall acceptability on day 12 of storage which was considered unacceptable. Generally, sausage samples with MPP (T5) recorded the highest score of all parameters compared with BHT. That might be due to the impact of MPP on lipid oxidation and the formation of a rancidity smell. Moreover, the antimicrobial properties of phenolic compounds in MPE, especially when the concentration of MPP (T5:2%) was increased, made it acceptable for more than 12 days.

Conclusions

The study demonstrated that Zebda mango peel powders had a higher antioxidant capacity, while the mango kernel powder displayed a lower antioxidant capacity. Comparing different segments showed that MPP exhibited a higher TFC, TPC, vitamin C and carotenoids, representing higher antioxidant capacity. Therefore, mango by-product segments are a rich source of bioactive compounds and could be utilized as a natural preservative. The incorporation of mango by-product powder significantly altered the beef sausage's physico-chemical, microbiological and sensory criteria. Especially the addition of MPP at a high concentration (2%) was retarding the development of lipid oxidation and, consequently, the deterioration of quality, such as microbial and color parameters stability of beef sausage stored at 4°C for 12 days. Whereas TBA values showed that the additional level of MPE (2%) had a higher effect on delaying lipid oxidation than the recommended addition level of the synthetic antioxidants (200 ppm BHT). Therefore, utilizing the Zebda mango by-product powder could benefit in achieving high stability of beef sausage during cold storage without any negative effects on the product's sensory characteristics.

Acknowledgments

This work was supported by the Deanship of Scientific Research, Vice Presidency for Graduate Studies and Scientific Research, King Faisal University, Saudi Arabia (Grant No. 3752).

Conflicts of Interest

The authors declare no conflict of interest.

References

1. FERNANDES R.P.P., TRINDADE M.A., LORENZO J.M., DE MELO M.P. Assessment of the stability of sheep sausages with the addition of different concentrations of *Origanum vulgare* extract during storage. *Meat Sci* **137**, 244, **2018**.
2. QI S., HUANG H., HUANG J., WANG Q., WEI Q. Lychee (*Litchi chinensis* Sonn.) seed water extract as potential antioxidant and anti-obese natural additive in meat products. *Food Control*, **50**, 195, **2015**.
3. CARBALLO J. Sausages: Nutrition, Safety, Processing and Quality Improvement. *Foods*, **10**, **2021**.
4. MOURE A., CRUZ J.M., FRANCO D., DOMÍNGUEZ J.M., SINEIRO J., DOMÍNGUEZ H., JOSÉ NÚÑEZ M.A., PARAJÓ J.C. Natural antioxidants from residual sources. *Food Chemistry*, **72**, 145-171, **2021**.
5. MUNEKATA P.E.S., DOMÍNGUEZ R., FRANCO D., BERMÚDEZ R., TRINDADE M.A., LORENZO, J.M. Effect of natural antioxidants in *Spanish salchichón* elaborated with encapsulated n-3 long chain fatty acids in konjac glucomannan matrix. *Meat Science*, **124**, 54, **2017**.
6. EL-BELTAGI H.S., EL-MOGY M.M., PARMAR A., MANSOUR A.T., SHALABY T.A., ALI M.R. Phytochemical Characterization and Utilization of Dried Red Beetroot (*Beta vulgaris*) Peels Extract in Maintaining the Quality of Nile Tilapia Fish Fillet. *Antioxidants*, **11**, 906, **2022**.
7. MARÇAL S., PINTADO M. Mango peels as food ingredient/additive: nutritional value, processing, safety and applications. *Trends in Food Science & Technology*, **114**, 472, **2021**.
8. DE ANCOS B., SÁNCHEZ-MORENO C., ZACARÍAS L., RODRIGO M.J., SÁYAGO AYERDÍ S., BLANCAS BENÍTEZ F.J., DOMÍNGUEZ AVILA J.A., GONZÁLEZ-AGUILAR G.A. Effects of two different drying methods (freeze-drying and hot air-drying) on the phenolic and carotenoid profile of 'Ataulfo' mango by-products. *Journal of Food Measurement and Characterization*, **12**, 2145, **2018**.
9. BERTHA C.-T., ALBERTO S.-B.J., TOVAR J., SÁYAGO-AYERDI S.G., ZAMORA-GASGA V.M. *In vitro* gastrointestinal digestion of mango by-product snacks: Potential absorption of polyphenols and antioxidant capacity. *International Journal of Food Science & Technology*, **54**, 3091, **2019**.
10. DORTA E., GONZÁLEZ M., LOBO M.G., LAICH F. Antifungal activity of mango peel and seed extracts against clinically pathogenic and food spoilage yeasts. *Natural Product Research*, **30**, 2598, **2016**.
11. MANZOOR A., AHMAD S., YOUSUF B. Effect of bioactive-rich mango peel extract on physicochemical, antioxidant and functional characteristics of chicken sausage. *Applied Food Research*, **2**, 100183, **2022**.
12. ZEIN R.E., EL-BAGOURY A.A., KASSAB H.E. Chemical and nutritional studies on mango seed kernels. *Journal of Food and Dairy Sciences*, **30**, 3285, **2005**.
13. BARRETO J.C., TREVISAN M.T.S., HULL W.E., ERBEN G., DE BRITO E.S., PFUNDSTEIN B., WÜRTELE G., SPIEGELHALDER B., OWEN R.W. Characterization and Quantitation of Polyphenolic Compounds in Bark, Kernel, Leaves, and Peel of Mango (*Mangifera indica* L.). *Journal of Agricultural and Food Chemistry*, **56**, 5599, **2008**.
14. GADALLAH M.G.E., ABDEL F.A.A. The antibacterial effect of mango seed kernel powder in minced beef during

- refrigerated storage. World Journal of Dairy & Food Sciences, **6** (2), 219, **2011**.
15. LUO F., LV Q., ZHAO Y., HU G., HUANG G., ZHANG J., SUN C., LI X., CHEN K. Quantification and purification of mangiferin from Chinese Mango (*Mangifera indica* L.) cultivars and its protective effect on human umbilical vein endothelial cells under H₂O₂-induced stress. International journal of molecular sciences, **13**, 11260, **2012**.
 16. ALI M.R., EL SAID R.M. Assessment of the potential of Arabic gum as an antimicrobial and antioxidant agent in developing vegan "egg-free" mayonnaise. Journal of Food Safety, **40**, e12771, **2020**.
 17. Egyptian Organization For Standardization (EOS). Standard Specifications for Chilled and Frozen beef sausage (1972) and (2-889), EOS: Egypt, Cairo, **2005**.
 18. ALI M.R., PARMAR A., NIEDBALA G., WOJCIECHOWSKI T., ABOU EL-YAZIED A., EL-GAWAD H.G.A., NAHHAS N.E., IBRAHIM M.F.M., EL-MOGY M.M. Improved Shelf-Life and Consumer Acceptance of Fresh-Cut and Fried Potato Strips by an Edible Coating of Garden Cress Seed Mucilage. *Foods (Basel, Switzerland)*, **10**, **2021**.
 19. DARWISH O.S., ALI M.R., KHOJAH E., SAMRA B.N., RAMADAN K.M.A., EL-MOGY M.M. Pre-Harvest Application of Salicylic Acid, Absciscic Acid, and Methyl Jasmonate Conserve Bioactive Compounds of Strawberry Fruits during Refrigerated Storage. *Horticulturae*, **7**, **2021**.
 20. SØRHAUG T., STEPANIAK L. Psychrotrophs and their enzymes in milk and dairy products: Quality aspects. Trends Food Sci. Technol., **8**, 35, **1997**.
 21. VELASCO-ARANGO V.A., HLEAP-ZAPATA J.I., ORDÓÑEZ-SANTOS L.E. Effect of Adding Guava (*Psidium guajava*) Epicarp Extract Flour on the Physicochemical, Textural, Colour and Sensory Properties of Frankfurters. Food technology and biotechnology, **59**, 185, **2021**.
 22. MAGIED M.A.M., ALI R.M. Effect of Drying Method on Physical Properties and Bioactive Compounds of Red Chili Pepper (*Capsicum annuum*) L. Current Nutrition & Food Science, **13**, 43, **2017**.
 23. HUNG L.M., MASON S.L., BICKERSTAFFE R. Total phenolic content of Tommy Atkins mangoes imported into New Zealand. Proceedings of the Nutrition Society of New Zealand, **34**, 34, **2009**.
 24. SULTANA B., HUSSAIN Z., ASIF M., MUNIR A. Investigation on the antioxidant activity of leaves, peels, stems bark, and kernel of mango (*Mangifera indica* L.). J Food Sci, **77**, 849, **2012**.
 25. VEGA-VEGA V., SILVA-ESPINOZA B.A., CRUZ-VALENZUELA M.R., BERNAL-MERCADO A.T., GONZÁLEZ-AGUILAR G.A., RUÍZ-CRUZ S., MOCTEZUMA E., SIDDQUI M.D.W., AYALA-ZAVALA J.F. Antimicrobial and antioxidant properties of byproduct extracts of mango fruit. Journal of Applied Botany and Food Quality, **86**, 205, **2013**.
 26. MOKHTAR S.M., ELDEEP G.S.S. Impact of Mango Peel Extract on the Physicochemical Properties, Microbiological Stability and Sensory Characteristics of Beef Burgers During Cold Storage. Egypt. J. Food. Sci., **48** (2), 245, **2020**.
 27. LI X., XIONG Q., ZHOU H., XU B., SUN Y. Analysis of Microbial Diversity and Dynamics During Bacon Storage Inoculated with Potential Spoilage Bacteria by High-Throughput Sequencing. Frontiers in microbiology, **12**, 713513, **2021**.
 28. BELLUCCI E.R.B., MUNEKATA P.E.S., PATEIRO M., LORENZO J.M., DA SILVA BARRETTO A.C. Red pitaya extract as natural antioxidant in pork patties with total replacement of animal fat. Meat Science, **171**, 108284, **2021**.
 29. PATEIRO M., VARGAS F.C., CHINCHA A.A.I.A., SANT'ANA A.S., STROZZI I., ROCCHETTI G., BARBA F.J., DOMÍNGUEZ R., LUCINI L., DO AMARAL SOBRAL P.J., ET AL. Guarana seed extracts as a useful strategy to extend the shelf life of pork patties: UHPLC-ESI/QTOF phenolic profile and impact on microbial inactivation, lipid and protein oxidation and antioxidant capacity. Food Research International, **114**, 55, **2018**.
 30. GARZÓN G.A., NARVÁEZ-CUENCA C.E., VINCKEN J.P., GRUPPEN H. Polyphenolic composition and antioxidant activity of açai (*Euterpe oleracea* Mart.) from Colombia. Food Chem., **217**, 364, **2017**.
 31. TOMASEVIC I., TOMOVIC V., MILOVANOVIC B., LORENZO J., ĐORĐEVIĆ V., KARABASIL N., DJEKIC I. Comparison of a computer vision system vs. traditional colorimeter for color evaluation of meat products with various physical properties. Meat Sci., **148**, 5, **2019**.
 32. EL-NASHI H.B., ABDEL FATTAH A.F.A.K., ABDEL RAHMAN N.R., ABD EL-RAZIK M.M. Quality characteristics of beef sausage containing pomegranate peels during refrigerated storage. Annals of Agricultural Sciences, **60**, 403, **2015**.
 33. KADAKADIYAVAR P., AMBADKAR R.K., RATHOD K.S. Assessment of quality of chicken nuggets treated with mango peel extract. International Journal of Livestock Research, **7**, 2, 71, **2017**.