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Original Research

# The effect of nanocapsules containing mango-eggplant peel extracts on the physicochemical, oxidative, microbial and sensory characteristics of refrigerated beef burgers during storage

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## Abstract

**Meat and meat products are classified as perishable food items characterized by a limited shelf life when stored under refrigeration. Consequently, considerable attention has been focused on extending the shelf life of these products and preserving their quality through the utilization of natural preservatives. The objective of this research was to examine the impact of both free and nonencapsulated forms of mango-eggplant peel extracts (M-EPEs) administered at concentrations of 200, 450, and 700 mg/kg as natural preservatives on the physicochemical, oxidative, microbial, and sensory attributes of beef burgers over a 7-day storage period at a controlled temperature of 4°C. The findings indicated that throughout the storage period, there was a significant increase in oxidative indices, specifically peroxide and thiobarbituric acid (TBA) levels, as well as in microbial load, which included counts of aerobic mesophilic bacteria, psychrophilic bacteria, coliforms, molds, and yeasts. Consequently, these changes resulted in an elevation of pH and total volatile basic nitrogen (TVB-N) levels, alongside a reduction in hardness and color indices L*, a*, and b* of the samples ($p < 0.05$) M-EPEs demonstrated significant antioxidant and antimicrobial properties in burgers, with these effects being concentration-dependent. Both forms of these extracts effectively diminished the rate of change in the physicochemical properties of the samples throughout the storage period. This was achieved by attenuating the oxidation rate of lipids and mitigating the microbial load present in the burgers. The highest oxidative stability and the lowest microbial load were observed at the maximum concentration of additives, specifically 700 mg/kg. At the conclusion of the storage period, the antioxidant and antimicrobial efficacy of the nonencapsulated extracts was found to be superior to that of their free counterparts. The findings from the sensory evaluation revealed a notable influence of the extracts on preserving the sensory acceptability of the burgers throughout the storage duration. In conclusion, the findings of this research indicate that M-EPEs exhibit significant antioxidant and antimicrobial properties. These natural extracts have the potential to serve as effective preservatives, thereby enhancing the quality and safety of meat burgers while also prolonging their shelf life without compromising sensory attributes. According to the findings, the sample containing nanocapsules of extracts at a concentration of 700 mg/kg emerges as the most effective treatment option.**

**Keywords:** **Burger, Eggplant, Encapsulation, Mango, Natural preservatives**

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## 1. Introduction

Red meat is a significant component of the human diet, serving as a substantial source of protein, vitamins, minerals, amino acids, and energy. Meat burgers rank among the most prevalent and widely consumed meat products globally, particularly among young consumers (1). Meat and its processed derivatives are highly susceptible to microbial spoilage due to favorable physical and chemical conditions. Conversely, meat is classified as a premium-priced commodity, and initiatives aimed at extending its shelf life, even by a few days, have the potential to significantly reduce spoilage-related waste. Such advancements may result in substantial economic benefits (2). In contemporary society, there has been a marked increase in consumer demand for products perceived as more natural and healthier. This shift underscores the significance of employing novel and natural methodologies for controlling microbial growth and preserving the quality of end products. Plant-derived materials, including fruits, vegetables, and spices, are characterized by their substantial concentrations of bioactive compounds, notably phenolic compounds and flavonoids. These constituents frequently demonstrate pronounced antioxidant and antimicrobial properties, which are considered beneficial (4).

Mango (*Mangifera indica*) is a commercially significant fruit that plays a vital role in the production of a diverse array of food products, including juice, jam, beverages, and concentrates. The byproducts generated during the processing of mango fruit account for approximately 60% of the total weight of the fruit. These byproducts primarily comprise 12% peel and 20% seed or core. Agricultural waste has generated a range of economic and environmental challenges for stakeholders within the agricultural sector. Nevertheless, these waste materials frequently serve as valuable sources of phenolic compounds and exhibit various biological activities, including antioxidant, anticancer, and antimicrobial properties. Mango peel is a significant source of various beneficial nutrients, including vitamins, carotenoids, dietary fiber, phenolic compounds, flavonoids, cinnamic acids and their derivatives, as well as galactotannins. The presence of significant concentrations of bioactive compounds in mango peel endows this by-product of mango processing with notable functional properties, including antioxidant activity (6). Eggplant (*Solanum melongena L.*) is an economically significant and productive cultivar within the Solanaceae family, characterized by its considerable diversity in size, shape, and coloration. Currently, the cultivation of eggplant is prevalent across various regions, including parts of Asia, as well as in North America, Europe, and Africa (7). The cultivation of eggplant (*Solanum melongena*) is experiencing a notable surge in interest, attributable to its significant nutritional benefits and diverse applications in the production of various food products, including fresh, frozen, and canned forms. This encompasses preparations such as pickled, fried, grilled, and stuffed eggplants, among others. Nonetheless, the industries engaged in the production of these products also generate considerable quantities of eggplant by-products, the majority of which are classified as waste and disposed of in landfills (7). The peel of the eggplant constitutes one of its primary by-products. It represents a highly abundant source of anthocyanins and is a significant source of dietary fiber, encompassing compounds such as pectin and cellulose. Phenolic compounds are predominantly concentrated in the by-products of eggplant, with a particular emphasis on the peel. Consequently, eggplant by-products represent a particularly abundant source of phenolic compounds compared to other agricultural by-products (9).

Plant materials serve as outstanding sources of a diverse array of bioactive compounds that

can be incorporated as formulation ingredients in processed meat products. Consequently, the utilization of plant-based preservatives is imperative to mitigate oxidative degradation and inhibit microbial proliferation, thereby enhancing the product's shelf life. Nonetheless, certain limitations, including pronounced organoleptic effects, instability, and reduced shelf life of various plant bioactive compounds, hinder their application in meat products. Currently, encapsulation or micro-coating techniques are utilized as effective and efficient strategies to address these challenges (10). Encapsulation refers to a process in which one or more active agents are confined within a carrier material or structural matrix. The enclosed or enveloped compound is referred to as the inner, core, or central material. It is also designated by various terms, including carrier material, membrane, shell, or carrier (11). Microencapsulation technology is extensively employed in the food industry to encase bioactive agents while preserving their biological functionalities. This process involves the formation of a protective barrier that safeguards the compounds from detrimental and adverse environmental conditions. These conditions include variations in pH, exposure to light, moisture levels, thermal influences, oxygen presence, and mechanical agitation at high shear rates. Moreover, microencapsulation protects the bioactive agents from the challenging conditions presented by the digestive tract, specifically the acidic environment of the stomach and the alkaline pH of the intestine (12). Numerous techniques exist for the microencapsulation of compounds and active agents, with the spray drying method being one of the most prevalently employed. This method is characterized by its simplicity and versatility, enabling the drying of a wide range of bioactive agents, as well as volatile and aromatic substances (13). Owing to its low viscosity, high solid content, and complete solubility in water, maltodextrin is regarded as an appropriate and advantageous material for the microencapsulation of food constituents and bioactive compounds. Furthermore, maltodextrin exhibits considerable emulsification stabilization and gelling capabilities (14). This study aimed to examine the impact of nanocapsules derived from mango peel and eggplant peel extracts (M-EPEs) as natural preservatives on the chemical, microbial, oxidative, and sensory attributes of veal burgers throughout their storage period under refrigeration.

## 2. Materials and methods

### 2.1. Materials

Mangoes and purple eggplants were purchased from a local market. After thorough washing, the peels were removed using a kitchen knife. The peels of the mango and eggplant were washed with water and then dried in an oven at a temperature of 35°C for 24 hours. After grinding the dried peels, the resulting powders were transferred into sealed containers and stored in a dark environment at freezer temperatures until further use. Maltodextrin (DE=20), Tween 40, culture media, and all chemicals used in this research were sourced from Merck (Germany).

### 2.2. Preparation of extracts

A hydroalcoholic solvent consisting of 50% ethanol was employed in the preparation of the extracts. A total of fifty grams of peel powder was combined with the hydroalcoholic solvent in a 1:5 ratio and subjected to stirring on a magnetic stirrer (Heidolph, Germany) for a duration of 48 hours. Following this period, the resulting mixture was filtered through Whatman filter paper. Subsequently, the solvent was removed to the greatest extent possible using a rotary evaporator (Heidolph, Germany). The resulting extracts were stored at refrigeration temperature until their subsequent application (15). The total phenolic content (TPC) of the

extracts was assessed utilizing the Folin-Ciocalteu method (16). Additionally, the antioxidant activity was evaluated through the DPPH radical scavenging assay, with absorbance measurements conducted at a wavelength of 517 nm (15).

### 2.3. Preparation of M-EPEs nanocapsules and its characterization

To formulate nano-capsules containing extracts, an aqueous solution of 30% maltodextrin was employed. In this study, 30 grams of maltodextrin were solubilized in 100 milliliters of distilled water, and the resulting mixture was subjected to a rotating hot water bath overnight to ensure complete saturation of the polymer molecules. Subsequently, Tween 40 was introduced to the aqueous phase at a concentration of 1% (w/w) as a surfactant, and the mixture was stirred for a duration of one hour. To formulate the solution, extracts of mango peel and eggplant peel were combined with the wall material in a ratio of 1:10. The mixture was subsequently homogenized for 15 minutes at room temperature and subjected to a centrifugal force of 129 × g. In the subsequent phase of the study, a probe ultrasound device (UP 400A, Iran) was employed, operating at a frequency of 20 kHz for 30 minutes, with intervals of 5 minutes each, to facilitate the reduction of particle size (17). The drying process was ultimately conducted using a spray dryer (CD3600, Iran). The inlet temperature of the dryer was established at 150°C, while the outlet temperature was configured at 100°C.

The mean particle size, polydispersity index (PDI), and zeta potential of the M-EPEs nanocapsules were assessed using a Zetasizer (Malvern, England). The encapsulation efficiency of the nanocapsule was determined by comparing the initial total phenolic content with the final total phenolic content within the nanocapsule. A scanning electron microscope (SEM), specifically the Tesca-Vega3 model from Tescan Co. in the Czech Republic, was employed to examine the microstructural characteristics of the nanocapsules. Prior to microscopic examination, the sample was coated with a thin layer of gold and subsequently analyzed at an accelerated voltage of 5 kV (18).

### 2.4. Preparation of beef burger treatments

Initially, fresh beef was processed using a meat grinder (Pars Khazar, Iran). The formulation of the control hamburger consisted of the following compositional percentages: 61.5% beef, 24% onion, 1.1% salt, 0.1% red pepper, 8% breadcrumbs, 5% wheat flour, 0.16% garlic powder, 0.07% nutmeg, and 0.07% turmeric. Following the amalgamation of the formulation ingredients, the burger patties were shaped using a mold with a diameter of 10 cm and an approximate height of 1 cm. The hamburger samples produced exhibited an approximate weight of 80 grams. The study employed both free and nanoencapsulated extracts derived from mango-eggplant peels at three concentration levels: 200 mg/kg, 450 mg/kg, and 700 mg/kg, within the burger formulation. Additionally, a control sample devoid of any additives was included for comparative analysis. The burger treatments were stored at refrigeration temperatures for a duration of seven days, with evaluations conducted on days 0, 2, 5, and 7 (19).

### 2.5. Burger tests

#### 2.5.1. Physicochemical characteristics of burgers

The pH of the burgers was assessed at room temperature utilizing a pH meter (HM-20S, manufactured in Japan). The determination of total viable nitrogen bases (TVB-N) was conducted utilizing the micro-Kjeldahl method, followed by titration with a 0.1 N sulfuric acid solution (20). The peroxide index was determined employing the titration method utilizing a 0.01 N sodium thiosulfate solution (21). The thiobarbituric acid (TBA) index was quantified utilizing a spectroscopic method with

absorbance readings conducted at a wavelength of 532 nm (22). The hardness of the burgers was assessed using a texture analyzer (Brookfield CT3, England), equipped with a 250 N load cell and a cylindrical probe featuring a flat end with a diameter of 7.5 mm. Samples measuring 2 cm × 2 cm were extracted from the central region of each burger. Compression was performed to a maximum of 50% of the initial height, utilizing a probe speed of 1 mm/s (23). The color indices of burgers, specifically brightness (L*), red-green chromaticity (a*), and yellow-blue chromaticity (b*), were measured using a colorimeter (Minolta, China). The total color change (ΔE) was computed using the equation presented in the following equation (24).

$$\Delta E = \sqrt{((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2)}$$

### 2.5.2. Microbial load of burgers

In order to conduct a microbial analysis of burger samples, an initial dilution was prepared by homogenizing 10 grams of each sample in 90 milliliters of sterile 0.1% peptone solution utilizing a shaking incubator for a duration of 180 seconds. Subsequently, serial dilutions were derived from the initial dilution to facilitate further analysis. The enumeration of aerobic mesophilic bacteria and psychrotrophic bacteria in the samples was conducted utilizing plate-count agar (PCA) as the culture medium, employing the surface culture methodology. The prepared plates were incubated in a greenhouse for a duration of 48 hours at a temperature of 30°C, followed by a subsequent incubation period of 7 days at 4°C. To enumerate coliform bacteria in the burger samples, the Violet Red Bile Agar (VRBA) culture medium was utilized, along with an incubation period of 48 hours at a controlled temperature of 35°C. The culture medium employed for the enumeration of molds and yeasts was YGC medium. Following incubation in a controlled environment at 25°C for a duration of five days, the resulting colonies were subsequently counted.

### 2.5.3. Sensory evaluation of burgers

This study involves the evaluation of the sensory attributes of beef burgers, specifically focusing on flavor, texture, color, odor, and overall acceptance. A panel of ten evaluators participated in this assessment using a 5-point hedonic scale, with scores assigned as follows: 5 indicating "very good," 4 signifying "good," 3 reflecting "moderate," 2 representing "bad," and 1 denoting "very bad." The burgers were cooked by frying in vegetable oil at a temperature of 150°C for a duration of 8 minutes, resulting in a center temperature of 72°C. Following the cooling process, the samples were presented to panelists in coded containers, accompanied by an evaluation form. The panelists received a fundamental explanation regarding the procedure for assessing the sensory characteristics of the samples (27).

## 3. Results and discussion

### 3.1. TPC and antioxidant activity of M-EPEs

The total phenolic content (TPC) of methanolic extracts of plant equivalents (M-EPEs) was quantified using the Folin-Ciocalteu method. Additionally, the antioxidant activity of the extracts was assessed employing the DPPH radical scavenging assay. The total phenolic content (TPC) and antioxidant activity of the eggplant peel extract generated in this study were determined to be 19.86 mg GAE/g dry weight (dw) and 75.35%. In contrast, the corresponding values for the mango peel extract were found to be 35.62 mg GAE/g dw and 89.86%. In the research of Ferarsa *et al*. (2018), the total phenolic content (TPC) of eggplant peel extract obtained through an ultrasound extraction system was reported to be 23.10 mg gallic acid equivalents (GAE) per gram of dry weight (dw) (28). This value is notably higher than those obtained in the current investigation. Sarabandi *et al*. (2019) conducted a study that contributes significantly to the existing body of

knowledge in the field. Their research offers valuable insights and lays the groundwork for further investigation on the topic. Sarabandi *et al*. (2019) reported TPC and antioxidant activity of eggplant peel extract nanocapsules as 5.20 mg GAE/g and 73.40%, respectively (29). The total phenolic content (TPC) and antioxidant activity of nanocapsules derived from eggplant peel extract were reported to be 5.20 mg gallic acid equivalent per gram (GAE/g) and 73.40%, respectively (29). These values were found to be lower than those obtained in the current investigation. The robust antioxidant properties of mango peel extract were corroborated by the findings of Sanchez-Camargo *et al.* (2021). In the study conducted by Bai *et al*. (2018), the DPPH radical scavenging activity of mango peel extract was determined to be 92%. The authors identified gallic acid as the most efficacious phenolic compound contributing to the antioxidant activity of the mango peel extract. Prior investigations have established that mango peel possesses considerable antioxidant and free radical scavenging properties. This functionality is attributed to the presence of various bioactive compounds, including polyphenols, carotenoids, and anthocyanins (32).

### 3.2. Characteristics of M-EPEs nanocapsules

In this study, M-EPEs nanocapsules were synthesized using the spray drying technique, utilizing maltodextrin as the wall material. The mean particle size of the synthesized nanocapsules was found to be 144.6 nm, with a polydispersity index (PDI) of 0.268 and a zeta potential value of -31.27. The Polydispersity Index (PDI) quantifies the uniformity of particle or molecular size distribution within the analyzed samples. A system is classified as uniform when its components exhibit comparable shape and dimensions. The index under consideration operates within a range of 0 to 1, wherein a lower PDI (polydispersity index) for the sample signifies a greater degree of uniformity. The nanocapsules synthesized in this study exhibited a generally small particle size accompanied by favorable particle size dispersion. In the study conducted by Rashid *et al*. (2022), the mean particle size and polydispersity index (PDI) of nanocapsules encapsulating pomegranate peel extract, which were formulated using maltodextrin as a coating agent, were reported to be 182.65 nm and 0.230, respectively. Zeta potential is a critical parameter in the encapsulation process of active agents, as it reflects the surface charge of particles and significantly impacts the stability of colloidal systems. Particles exhibiting a high zeta potential demonstrate resistance to flocculation and aggregation. The surface charge of the M-EPEs nanocapsules synthesized in the current study was found to be negative. Furthermore, the zeta potential of these nanocapsules exceeded 30 mV, indicating that they possess good stability within colloidal systems. Consequently, the likelihood of particle aggregation in these nanocapsules is significantly reduced. Ćujić-Nikolić *et al*. (2019) reported the zeta potential of gooseberry fruit extract capsules prepared with maltodextrin to be -35.73 mV, while pomegranate peel extract nanocapsules prepared by maltodextrin coating in Rashid *et al*.'s (2022) study have a zeta potential of around -27.8 mV. Encapsulation efficiency is a measure of the capacity of the wall material employed in the encapsulation process to retain the active compound (core) within its matrix. It is important to note that various biopolymer materials can exhibit differing levels of encapsulation efficiency. The encapsulation efficiency of nanocapsules containing extracts is frequently assessed based on the quantity of phenolic compounds retained within the structural matrix of the capsules. In the current investigation, the synthesized M-EPEs nanocapsules exhibited a high encapsulation efficiency of 91.32%. Savikin *et al*. (2021) conducted a comprehensive study that explores the implications of the application of maltodextrin as a wall material, demonstrating

its capability to yield pomegranate peel extract capsules characterized by a notably high encapsulation efficiency. An analysis of the morphology of M-EPEs nanocapsules was conducted utilizing scanning electron microscopy (SEM), as illustrated in Fig. 1. The findings indicated that the nanocapsules exhibited a spherical morphology characterized by uneven surfaces and depressions. Furthermore, no aggregation of particles was detected within the nanocapsules, corroborating the zeta potential results. In the study conducted by Saborirad *et al*. (2014), the encapsulation of mango peel extract through the spray drying method was explored. The researchers identified that the capsules, utilizing maltodextrin as the wall material, exhibited a spherical morphology characterized by uneven surfaces. Furthermore, it was noted that there was no observable aggregation among the particles (38).

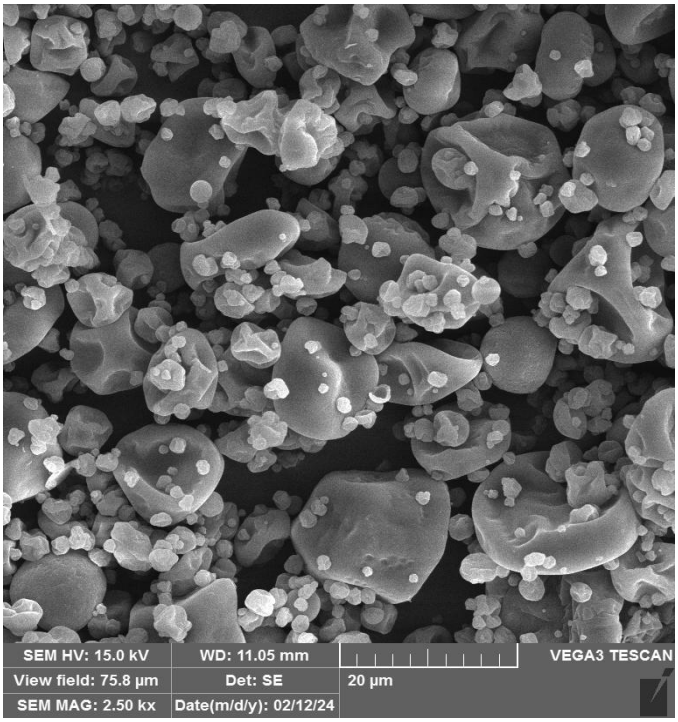



**Fig. 1. SEM image of M-EPE nanocapsules**

### 3.3. pH of burgers

The evaluation of pH values in beef burgers, as presented in Table 1, indicated that the incorporation of M-EPEs at the onset of the storage period did not result in significant alterations to the pH of the burgers. However, over time, a significant increase ($p < 0.05$) in the pH values of the burger samples was observed, with pH levels rising from a range of 5.69–5.71 on the first day to between 5.83 and 6.32 by the conclusion of the storage period. The observed increase in the pH of burgers over time can be attributed to the degradation of proteins by the intrinsic proteolytic enzymes present in the meat or by proteolytic enzymes secreted by microbial communities. This degradation of proteins leads to the formation of volatile alkaline compounds, such as amines and ammonia. Consequently, the generation of these compounds contributes to an elevation in the pH level of the product (39). As anticipated, the control sample, which lacked preservatives, exhibited the highest microbial load. Additionally, this sample demonstrated the

most significant increase in pH over time. The incorporation of various forms of M-EPEs, owing to their antimicrobial properties, resulted in a reduced rate of protein degradation and a diminished production of alkaline compounds in the burgers throughout the storage period. Consequently, the rate of pH increase in the treated samples was significantly lower in comparison to the control sample. In the study conducted by Heck *et al*. (2018), it was observed that the pH values of burger samples experienced a significant increase during the storage period. This phenomenon was attributed to the degradation of proteins (40). Anvar *et al*.) conducted a study that explores. In a study conducted in 2023, it was observed that both the essential oil derived from dill seeds and gallic acid, in both free and encapsulated forms, were effective in significantly mitigating the rate of pH changes in minced meat during refrigerated storage when compared to the control group (41). In the study conducted

by Zafra Ciprián *et al*., a notable reduction in the rate of pH changes in ground beef, attributable to the application of mango peel extract, was observed in comparison to the control group throughout the storage period. In the year 2023, the findings published in reference (42) underscore significant developments in the field.

### 3.4. TVB-N of burgers

TVB-N serves as a significant index utilized for examining the enzymatic and bacterial degradation of both meat proteins and non-protein nitrogenous compounds. The total volatile basic nitrogen (TVB-N) values of the burgers are presented in Table 1. It is evident that throughout the storage period, the TVB-N values of the meat burgers exhibited a statistically significant increase ($p < 0.05$)Initially, the TVB-N levels were recorded within the range of 9. 63 to 985 mg/100g, subsequently rising to between 16. 45 and 2741 mg/100g by the conclusion of the storage period. The observed increase may be attributed to several biochemical reactions, including the deamination of amino acids, microbial activity, the proteolytic degradation of proteins by protease enzymes, the oxidation of amines, and the degradation of nucleotides (3). The control sample exhibited a significantly higher microbial load, which in turn led to an elevated rate of volatile nitrogen compound production. Consequently, there was a notable increase in the total volatile base nitrogen (TVB-N) concentration over time within this sample. In contrast, the incorporation of antimicrobial agents from M-EPEs into the burger formulation resulted in a marked reduction in the rate of protein degradation. This alteration in the protein degradation process subsequently led to the generation of fewer volatile nitrogenous compounds in the treated samples throughout the storage period, when compared to the control sample. The incorporation of both free and micro-encapsulated extracts in burgers has been associated with an enhanced antimicrobial activity, leading to a significant reduction in total volatile basic nitrogen (TVB-N) levels in the product. The permissible limit for total volatile basic nitrogen (TVB-N) in meat and meat products is established at 25 mg N per 100 g (43). The findings from the current study indicate that the control sample, which was stored for five days, as well as the other samples, which were monitored until the seventh day of storage, exhibited TVB-N values that remained below the maximum acceptable threshold. Consistent with the findings of the present research, Anvar *et al*. also observed a reduction in the total volatile basic nitrogen (TVB-N) levels in minced meat as a result of incorporating both free form and encapsulated dill seed essential oil, as well as gallic acid, throughout the storage period (44).

**Table 1. Comparison of the pH, TVB-N, peroxide and TBA values of the beef burger samples during refrigerated storage**

| Samples | Storage period (Day) | pH | TVB-N (mg N/100g) | Peroxide (meq/kg) | TBA (mg MDA/kg) |
|---|---|---|---|---|---|
| Control | 0 | 5.71 ± 0.01 $^{Da}$ | 9.85 ± 0.25 $^{Da}$ | 1.13 ± 0.04 $^{Da}$ | 0.475 ± 0.021 $^{Da}$ |
| | 2 | 5.86 ± 0.02 $^{Ca}$ | 16.17 ± 0.13 $^{Ca}$ | 2.99 ± 0.08 $^{Ca}$ | 0.851 ± 0.009 $^{Ca}$ |
| | 5 | 6.04 ± 0.00 $^{Ba}$ | 21.89 ± 0.16 $^{Ba}$ | 3.51 ± 0.03 $^{Ba}$ | 1.431 ± 0.016 $^{Ba}$ |
| | 7 | 6.32 ± 0.02 $^{Aa}$ | 27.41 ± 0.32 $^{Aa}$ | 5.27 ± 0.04 $^{Aa}$ | 1.740 ± 0.013 $^{Aa}$ |
| F-E200 | 0 | 5.69 ± 0.02 $^{Da}$ | 9.66 ± 0.30 $^{Da}$ | 0.94 ± 0.07 $^{Db}$ | 0.459 ± 0.024 $^{Da}$ |
| | 2 | 5.77 ± 0.01 $^{Cb}$ | 11.57 ± 0.28 $^{Cbc}$ | 1.31 ± 0.02 $^{Cc}$ | 0.580 ± 0.015 $^{Cb}$ |
| | 5 | 5.88 ± 0.01 $^{Bb}$ | 15.51 ± 0.31 $^{Bb}$ | 1.41 ± 0.07 $^{Bde}$ | 0.782 ± 0.019 $^{Bb}$ |
| | 7 | 5.95 ± 0.02 $^{Ab}$ | 19.75 ± 0.15 $^{Ab}$ | 2.79 ± 0.03 $^{Ab}$ | 0.948 ± 0.021 $^{Ab}$ |
| F-E450 | 0 | 5.69 ± 0.01 $^{Da}$ | 9.81 ± 0.34 $^{Da}$ | 0.95 ± 0.05 $^{Db}$ | 0.462 ± 0.017 $^{Da}$ |
| | 2 | 5.76 ± 0.00 $^{Cb}$ | 11.41 ± 0.32 $^{Cc}$ | 1.17 ± 0.03 $^{Cd}$ | 0.521 ± 0.012 $^{Cc}$ |
| | 5 | 5.84 ± 0.02 $^{Bcd}$ | 15.02 ± 0.12 $^{Bc}$ | 1.44 ± 0.03 $^{Bde}$ | 0.693 ± 0.015 $^{Bc}$ |
| | 7 | 5.91 ± 0.00 $^{Ac}$ | 18.93 ± 0.27 $^{Ac}$ | 2.65 ± 0.06 $^{Ac}$ | 0.822 ± 0.014 $^{Ad}$ |
| F-E700 | 0 | 5.70 ± 0.00 $^{Ca}$ | 9.84 ± 0.28 $^{Da}$ | 0.93 ± 0.04 $^{Cb}$ | 0.457 ± 0.019 $^{Ca}$ |
| | 2 | 5.72 ± 0.02 $^{Cc}$ | 11.29 ± 0.24 $^{Cc}$ | 0.99 ± 0.07 $^{Ce}$ | 0.482 ± 0.010 $^{Cd}$ |
| | 5 | 5.79 ± 0.01 $^{Be}$ | 14.34 ± 0.15 $^{Be}$ | 1.38 ± 0.05 $^{Be}$ | 0.603 ± 0.018 $^{Bd}$ |
| | 7 | 5.86 ± 0.02 $^{Ad}$ | 18.20 ± 0.22 $^{Ad}$ | 2.40 ± 0.05 $^{Ad}$ | 0.716 ± 0.025 $^{Af}$ |
| NE-E200 | 0 | 5.71 ± 0.02 $^{Da}$ | 9.63 ± 0.21 $^{Da}$ | 1.01 ± 0.08 $^{Dab}$ | 0.467 ± 0.028 $^{Da}$ |
| | 2 | 5.75 ± 0.01 $^{Cbc}$ | 12.04 ± 0.27 $^{Cb}$ | 1.37 ± 0.03 $^{Cb}$ | 0.589 ± 0.023 $^{Cb}$ |
| | 5 | 5.86 ± 0.01 $^{Bbc}$ | 14.97 ± 0.18 $^{Bcd}$ | 1.95 ± 0.10 $^{Bb}$ | 0.743 ± 0.024 $^{Bb}$ |
| | 7 | 5.93 ± 0.01 $^{Ab}$ | 18.89 ± 0.10 $^{Ac}$ | 2.48 ± 0.03 $^{Ad}$ | 0.854 ± 0.011 $^{Ac}$ |
| NE-E450 | 0 | 5.70 ± 0.01 $^{Da}$ | 9.69 ± 0.33 $^{Da}$ | 0.95 ± 0.03 $^{Db}$ | 0.466 ± 0.010 $^{Da}$ |
| | 2 | 5.74 ± 0.00 $^{Cc}$ | 11.55 ± 0.26 $^{Cbc}$ | 1.23 ± 0.04 $^{Cd}$ | 0.573 ± 0.016 $^{Cb}$ |
| | 5 | 5.82 ± 0.00 $^{Bd}$ | 14.51 ± 0.32 $^{Bde}$ | 1.49 ± 0.04 $^{Bcd}$ | 0.697 ± 0.013 $^{Bc}$ |
| | 7 | 5.90 ± 0.01 $^{Ac}$ | 17.37 ± 0.18 $^{Ae}$ | 2.39 ± 0.06 $^{Ad}$ | 0.775 ± 0.009 $^{Ae}$ |
| NE-E700 | 0 | 5.71 ± 0.01 $^{Ca}$ | 9.78 ± 0.16 $^{Da}$ | 0.95 ± 0.03 $^{Db}$ | 0.458 ± 0.014 $^{Da}$ |
| | 2 | 5.73 ± 0.01 $^{Cc}$ | 11.38 ± 0.18 $^{Cc}$ | 1.15 ± 0.05 $^{Cd}$ | 0.510 ± 0.022 $^{Ccd}$ |
| | 5 | 5.78 ± 0.02 $^{Be}$ | 13.76 ± 0.12 $^{Bf}$ | 1.54 ± 0.05 $^{Bc}$ | 0.586 ± 0.011 $^{Bd}$ |
| | 7 | 5.83 ± 0.01 $^{Ad}$ | 16.45 ± 0.25 $^{Af}$ | 2.16 ± 0.04 $^{Ae}$ | 0.627 ± 0.019 $^{Ag}$ |

Values represent mean (n=3) ± SD. Different letters in each column represent significant difference at 5% level of probability among samples. F-E: free extracts, NE-E: nanoencapsulated extracts

### 3.5. Oxidative stability of burgers

A significant factor contributing to the oxidation of meat and meat products is the oxidation of lipids, which transpires due to the interaction between unsaturated fatty acids and molecular oxygen. Hydroperoxides serve as the primary oxidation products resulting from the oxidation processes of fats and oils. Consequently, the assessment of primary fat oxidation is conducted by quantifying the peroxide value. These compounds are characterized by their colorless and odorless properties; however, they facilitate the production of secondary compounds such as aldehydes and ketones, thereby contributing to oxidative stress in oils and fats (3). The oxidative stability of the burgers was evaluated through the determination of peroxide values and thiobarbituric acid (TBA) indices. The findings are presented in Table 1. At the onset of the storage period, the incorporation of various forms of M-EPEs resulted in a reduction in the peroxide index of the treated burgers in comparison to the control group. However, this intervention did not produce a statistically significant alteration in the TBA index of the burgers. Over the course of the study, the oxidation indices in the burger samples exhibited a significant increase ($p < 0.05$), attributable to the progression of lipid oxidation and the subsequent generation of elevated quantities of primary and secondary oxidation products The findings indicate that the incorporation of free-form and microcoated M-EPEs into the burger formulation effectively delayed lipid oxidation. This effect can be attributed to the antioxidant properties of the extracts, which resulted in reduced levels of primary and secondary oxidation compounds in the treated burgers when compared to the production control sample. The elevation in the concentration of extracts, attributed to an increase in the content of phenolic and bioactive compounds, corresponded with a significant enhancement in antioxidant activity and a substantial reduction in oxidative indices. The micro-coating process confers a protective effect on the bioactive compounds contained within the extracts throughout the storage period. Consequently, at the conclusion of the storage duration, the micro-coated extracts demonstrated a superior efficacy in mitigating the rate of lipid oxidation in burgers compared to their free form counterparts. The established maximum permissible limits for the peroxide index and the thiobarbituric acid (TBA) index in meat and meat products intended for human consumption are set at 5 meq/kg and 2 mg malondialdehyde (MDA)/kg, respectively (3). The findings of the present study revealed that the control sample maintained peroxide index values below the maximum acceptable threshold up to the fifth day of storage. Additionally, all examined samples exhibited TBA index values within acceptable limits throughout the entire duration of the study, concluding on the seventh day of storage.

Phenolic compounds are recognized for their substantial antioxidant properties, attributable to their capacity to neutralize free radicals, chelate metal ions, and inhibit the activity of oxidative enzymes (45). The encapsulation process serves as a protective strategy that enhances the stability of bioactive compounds while safeguarding them from various environmental factors, including elevated temperatures, fluctuations in pH, oxidative degradation, and exposure to light. Furthermore, the method facilitates the controlled release of active compounds, thereby extending the shelf life of these compounds in food products (46). The researchers identified two significant polyphenolic compounds present in mango peel: quercetin-3-galactoside and mangiferin. Mangiferin is a promising antioxidant compound that exhibits antioxidant activity surpassing that of vitamin C and vitamin E, and it has the ability to form complexes with iron (42). The researchers identified that phenolic compounds are predominantly

concentrated in the by-products of eggplant, particularly in its skin. Consequently, eggplant by-products, in comparison to other agricultural by-products, are significantly abundant in phenolic compounds (9). The significant antioxidant properties of eggplant extract, when encapsulated within nanoemulsions, have been demonstrated to effectively inhibit lipid oxidation in soybean oil, as reported by Sharma *et al* (44).

### 3.6. Color of burgers

Color indices represent a critical quality parameter for meat and meat products, significantly influencing consumer acceptance of these products. Table 2 presents the color indices, specifically L* (brightness), a* (red color), b* (yellow-blue), and ΔE (overall color difference in comparison to the initial day). At the outset of the storage period, the incorporation of mango peel and eggplant peel extracts into the burger formulation resulted in a reduction of brightness and red chroma, while simultaneously increasing the intensity of yellow coloration. This change in color characteristics can be attributed to the pigmentation properties of the mango and eggplant peel extracts, specifically the presence of natural pigments such as carotenoids and anthocyanins. Throughout the storage period at refrigeration temperatures, there was a gradual reduction in the brightness, redness, and yellowness of the burgers. Notably, the decline in color metrics was statistically significant solely in one of the samples. The progressive alteration in the color of the burgers, characterized by a reduction in the a* and b* indexes over time, can be ascribed to the gradual oxidation of myoglobin and the consequent elevation in metmyoglobin levels. Furthermore, the substantial antioxidant activity of the M-PES indicates that the degree of color change in the burgers supplemented with these extracts was markedly less pronounced compared to the control sample. Amiri *et al*. (۲۰۱۹) conducted a study that examines. In the study conducted in 2019, it was posited that the observed darkening of meat color, as well as the emergence of a dark brown hue in the product throughout the storage period, can be attributed to the formation of metmyoglobin, a reduction in light refraction, and a decrease in the surface moisture of the product (49). Previous research has indicated that the incorporation of herbal additives produces a significant influence on the preservation and stabilization of meat color throughout the storage period (50, 51). In the study conducted by Parafati *et al*. (2019), a notable decrease in the L* index, accompanied by increases in the a* and b* indicators of beef burgers, was observed following the application of a combination of free prickly pear extract and its nanocapsules (52). The researchers demonstrated that, over time, the growth of microorganisms and alterations in pH levels resulted in a decrease in the a* index. Additionally, the formation of metmyoglobin contributed to a reduction in the b* index. However, the application of the extract effectively preserved the color of the burgers throughout the duration of the study, corroborating the findings of the present investigation. Bunmee *et al*. (۲۰۲۲) reported a reduction in the intensity of brightness and redness, accompanied by an increase in yellowness of beef patties, following an elevation in the concentration of eggplant peel flour. The reduction of L*, a*, and b* indices in beef burgers throughout the storage period was similarly observed in the research conducted by Mokhtar and Eldeep (2020). The findings of their study corroborate the results presented in the current investigation, which highlights the efficacy of mango skin extract in maintaining the color of burgers during storage, in comparison to the control sample (54).

**Table 2. Comparison of the color indices values of the beef burger samples during refrigerated storage**

| Samples | Storage period (Day) | L* | a* | b* | ΔE |
|---|---|---|---|---|---|
| Control | 0 | 47.68 ± 1.34 $^{Aa}$ | 12.34 ± 0.12 $^{Aa}$ | 12.51 ± 0.16 $^{Af}$ | - |
| | 2 | 46.81 ± 0.95 $^{Aa}$ | 11.54 ± 0.15 $^{Ba}$ | 11.63 ± 0.24 $^{Bf}$ | 1.47 ± 0.27 $^{Ca}$ |
| | 5 | 46.52 ± 1.26 $^{ABa}$ | 10.61 ± 0.13 $^{Ca}$ | 10.57 ± 0.19 $^{Cf}$ | 2.85 ± 0.40 $^{Ba}$ |
| | 7 | 44.19 ± 1.37 $^{Ba}$ | 8.85 ± 0.07 $^{Dc}$ | 9.33 ± 0.13 $^{Df}$ | 5.87 ± 0.25 $^{Aa}$ |
| F-E200 | 0 | 43.80 ± 0.78 $^{Abc}$ | 9.98 ± 0.09 $^{Ac}$ | 14.69 ± 0.23 $^{Ad}$ | - |
| | 2 | 43.73 ± 1.14 $^{Abc}$ | 9.91 ± 0.13 $^{ABc}$ | 14.65 ± 0.10 $^{Ad}$ | 0.29 ± 0.08 $^{Cc}$ |
| | 5 | 43.26 ± 1.20 $^{Abc}$ | 9.70 ± 0.11 $^{BCb}$ | 14.26 ± 0.27 $^{ABd}$ | 0.75 ± 0.26 $^{Bbc}$ |
| | 7 | 42.80 ± 0.94 $^{Aa}$ | 9.49 ± 0.15 $^{Cb}$ | 14.10 ± 0.18 $^{Bd}$ | 1.30 ± 0.19 $^{Ab}$ |
| F-E450 | 0 | 41.54 ± 1.13 $^{Ad}$ | 8.19 ± 0.16 $^{Ad}$ | 17.03 ± 0.21 $^{Ab}$ | - |
| | 2 | 41.52 ± 1.17 $^{Ac}$ | 8.10 ± 0.05 $^{Ae}$ | 16.81 ± 0.14 $^{ABb}$ | 0.24 ± 0.10 $^{Ccd}$ |
| | 5 | 41.34 ± 1.33 $^{Ac}$ | 7.94 ± 0.09 $^{Ad}$ | 16.57 ± 0.23 $^{BCb}$ | 0.56 ± 0.17 $^{Bbcd}$ |
| | 7 | 40.95 ± 0.88 $^{Ab}$ | 7.73 ± 0.11 $^{Be}$ | 16.38 ± 0.20 $^{Cb}$ | 0.99 ± 0.21 $^{Abc}$ |
| F-E700 | 0 | 38.93 ± 1.38 $^{Ae}$ | 6.35 ± 0.11 $^{Ae}$ | 19.28 ± 0.17 $^{Aa}$ | - |
| | 2 | 38.61 ± 1.25 $^{Ad}$ | 6.34 ± 0.09 $^{Af}$ | 19.21 ± 0.25 $^{ABa}$ | 0.33 ± 0.11 $^{Bbc}$ |
| | 5 | 38.56 ± 1.13 $^{Ad}$ | 6.28 ± 0.12 $^{Ae}$ | 19.15 ± 0.15 $^{ABa}$ | 0.40 ± 0.15 $^{ABcde}$ |
| | 7 | 38.41 ± 1.10 $^{Ac}$ | 6.17 ± 0.15 $^{Af}$ | 18.94 ± 0.11 $^{Ba}$ | 0.65 ± 0.17 $^{Ac}$ |
| NE-E200 | 0 | 45.17 ± 1.26 $^{Aab}$ | 10.82 ± 0.15 $^{Ab}$ | 13.91 ± 0.10 $^{Ae}$ | - |
| | 2 | 44.99 ± 1.08 $^{Aab}$ | 10.69 ± 0.12 $^{ABb}$ | 13.76 ± 0.27 $^{ABe}$ | 0.60 ± 0.17 $^{Ab}$ |
| | 5 | 44.95 ± 0.97 $^{Aab}$ | 10.55 ± 0.08 $^{BCa}$ | 13.68 ± 0.19 $^{ABe}$ | 0.92 ± 0.22 $^{Ab}$ |
| | 7 | 44.68 ± 1.24 $^{Aa}$ | 10.36 ± 0.14 $^{Ca}$ | 13.51 ± 0.14 $^{Be}$ | 0.61 ± 0.21 $^{Ac}$ |
| NE-E450 | 0 | 43.84 ± 1.21 $^{Abcd}$ | 10.06 ± 0.14 $^{Ac}$ | 15.44 ± 0.19 $^{Ac}$ | - |
| | 2 | 43.72 ± 1.17 $^{Ab}$ | 9.89 ± 0.19 $^{ABc}$ | 15.32 ± 0.18 $^{Ac}$ | 0.24 ± 0.09 $^{Bcd}$ |
| | 5 | 43.63 ± 1.29 $^{Abc}$ | 9.82 ± 0.10 $^{ABb}$ | 15.29 ± 0.10 $^{Ac}$ | 0.36 ± 0.12 $^{ABde}$ |
| | 7 | 43.57 ± 1.16 $^{Aa}$ | 9.66 ± 0.18 $^{Bb}$ | 15.13 ± 0.27 $^{Ac}$ | 0.57 ± 0.18 $^{Ac}$ |
| NE-E700 | 0 | 42.25 ± 0.82 $^{Acd}$ | 8.44 ± 0.20 $^{Ad}$ | 16.95 ± 0.17 $^{Ab}$ | - |
| | 2 | 42.19 ± 1.24 $^{Ac}$ | 8.34 ± 0.13 $^{Ad}$ | 16.94 ± 0.12 $^{Ab}$ | 0.12 ± 0.05 $^{Bd}$ |
| | 5 | 42.17 ± 0.87 $^{Ac}$ | 8.29 ± 0.16 $^{Ac}$ | 16.82 ± 0.18 $^{ABb}$ | 0.21 ± 0.08 $^{ABe}$ |
| | 7 | 42.08 ± 1.33 $^{Aab}$ | 8.23 ± 0.11 $^{Ad}$ | 16.51 ± 0.24 $^{Bb}$ | 0.52 ± 0.25 $^{Ac}$ |

Values represent mean (n=3) ± SD. Different letters in each column represent significant difference at 5% level of probability among samples. F-E: free extracts, NE-E: nanoencapsulated extracts

### 3.7. Hardness of burgers

The results of the investigation into the hardness of beef burgers, as measured by a texture analyzer, are presented in Figure []. The findings indicated that, during the initial phase of the storage period, the integration of various forms of M-EPEs did not result in a statistically significant alteration in the hardness of the burgers. The measured hardness of the samples remained within the range of 16. 11 to 1748 N. Over time, the harness of the burger samples exhibited a gradual decline, with this decrease achieving statistical significance ($P < 0.05$) in one specific sample The primary factor contributing to alterations in meat products is the oxidation of proteins. Consequently, the incorporation of antioxidant additives may enhance the preservation of texture in these products throughout the storage period by diminishing the rate of protein oxidation (48). Consistent with the findings of the current study, the research conducted by Utrera *et al* (2015; 55). The application of wild Nasturtium extract has been documented to mitigate protein oxidation, thereby preventing alterations in the hardness of meat patties over time. In the research conducted by Kumar and Kumar (2020), it was observed that the incorporation of double nanoemulsions containing encapsulated Murraya koenigii berry extract into meat paste did not result in a significant alteration in the hardness of the samples (56).

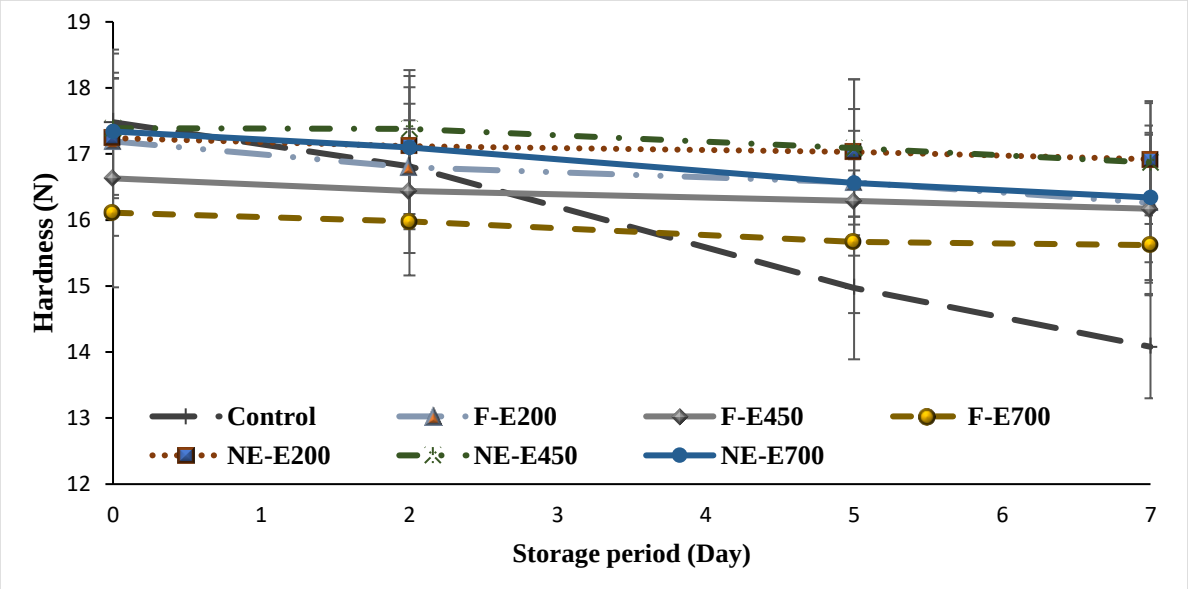



**Fig. 2. Changes in hardness values of the beef burger samples during refrigerated storage**

### 3.8. Microbial load of burgers

The analysis of microbial load in burgers, as presented in Table 3, indicated that the initial phase of the storage period revealed no significant alterations in the counts of aerobic mesophilic bacteria, psychrophilic bacteria, molds, and yeasts as a result of the incorporation of M-EPEs. However, a notable reduction in coliform counts was observed in comparison to the control sample. Over time, the growth and proliferation of bacteria, molds, and yeasts led to a significant increase in the quantity of these microorganisms within the burger samples. However, as anticipated, the substantial antimicrobial properties of the M-EPEs resulted in a marked reduction in the growth and proliferation of these microorganisms when

these extracts were integrated into the burger formulation, in comparison to the control samples ($p < 0.05$) An increase in the concentration of the extracts correlated with a heightened presence of bioactive and phenolic compounds, which subsequently facilitated an enhancement in antimicrobial activity. This increase in antimicrobial efficacy resulted in a reduction of the microbial load in the burgers. The encapsulation process offers several notable advantages, one of which is the enhanced protection of bioactive compounds. Consequently, at the conclusion of the storage period, the nanoencapsulated forms of the extracts typically exhibited greater antimicrobial activity compared to their free counterparts. The antimicrobial properties of polyphenolic compounds are attributed to a variety of mechanisms. These mechanisms include alterations to the cytoplasmic membrane, enhancement of cell membrane permeability, and the chelation of essential elements such as zinc and iron. Additionally, polyphenolic compounds impede the function and synthesis of microbial enzymes, as well as disrupt microbial metabolic processes (57). Anthocyanins exhibit antimicrobial properties and possess the ability to disrupt bacterial cell walls, interfere with the biosynthesis of essential compounds, and ultimately induce cell death (58). The maximum permissible limit for total bacterial counts and psychrophilic bacteria in meat and meat products is established at 7 log CFU/g (59). Products exhibiting bacterial counts below this threshold are deemed suitable for human consumption. The findings of the current study indicated that the control sample exhibited aerobic mesophilic bacterial counts below the maximum acceptable level through the fifth day of storage, while the other samples maintained counts below this threshold until the seventh day of storage. Consistent with the findings of the present study, Sembring and Chin (2019) documented the impact of eggplant powder on the reduction of microbial load in pork sausage (60). Karimifar and colleagues in a study conducted in 2022, it was reported that nanocapsules containing essential oils derived from Rosmarinus officinalis and Ziziphora clinopodioides exhibited notable antimicrobial properties in mutton patties. These nanocapsules significantly decreased the microbial load of the patties throughout the storage period when compared to the control group (61). The study conducted by Hashemi *et al*. demonstrated a significant reduction in the microbial load of fish burgers following the application of coatings infused with both free and nanoencapsulated forms of Carum copticum essential oil during the storage period, in comparison to the control group. According to the findings of the researchers in 2023, it was indicated that the encapsulated form of essential oil exhibits greater antimicrobial activity compared to its unencapsulated form (44).

**Table 3. Comparison of the microbial load (log CFU/g) of the beef burger samples during refrigerated storage**

| Samples | Storage period (Day) | Total aerobic mesophilic bacteria | Psychrophilic bacteria | Coliforms | Molds & Yeasts |
|---|---|---|---|---|---|
| Control | 0 | 4.37 ± 0.06 $^{Da}$ | 4.10 ± 0.04 $^{Da}$ | 1.46 ± 0.02 $^{Da}$ | 1.81 ± 0.10 $^{Da}$ |
| | 2 | 5.62 ± 0.09 $^{Ca}$ | 5.36 ± 0.07 $^{Ca}$ | 2.26 ± 0.04 $^{Ca}$ | 3.46 ± 0.12 $^{Ca}$ |
| | 5 | 6.89 ± 0.04 $^{Ba}$ | 6.44 ± 0.03 $^{Ba}$ | 2.79 ± 0.05 $^{Ba}$ | 4.21 ± 0.09 $^{Ba}$ |
| | 7 | 7.46 ± 0.03 $^{Aa}$ | 6.89 ± 0.03 $^{Aa}$ | 3.54 ± 0.02 $^{Aa}$ | 4.77 ± 0.15 $^{Aa}$ |
| F-E200 | 0 | 4.32 ± 0.03 $^{Da}$ | 4.05 ± 0.02 $^{Da}$ | 1.40 ± 0.03 $^{Db}$ | 1.74 ± 0.09 $^{Da}$ |
| | 2 | 4.78 ± 0.08 $^{Cb}$ | 4.71 ± 0.03 $^{Cb}$ | 1.71 ± 0.06 $^{Cb}$ | 1.89 ± 0.05 $^{Cb}$ |
| | 5 | 5.26 ± 0.10 $^{Bb}$ | 5.28 ± 0.06 $^{Bb}$ | 2.04 ± 0.04 $^{Bb}$ | 2.33 ± 0.10 $^{Bb}$ |
| | 7 | 5.81 ± 0.09 $^{Ab}$ | 5.74 ± 0.02 $^{Ab}$ | 2.31 ± 0.05 $^{Ab}$ | 2.69 ± 0.11 $^{Ab}$ |
| F-E450 | 0 | 4.29 ± 0.08 $^{Da}$ | 4.07 ± 0.02 $^{Da}$ | 1.37 ± 0.03 $^{Db}$ | 1.80 ± 0.05 $^{Ca}$ |
| | 2 | 4.52 ± 0.03 $^{Cc}$ | 4.55 ± 0.04 $^{Cc}$ | 1.47 ± 0.02 $^{Cc}$ | 1.86 ± 0.07 $^{Cb}$ |
| | 5 | 4.91 ± 0.04 $^{Bd}$ | 4.87 ± 0.05 $^{Bc}$ | 1.66 ± 0.03 $^{Bc}$ | 2.18 ± 0.12 $^{Bbc}$ |
| | 7 | 5.24 ± 0.03 $^{Ad}$ | 5.49 ± 0.04 $^{Ac}$ | 1.85 ± 0.03 $^{Ac}$ | 2.50 ± 0.07 $^{Ac}$ |
| F-E700 | 0 | 4.31 ± 0.03 $^{Ca}$ | 4.03 ± 0.06 $^{Da}$ | 1.37 ± 0.03 $^{Cb}$ | 1.79 ± 0.11 $^{Ca}$ |
| | 2 | 4.42 ± 0.11 $^{Ccd}$ | 4.27 ± 0.06 $^{Ce}$ | 0.40 ± 0.04 $^{Cd}$ | 1.83 ± 0.12 $^{BCb}$ |
| | 5 | 4.75 ± 0.07 $^{Be}$ | 4.57 ± 0.05 $^{Be}$ | 1.57 ± 0.03 $^{Bd}$ | 1.97 ± 0.09 $^{Bd}$ |
| | 7 | 5.09 ± 0.05 $^{Af}$ | 4.99 ± 0.03 $^{Ae}$ | 1.78 ± 0.03 $^{Ad}$ | 2.24 ± 0.08 $^{Ae}$ |
| NE-E200 | 0 | 4.35 ± 0.05 $^{Da}$ | 4.06 ± 0.03 $^{Da}$ | 1.35 ± 0.04 $^{Db}$ | 1.81 ± 0.12 $^{Ca}$ |
| | 2 | 4.71 ± 0.06 $^{Cb}$ | 4.65 ± 0.04 $^{Cb}$ | 1.48 ± 0.03 $^{Cc}$ | 1.94 ± 0.02 $^{Cb}$ |
| | 5 | 5.10 ± 0.05 $^{Bc}$ | 4.91 ± 0.04 $^{Bc}$ | 1.69 ± 0.02 $^{Bc}$ | 2.20 ± 0.13 $^{Bbc}$ |
| | 7 | 5.45 ± 0.11 $^{Ac}$ | 5.33 ± 0.07 $^{Ad}$ | 1.82 ± 0.04 $^{Acd}$ | 2.58 ± 0.05 $^{Abc}$ |
| NE-E450 | 0 | 4.33 ± 0.05 $^{Da}$ | 4.05 ± 0.02 $^{Da}$ | 1.37 ± 0.03 $^{Cb}$ | 1.79 ± 0.07 $^{Ba}$ |
| | 2 | 4.53 ± 0.05 $^{Cc}$ | 4.37 ± 0.03 $^{Cd}$ | 1.39 ± 0.02 $^{Cd}$ | 1.87 ± 0.04 $^{Bb}$ |
| | 5 | 4.86 ± 0.03 $^{Bd}$ | 4.69 ± 0.02 $^{Bd}$ | 1.53 ± 0.05 $^{Bd}$ | 2.29 ± 0.08 $^{Ab}$ |
| | 7 | 5.17 ± 0.02 $^{Ae}$ | 4.97 ± 0.05 $^{Ae}$ | 1.70 ± 0.03 $^{Ae}$ | 2.45 ± 0.10 $^{Ac}$ |
| NE-E700 | 0 | 4.30 ± 0.07 $^{Ca}$ | 4.05 ± 0.02 $^{Da}$ | 1.35 ± 0.04 $^{Bb}$ | 1.79 ± 0.11 $^{Ba}$ |
| | 2 | 4.40 ± 0.03 $^{Cd}$ | 4.13 ± 0.05 $^{Cf}$ | 1.36 ± 0.03 $^{Bd}$ | 1.84 ± 0.10 $^{Bb}$ |
| | 5 | 4.66 ± 0.04 $^{Be}$ | 4.35 ± 0.02 $^{Bf}$ | 1.42 ± 0.03 $^{Be}$ | 2.03 ± 0.06 $^{Acd}$ |
| | 7 | 4.89 ± 0.09 $^{Ag}$ | 4.71 ± 0.03 $^{Af}$ | 1.59 ± 0.05 $^{Af}$ | 2.21 ± 0.04 $^{Ae}$ |

Values represent mean (n=3) ± SD. Different letters in each column represent significant difference at 5% level of probability among samples. F-E: free extracts, NE-E: nanoencapsulated extracts

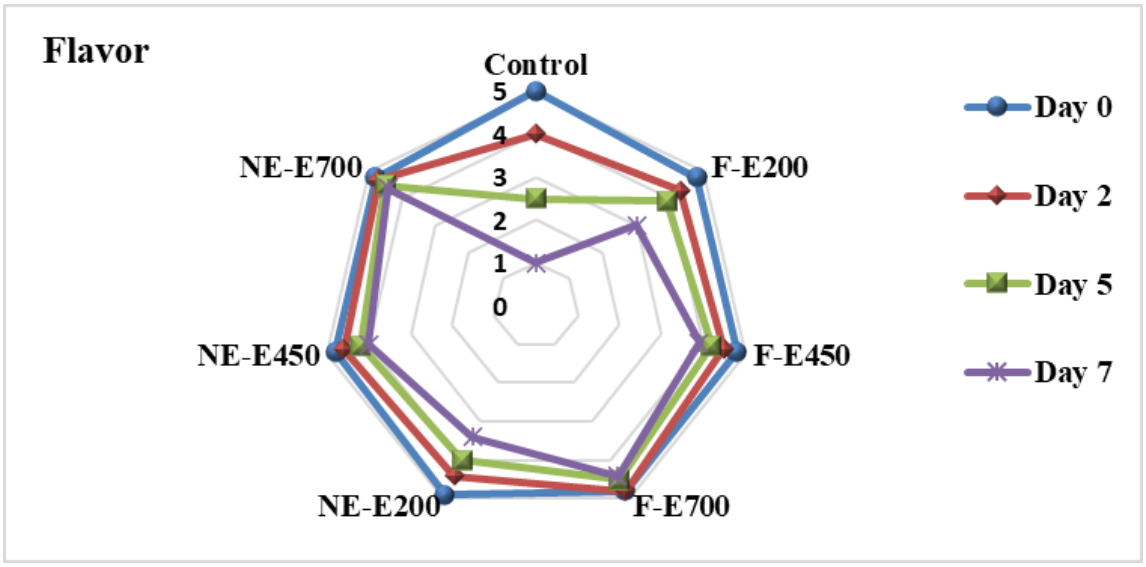
### 3.9. Sensory evaluation of burgers

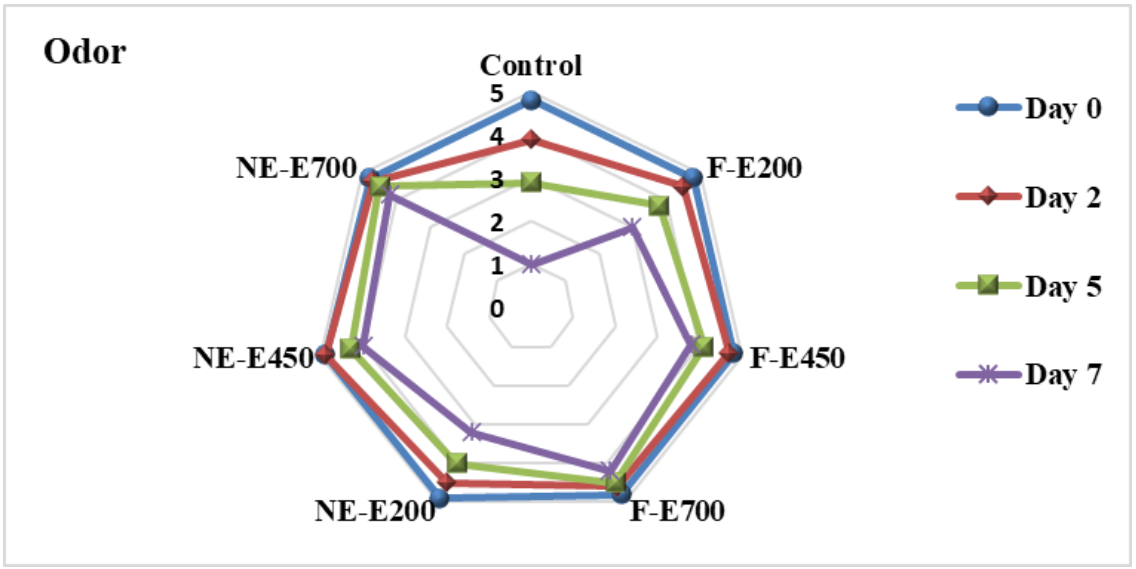
The findings pertaining to the sensory characteristics of the burger samples are delineated in Table 3. Initially, during the early stages of the storage period, all burger samples received elevated sensory scores. However, as time progressed, there was a gradual decline in the sensory scores of the samples. Notably, the control sample exhibited the most significant rate of decline in sensory scores. The deterioration in the texture and olfactory characteristics of burgers over time can be attributed to the degradation and oxidation of proteins, alongside the formation of ammonia compounds. The oxidation of lipids results in the formation of various secondary compounds, including aldehydes, ketones, hydrocarbons, and alcohols. These compounds contribute to the development of rancidity, characterized by an undesirable taste and unpleasant odor in the affected product. The proliferation of microorganisms constitutes a significant factor contributing to the diminished sensory acceptance of meat products throughout the storage period. This phenomenon is largely attributable to the enzymatic activities of these microorganisms, which catalyze enhanced protein degradation and the subsequent generation of various secondary odorous compounds. The decline in color score of burgers over time can be attributed to the oxidation of myoglobin and oxymyoglobin, which ultimately leads to their conversion into metmyoglobin. This biochemical transformation results in the development of a brown coloration in meat products. The reduction in humidity over time may contribute to the observed alterations in the color and texture scores of burgers throughout the storage period. The incorporation of various forms of M-EPEs into the formulation enhanced the preservation of the sensory attributes of the burgers throughout the storage period, attributable to the antioxidant and antimicrobial properties associated with these extracts. Consistent with these findings, Sarabandi *et al*. A study conducted in 2019 demonstrated that the incorporation of eggplant peel extract capsules into the formulation of gummy candy resulted in enhanced color and overall acceptability of the product (29). The research conducted by Karimifar *et al*. demonstrated that the incorporation of nanocapsules containing essential oils derived from Rosmarinus officinalis and Ziziphora clinopodioides effectively preserved the sensory acceptability of mutton meat. The year 2022 is referenced in the context of the citation (61). Anvar *et al.* () conducted a study that examines. [continue with the relevant information or context from the original text]. In 2023, the authors reported comparable findings, indicating that the incorporation of dill seed essential oil and gallic acid nanocapsules into minced meat effectively preserved sensory acceptance (41).

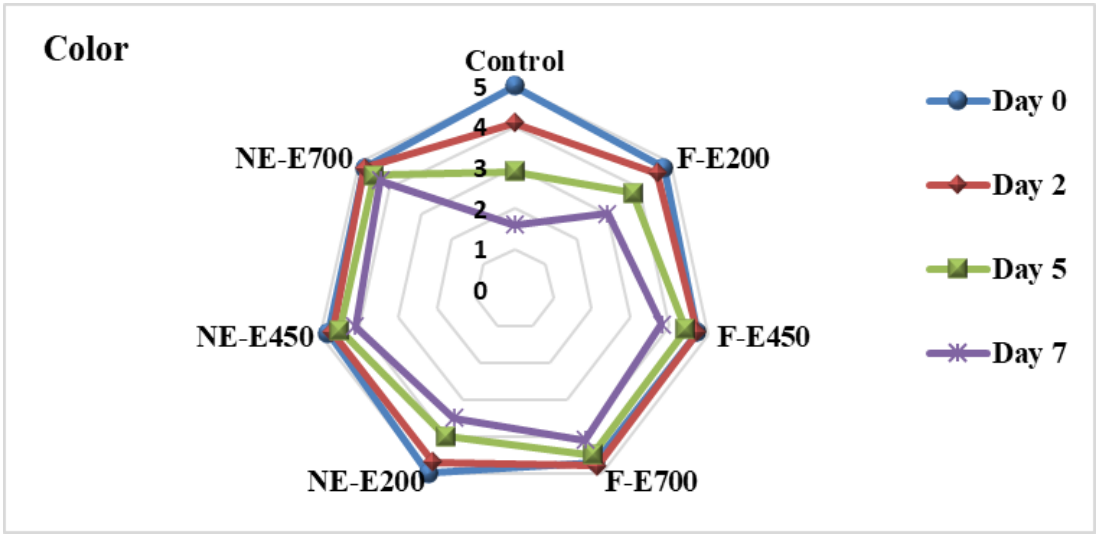
## 4. Conclusion

The findings of this study indicate that the incorporation of both free and nanoencapsulated forms of M-EPEs into burger formulations significantly mitigates alterations in physicochemical characteristics and effectively inhibits the growth and reproduction of microorganisms, as well as reducing lipid oxidation, when compared to the control group. A direct correlation was observed between the concentration of extracts and their respective antioxidant and antimicrobial activities in burgers. Notably, the most pronounced antioxidant and antimicrobial effects were associated with the highest extract concentration, specifically at a level of 700 mg/kg. The encapsulation process demonstrated a significant ability to preserve the bioactive compounds of the extracts within the burgers throughout the storage period. Notably, by the conclusion of the storage duration, the burgers containing the nanoencapsulated form of the extracts exhibited enhanced oxidative stability, as well as a reduced microbial load, in

comparison to those containing the free form of the extracts. The incorporation of various forms of M-EPEs effectively sustained the sensory acceptability of the samples throughout the duration of refrigeration storage. The findings of this study indicate that M-EPEs, particularly in their nanoencapsulated form, significantly enhance the oxidative and microbial stability of beef burgers throughout the storage period. Furthermore, these additives effectively preserve the sensory acceptability of the burgers when stored at refrigeration temperatures. Hence, it is recommended that M-EPEs be utilized as natural preservatives in the formulation of beef burgers.

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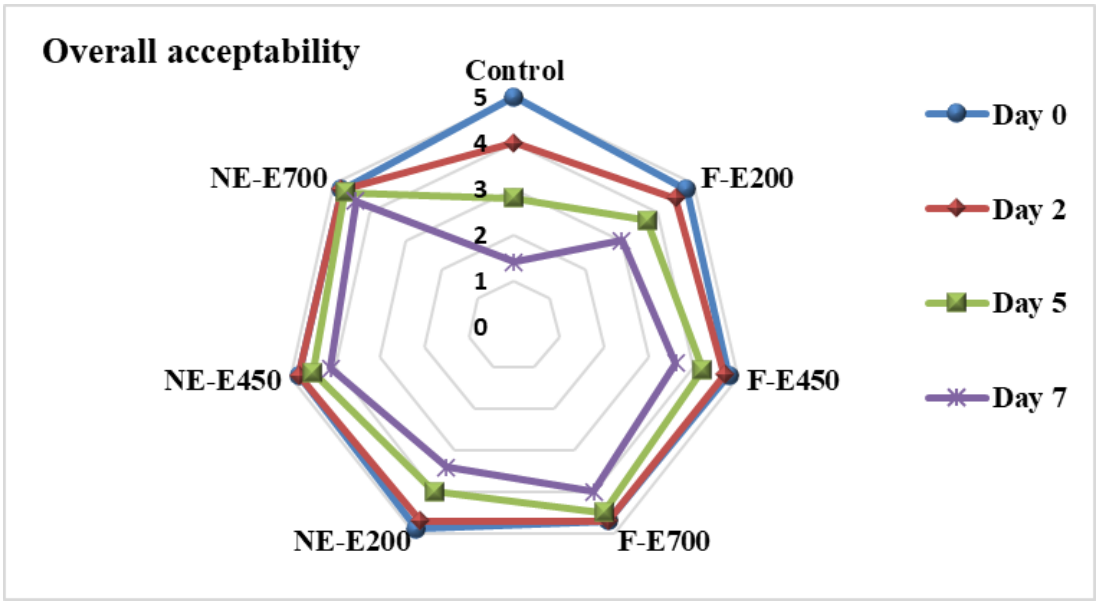
Overall acceptability
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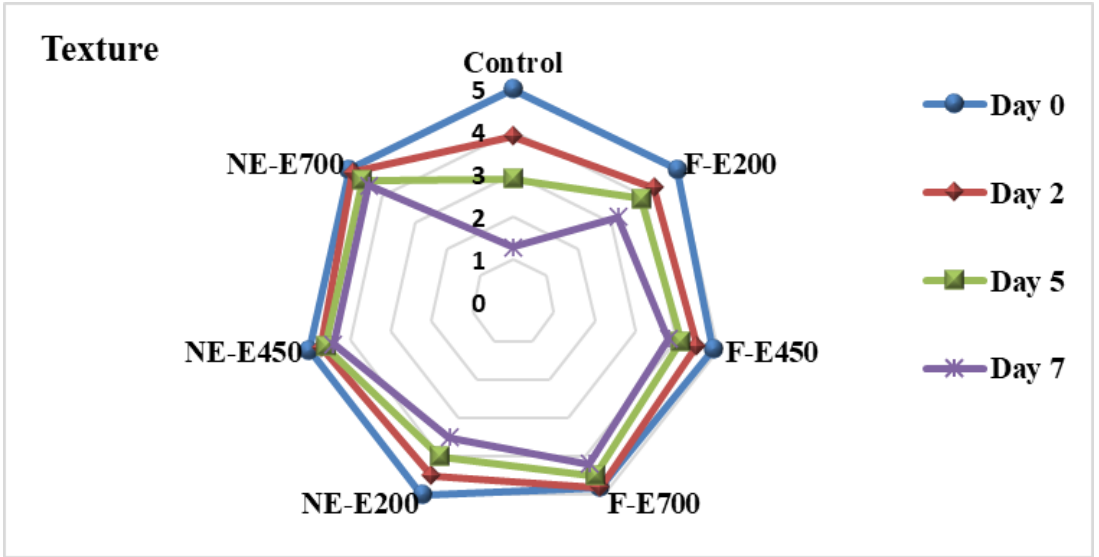
Texture
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