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Protective effect of chitosan-loaded nanoemulsion containing *Zataria multiflora* Boiss and *Bunium persicum* Boiss essential oils as coating on lipid and protein oxidation in chill stored turkey breast fillets

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Abstract: The present study was conducted to evaluate the lipid and protein oxidation responses of cold stored turkey meat using chitosan-contained nanoemulsions supplemented with the essential oils of two aromatic plants including *Zataria multiflora* Boiss and *Bunium persicum* Boiss. Chemical traits such as total volatile basic nitrogen (TVB-N), peroxide value (PV), thiobarbituric reactive substances (TBARs), free fatty acids (FFA), fatty acid composition and TC (total carbonyl) of samples were carried out at 4°C. Moreover, their pH and sensory properties were also determined at the same conditions. The initial value of the TVB-N (2.24 mg N/100 g) reached 20.81 mg N/100 g. TVB-N values achieved for all meat samples were lower than the highest acceptable limit (28–29 mg N/100 g). In all the treatments, PV and TBARs values were increased until day 10, and afterward a decrease was observed until day 20 of storage. TBARs values of the samples (mg MDA/kg) ranged from 1.97 ± 0.04 to 4.48 ± 0.39 in CNE + ZEO 1% to 2.72 ± 0.32 to 6.66 ± 0.21 in CON at zero time and day 5, respectively. FFA and TC were enhanced at a slower rate in the treated samples. The most efficient treatment against chemical deterioration was found to be CNE + ZEO 1%. Chitosan and sonicated chitosan treatments had the highest color score and lowest odor score at zero time. The obtained results suggested coating turkey meat fillets with ZEO and BEO as an effective strategy to delay at their chemical deterioration.

KEYWORDS
chemical changes, chitosan, nanoemulsion, shelf life extension, turkey meat

Practical Application: The spoilage risk of fresh products is higher than other foods. Turkey meat spoils because of biological reactions such as the oxidation of lipids and protein, the action of endogenous enzymes, and the metabolic activities of microorganisms that end in a short shelf life. The oxidation of lipids not only reduces or retards, but also inhibits by edible coatings. Edible coatings formed from bioactive compounds would effectively provide possibility of active

compounds onto surface of minimally processed foods. Therefore, application chitosan-loaded nanoemulsion coating containing *Zataria multiflora* Boiss and *Bunium persicum* Boiss essential oils is recommended in food industry especially for poultry industry to increase the chemistry and sensory quality of turkey breast fillets.

1 | INTRODUCTION

Turkey meat has received considerable attention for consumption due to its several health benefits. The biochemical properties of the turkey meat such as containing high content of unsaturated fatty acids in spite of low level of fats as well as high quality proteins, B-group vitamins and minerals have made it an exceptional nutritional source (Vural et al., 2013). The microbial growth and generation of free radicals result in changing flavor, color and texture, and consequently the nutritional quality of the products (Amiri et al., 2019).

Many researchers are interested in making new natural preservatives and biopolymers from diverse food waste products. Chitosan, GRAS food additive, can be considered safe ingested at the levels up to 2.4 g/day (Ceylan, Sengor, et al., 2018). Due to antimicrobial and antioxidant properties (Abd El-Hack et al., 2020), it can be utilized for some purposes such as shelf life extension of food and coating forming (Ghaderi-Ghahfarokhi et al., 2017). Poly (vinyl alcohol) nanofiber integrating chitosan nanoparticles kept the fish quality and slowed down the enhancement of the total volatile basic nitrogen and pH values (Ceylan, Sengor, et al., 2018).

Zataria multiflora Boiss is a medicinal herb, and its essential oils have been widely utilized due to their potent antibacterial activities. Thymol and carvacrol are two main phenolic components of *Zataria multiflora* Boiss (ZEO). The potentials of single electron or hydrogen donation of these phenolics contribute to cell protection against oxidative stress (Amiri et al., 2019). *Bunium persicum* Boiss, commonly known as great pignut or black cumin and belongs to the family *Apiaceae,* is an economically important plant. Essential oils of *Bunium persicum* Boiss (BEO) include γ-terpinene, β-pinene and cuminaldehyde (Jamshidi et al., 2014). If the essential oils are encapsulated in delivery systems, their adverse effects on physiochemical features of food will be decreased and their biological activity will also be maintained (Amiri et al., 2019).

Nanoapplications are named as one of the novel methods, which provide high immobilization efficiency for essential oils (Ceylan, Meral, Alav, et al., 2020). The nanoemulsion as a constant delivery system has unique physicochemical and practical characteristics including high bioavailability and physical stability as well as optical transparency (Noudoost et al., 2015).

Incorporation of different essential oils and other bioactive compounds into chitosan biopolymer has been studied in different food products. Numerous studies have examined the use of chitosan coating incorporation with different essential oils. For example, chitosan nanoparticles loading with cinnamon essential oils were investigated on beef patties (Ghaderi-Ghahfarokhi et al., 2017). Polydispersity index, zeta potential and the size of the formed nanoparticles were 0.33, 25.1 mV and 235.6 nm, respectively. Ceylan, Meral, Kose, et al. (2020) reported curcumin and rosemary oil nanoemulsions with particle size of 184.3 nm, and 158.3 nm decreased the growth rates and total numbers of both mesophilic and psychrophilic bacteria in rainbow trout fillets. Severino et al. (2014) evaluated the effects of modified chitosan-based covering with nanoemulsion of mandarin essential oil in green beans. However, inadequate reports are available on the application of edible coating in turkey meat fillets as a coating-based chitosan-loaded nanoemulsion, particularly in combination with essential oils. Moreover, to the best of authors' knowledge, no study has been carried out on chemical and sensory evaluations of refrigerated turkey breast fillet so far. On the basis of the above-mentioned evidence, the present study was conducted to develop edible coating-based nanoemulsion by incorporation of essential oils to chitosan. For this aim, coating-based nanoemulsions were fabricated using sonicator device, and the nanoemulsion were characterized in terms of Polydispersity index (PDI) and particle size properties and antioxidant capacity of the nanoemulsions. The final aim was to study the impact of chitosan-coated nanoemulsion with essential oils as a functional coating on sensory and chemical properties of turkey meat fillets in a 20-day period of chilling condition.

2 | MATERIALS AND METHODS

2.1 | Chemicals

The obtained essential oils of *Bunium persicum* Boiss *and Zataria multiflora* Boiss using steam distillation

were provided from the Iranian Institute of Medicinal Plants (Karaj, Iran) and stored in a dark container at 4°C until further use. Low molecular-weighted chitosan (50–190 kDa, 20–300 CP, 1 wt.% in 1% acetic acid), 2, 2-diphenyl-1-picrylhydrazyl [DPPH] and 2, 4-dinitrophenylhydrazine [DNPH]) was obtained from Sigma-Aldrich (St. Louis, MO, USA). Thiobarbituric acid was purchased from Merck (Darmstadt, Germany). All reagents were of analytical grade.

2.2 | Production of chitosan coating nanoemulsions comprising ZEO and BEO

The essential oils of *Zataria multiflora* Boiss and *Bunium persicum* Boiss were used as antimicrobial agents in nanoemulsions preparation. The essential oils were analyzed using a gas chromatography (Agilent 7890A/5975C) equipped with a Chrome-pack CP-Sil 8 CB capillary column (50 m × 250 μm × 0.12 μm) as previously described by Keykhosravy et al. (2020). To produce emulsion, a mixture of glycerol (0.75 ml/g) and chitosan (2% w/v, in 1% acetic acid) was dispersed in bi-distilled water. Tween 80 (0.2% w/v) as a surfactant was mixed with two concentrations (0.5% and 1% [w/v]) of the above-mentioned essential oils until complete incorporation into the essential oil. After adding the mixture to the chitosan solution, the emulsion was mixed for 2 min at 10,000 rpm using a laboratory T25 digital Ultra-Turrax mixer (IKA, Staufen, Germany). To form nanoemulsion, this mixture was exposed to an ultrasound device (Sonoplus, Bandelin, Germany) with the pulse duration of 45 s on-time and 15 s off-time for 6 min at 50% amplitude. The product was placed in a water bath with ice at the outlet of the interaction chamber. The temperature of product was always kept constant (below 20°C) (Salvia-Trujillo et al., 2013). The size of the nanoemulsion droplets was measured using a dynamic light scattering device (Malvern Instruments Ltd., UK). The distribution of droplet size was defined using polydispersity index and mean droplet size expressed as PDI and *z*-diameter, respectively. The backscattered (173°) light was measured at 25°C through 1:100 diluted samples with bi-distilled water. The *z*-diameter and PDI values of CNE + ZEO 1% were determined to be 506.83 ± 15.83 nm and 0.48 ± 0.07, while for CNE + ZEO 0.5%, these parameters were 482.56 ± 3.08 nm and 0.46 ± 0.05, respectively. *z*-Diameters of the CNE + BEO 1% and CNE + BEO 0.5% were measured as 455.13 ± 4.46 nm and 342.33 ± 2.51 nm, and their PDI values were 0.31 ± 0.03 and 0.39 ± 0.01, respectively.

2.2.1 | DPPH radical scavenging activity assay for coating solutions

The antioxidant activity of coating solutions was evaluated using DPPH radical scavenging protocol (Jebelli Javan et al., 2013). The reagent used in this spectrophotometric assay was the stable radical DPPH. In brief, 50 μl of coating solutions was added to 5 ml of the DPPH solution (0.004% methanol solution). The samples were incubated at ambient temperature for half an hour, their absorbance was determined at 517 nm, and pure methanol was applied as blank. Inhibition percentage (I) showing the radical scavenging activities of the samples were determined as follows: I (%) = (A blank − A sample/A blank) × 100. The absorbance of the control sample which has all reagents except for the test compound is shown as A blank. The absorbance of the test compound is defined as A sample. All tests were repeated three times.

2.3 | Treatments of turkey meat slices

The meat samples of turkey fillets (average weight 400 ± 50 g) were provided from a local market (Mashhad, Iran). They were immediately placed in insulated polystyrene ice flasks and transported to the food hygiene laboratory, Ferdowsi University of Mashhad, Mashhad, Iran. Turkey meat pieces were washed completely to remove external particles and randomly divided into seven groups: (1) CON: without any covering solution, (2) CH: chitosan covering, (3) SCH: sonicated chitosan covering, (4) CNE + ZEO 0.5%: chitosan covering nanoemulsion comprising 0.5% (w/v) ZEO, (5) CNE + ZEO 1%: chitosan covering nanoemulsion comprising 1% (w/v) ZEO, (6) CNE + BEO 0.5%: chitosan covering nanoemulsion comprising 0.5% (w/v) BEO and (7) CNE + BEO 1%: chitosan covering nanoemulsion comprising 1% (w/v) BEO.

Before draining the turkey pieces for 1 h, they were covered with various solutions for 2 min. All of the fillets were placed into zip packs (Gahruie et al., 2017). Lastly, the meat slices were kept at 4 ± 1°C for an 18-day storage time, and they were analyzed for chemical properties during 5-day intervals (days 0, 5, 10, 15 and 20).

2.3.1 | Chemical composition of turkey meat sample

The moisture content, total ash, total crude protein, crude fat content and total carbohydrate content were determined by Horwitz (1975).

2.4 | pH value

Initially, two buffers with pH 7 and pH 4 (BDH Laboratory Supplies) were used to calibrate a digital pH meter equipped with a glass pH electrode (Martini, Mi 151, pH/ORP/Temperature Bench Meter). The sample (10 g) was exhaustively mixed with 100 ml of distilled water for 30 s. The mixture was utilized to record the pH value at ambient temperature (Gharibzahedi & Mohammadnabi, 2017).

2.5 | Total volatile basic nitrogen

The values of total volatile basic nitrogen (TVB-N) were estimated via a two-step process according to the method described by Shokri et al. (2015) which included distillation and titration step with sulfuric acid. TVB-N value (sulfuric acid (X) × N × 14 mg/100 g of sample) was calculated on the basis of the consumed sulfuric acid:

$$\text{TVB} - \text{N}\,(\text{mg N}100\,\text{g} - 1) = \frac{1.4 \times \text{used H2S04} \times 100 \times \text{amount of sample}}{1000\,\text{mg}}. \quad (1)$$

2.6 | Total lipid extraction

The lipid content was assessed according to a modified method described by Kamkar et al. (2014). Briefly, a certain amount of the sample (70 g) was mixed with 140 ml chloroform and 280 ml methanol. The mixture was homogenized for 2 min and rehomogenized with 140 ml chloroform, after adding 210 ml distilled water. The mixture was shaken for 1 h. The filtration was conducted under suction, and the final biphasic system was separated into two layers. The lower layer comprising chloroform and lipid was collected and shifted to a pear-shaped flask. At the final step, the solvent was evaporated using rotary, and the residue was further dried under a stream of nitrogen.

2.6.1 | Peroxide value

The peroxide values (PV) of meat slices were determined using IDF standard method. The PV, defined as milliequivalents of peroxide per kilogram of meat fillets, was determined using the following equation. A_S and A_b are shown as the absorbance of the sample and blank, respectively. The slope of the calibration curve is expressed as m and the sample weight (gram) is defined by mo. Iron atomic weigh is 55.84 and 2 defines the denominator and gives the concentration of Fe^{2+} oxidized to Fe^{3+} in micrograms. The division by 2 expresses the milliequvalent of peroxide instead of milliequvalent of oxygen, as explained in IDF method:

$$\frac{(As - Ab) \times m}{55.84 \times mo \times 2}. \quad (2)$$

2.6.2 | Thiobarbituric acid reactive substance

The value of TBARs was assessed using colorimetry and according to the procedure explained by Gharibzahedi and Mohammadnabi (2017). The findings were expressed as milligram of malondialdehyde (MDA) per kilogram of meat. After preparing the plank sample without meat, its absorbance (A_b) was determined. The TBARs values were calculated according to the following formula:

$$\text{TBARs} = (A_s - A_b) \times 0.25. \quad (3)$$

2.6.3 | Free fatty acid

Free fatty acids (FFA) were measured according to Gharibzahedi and Mohammadnabi (2017) and presented as oleic acid percentage. The content of acid and FFA was determined using the following equations:

Acid value = $56.1 \times N \times V$,

where N is normality of the solution and V is weight of the fat intake of sodium hydroxide.

FFA (%) = Acid value × 1/2.

2.6.4 | Trans-esterification of fatty acids and gas chromatography analysis

Trans-esterification of fatty acids was conducted using n-heptane and methanolic KOH (Ehsani et al., 2018). First, 7 ml of n-heptane was added to the extracted lipid, and at the next step, 2 ml of 2 mol L^{-1} methanolic KOH was added. After vortexing the mixture and complete dissolving, it was warmed up at 70°C for 15 min. When it reached ambient temperature, it was centrifuged at 1792 *g* for 10 min. After the separation of the mixture into two layers, the upper phase including FA methyl esters and n-heptane was harvested and shifted to a micro tube. Fatty acid profile of turkey meat fillets was determined using gas chromatography (Agilent Technologies Inc., Santa Clara, CA, USA), equipped with a flame ionization detector and a cyanopropyl polysilphenylene-siloxane column (BPX70, 120 m × 0.250 mm inner diameter × 0.25 μm film thickness). Ultra-high purity nitrogen (24.9%) at a flow rate of 1 ml min^{-1} was applied as carrier gas. Column temperature was planned at 140°C as the first temperature for 5 min and

increased to 240°C at a rate of 4°C min^{-1}. The injector and detector temperatures were set at 260°C. For each analysis, a certain value of the sample (1 μl) was injected. Retention time of each FA was identified and compared with a mixture of the external commercial standard fatty acid methyl esters (F.A.M.E. Mix, C4-C24, catalog No. 18919-1AMP, Merck) under the same conditions. Therefore, fatty acid contents were quantified, and the findings were presented as the concentration ratio of each fatty acid per total fatty acids of the samples.

2.7 | Total carbonyl

Total carbonyl value was assessed using the protocol applied by Ganhão et al. (2010). The protein concentration was determined after comparison with the standard curve. The calibration curve was plotted using bovine serum albumin (BSA) as a standard protein and sodium phosphate buffer (20 mM) with 6 M guanidine hydrochloride (pH 6.5) solution. The carbonyls amounts were shown as [Abs370 nm/21.0 mM^{-1} cm^{-1} × 1000]. In this formula, the molar extinction coefficient of carbonyls is 21.0 mM^{-1} cm^{-1}. The assay was repeated three times.

2.8 | Sensory evaluation

2.8.1 | Raw turkey fillet

First, panel participants were trained with elementary sensory evaluation methods and the product characteristics such as color, odor, taste and overall suitability. Then, they were selected from the employees of food quality control laboratory (TESTA), Mashhad, Iran. Furthermore, 21 males and females aged 27 and 45-year-old were selected as judges. Panelists assessed the fillets in isolated stands under glowing light. For each sample, three repeats were tested randomly. The sensory evaluation was based on a nine-point hedonic scale fluctuating from 1 (“dislike intensely”) to 9 (“like intensely”). According to the shelf life principles, obtaining the sensory attributes under 4 leads to sample rejection (Fan et al., 2009).

2.8.2 | Cooked turkey fillet

The sensory characteristics were evaluated according to the same procedure mentioned in the former section (Chouliara et al., 2008). All the treatments were evaluated immediately after coating. For sensory evaluation, the samples were prepared by microwave oven at 700 W power for 10 min, and salt (1.5%) was added.

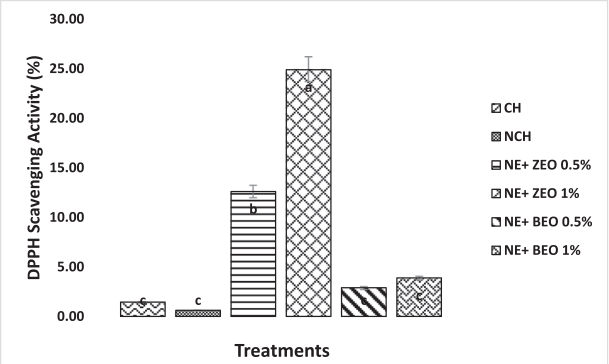

FIGURE 1 2, 2-Diphenyl-1-picrylhydrazyl (DPPH) scavenging activity of chitosan-loaded nanoemulsion containing essential oils. Date is expressed as mean ± SD ($n = 3$). Different letters (a–c) indicate a statistically significant difference ($p < 0.05$)

2.9 | Statistical analysis

In this study, all experiments were conducted in triplicate. The software of SPSS V21.0 (SPSS, Inc. Chicago, IL, USA) was applied for statistical data analysis. To evaluate the significant differences at $p < 0.05$ level, repeated measure analysis of variance followed by Dunnett T3 tests was used. Distribution of sensory score among groups were compared using nonparametric Friedman test. Willcoxon signed rank test was used for pairwise comparison. Due to multiple testing of the data, $p < 0.01$ was considered as significant. Also, Pearson correlation test was used to examine the correlation among groups.

3 | RESULTS AND DISCUSSION

3.1 | Free radical scavenging activity

Radical scavenging activity of samples was quickly screened and determined using DPPH assay. DPPH radical scavenging activity of several coating solutions is shown in Figure 1. All treatments with and without Essential oils (EOs) exhibited scavenging activity. Although different studies have reported substantial antioxidant activity for chitosan in vitro condition, there are some studies indicating low or no antioxidant activity of this biopolymer (Genskowsky et al., 2015; Ruiz-Navajas et al., 2013). In the present study, the lowest antioxidant activity was reported for chitosan (1.44%) and nanochitosan (0.62%) solutions. The highest scavenging efficiency (24.89%) was obtained for CNE + ZEO 1% sample. As shown in Figure 1, increasing EO concentration led to the enhancement of DPPH radical scavenging activity of the treatments significantly ($p < 0.05$). This finding was approved with the results reported by Jebelli Javan

et al. (2013). Incorporation of the essential oils of *Zataria multiflora* Boiss to the samples was more effective in decreasing DPPH radical scavenging activity compared to *Bunium persicum* Boiss essential oils. It appears that high antiradical activity of ZEO may be related to high level of oxygenated monoterpenes, specially carvacrol and thymol, and the great presence of gamma-terpinene (Aminzare et al., 2017).

3.2 | Proximate composition

The mean values of ash, lipid, protein and moisture (g/100 g turkey meat) in the examined turkey breast meat slices were determined to be 0.94%, 5.35%, 21.4% and 72.5%, respectively. As compared with previous studies (Oblakova et al., 2016), the proximate structure of the studied turkey breast fillet indicated dissimilarity particularly in lipid content. Some parameters such as farming, sexual variation, age, nutrition, living area and other environmental variables strongly affect the biochemical composition and lipid content of the turkey meat (Oblakova et al., 2016).

3.3 | pH value

Practical properties of meat proteins are directly affected by pH value (Rajaei et al., 2017). Table 1 shows the variations of pH values of the turkey fillets during storage under refrigeration. Similar to a previous study (Taheri et al., 2018), in the present study the initial pH of control turkey meat was found to be 6.29 and reached 6.82 ± 0.34 at the completion of storage. The pH value of the control sample was more than other treatments, significantly ($p < 0.05$). As shown in Table 1, the pH values in all the treatments were lower than the amounts achieved for control groups at zero time of chill storage. These results are confirmed by Pabast et al. (2018) and might be related to the existence of 1% acetic acid and phenolic compounds in the coating. Inhibitory influences of phenolics on the growth of bacteria and subsequent decomposition of amino complexes during the storage period may explain the slow trend of pH raising for the EOs-contained samples. There is evidence reported by Amiri et al. (2019) to support this explanation. The pH values of coated samples were decreased gradually between 10 and 15 days of the storage period and increased significantly between days 15 and 20, as reported in a previous study (Taheri et al., 2018). pH reduction during the 10 and 15 days of the storage may occur as a result of fast growth of lactic acid bacteria. Enhancement in pH values of the groups is connected to the volatile bases made by microorganism and enzymatic processes (Ceylan, Unal Sengor, et al., 2018).

3.4 | Determination of TVB-N

The TVB-N amounts of the turkey meat slices during storage under refrigerator are shown in Table 1. The initial value of the TVB-N (2.24 mg N/100 g) reached to 20.81 mg N/100 g. The obtained values for TVB-N were much lower than the acceptability limit (28–29 mg N/100 g) suggested in the literature for poultry meat products (Taheri et al., 2018). The studied samples were categorized as fresh and high-quality products. In this study, the TVB-N level for the control samples did not surpass the acceptability level, and the achieved results were in agreement with previous studies (Jasour et al., 2015; Mahmoudzadeh et al., 2010). During the storage time, a significant enhancement ($p < 0.05$) was attained in TVB-N content of treated and control groups. This elevation can be related to the presence of some microorganisms such as bacteria, the metabolic activity of endogenous enzymes, the biosynthesis of alkaline metabolites during the proliferation and stationary growth phase of bacteria and the proteins deamination process. The bacterial decomposition in aerobic conditions occurs with a higher rate than the anaerobic conditions and is regarded as the main reason for the production of volatile compounds (Mahmoudzadeh et al., 2010). Edible coating could contribute to the formation of anaerobic conditions in treated samples and prevented the increasing of TVB-N value in this group. In this study, the TVB-N values were under the acceptability limit during the whole storage period in covered meat slices. Decreasing the bacterial population or bacterial ability for oxidative deamination of nonprotein nitrogenous metabolites may be the reason. During the storage period, the minimum TVB-N amount was achieved for the turkey fillets treated with CNE + ZEO 1% (6.16 mg N/100 g) and CNE + BEO 1% (5.97 mg N/100 g) at the final day of the experiment. These obtained findings are in agreement with those reported previously (Ehsani, Hashemi, et al., 2019).

3.5 | Change in PV

The PV level indicates an increase in the amounts of produced peroxide and hydroperoxide metabolites during primary step of lipid oxidation process (Taheri et al., 2018). The PV values of turkey meat samples are shown in Table 1. The value of peroxide index between 10 and 20 meq kg^{-1} is considered acceptable (Ehsani et al., 2020). At the initiation of the storage period, PV levels were in the ranges of 2.52−3.42 meq kg^{-1}. Lipid oxidation was increased progressively until day 10 of storage, and afterward it was decreased gradually. The same results were reported by Ehsani et al. (2018). This enhancement may be

TABLE 1 Changes in the chemical spoilage parameters of chilled turkey breast fillets during 20 days of storage[1]

Attributes	Sampling time (day)	Treatments						
		CON	CH	NCH	NE + ZEO 0.5%	NE + ZEO 1%	NE + BEO 0.5%	NE + BEO 1%
pH	0	6.29 ± 0.13^{aB}	5.94 ± 0.18^{bA}	5.87 ± 0.14^{bA}	5.75 ± 0.00^{bA}	5.79 ± 0.01^{bA}	5.88 ± 0.13^{bA}	5.74 ± 0.06^{bA}
	5	6.31 ± 0.20^{aAB}	5.97 ± 0.07^{abA}	5.97 ± 0.22^{abA}	6.01 ± 0.14^{abA}	5.93 ± 0.02^{abA}	5.92 ± 0.12^{abA}	5.89 ± 0.13^{bA}
	10	6.40 ± 0.07^{aAB}	5.98 ± 0.27^{aA}	5.92 ± 0.18^{aA}	6.04 ± 0.21^{aA}	6.11 ± 0.41^{aA}	5.94 ± 0.34^{aA}	5.93 ± 0.24^{aA}
	15	6.58 ± 0.06^{aAB}	5.84 ± 0.24^{bA}	5.89 ± 0.14^{bA}	5.76 ± 0.09^{bA}	6.08 ± 0.35^{abA}	5.85 ± 0.28^{bA}	5.80 ± 0.00^{bA}
	20	6.82 ± 0.34^{aA}	6.10 ± 0.30^{abA}	6.04 ± 0.11^{abA}	5.92 ± 0.26^{bA}	6.05 ± 0.30^{abA}	5.99 ± 0.23^{abA}	6.03 ± 0.49^{abA}
TVB-N (mg/100 g)	0	2.24 ± 0.28^{aE}	1.77 ± 0.16^{aD}	1.96 ± 0.56^{aC}	1.96 ± 0.00^{aC}	1.68 ± 0.00^{aE}	2.24 ± 0.28^{aB}	1.96 ± 0.00^{aD}
	5	7.65 ± 0.64^{aD}	3.64 ± 0.00^{bC}	3.26 ± 0.16^{bC}	3.08 ± 0.28^{bBC}	2.89 ± 0.16^{bD}	3.26 ± 0.32^{bB}	2.80 ± 0.00^{bCD}
	10	11.76 ± 1.22^{aC}	5.60 ± 0.00^{bB}	5.50 ± 0.98^{bB}	4.85 ± 0.85^{bAB}	4.38 ± 0.16^{bC}	5.22 ± 0.7^{bA}	4.00 ± 0.83^{bBC}
	15	17.73 ± 0.42^{aB}	6.06 ± 1.13^{bB}	6.62 ± 0.90^{bAB}	5.88 ± 1.45^{bA}	5.60 ± 0.28^{bB}	5.80 ± 0.79^{bA}	5.69 ± 1.29^{bAB}
	20	20.81 ± 1.98^{aA}	9.05 ± 0.9^{bA}	7.84 ± 0.74^{bcA}	6.34 ± 0.42^{cA}	6.16 ± 0^{cA}	6.72 ± 0.96^{bcA}	5.97 ± 0.16^{cA}
PV (meq active oxygen kg-1 of fat)	0	3.17 ± 0.16^{aC}	3.33 ± 0.14^{aC}	3.42 ± 0.28^{aC}	3.21 ± 0.17^{aC}	2.52 ± 0.42^{bB}	3.39 ± 0.17^{aD}	2.94 ± 0.07^{abB}
	5	7.72 ± 0.99^{aB}	5.13 ± 0.30^{bB}	4.02 ± 0.19b^{cC}	3.65 ± 0.21^{cC}	2.89 ± 0.12^{cB}	3.93 ± 0.44^{bcD}	3.63 ± 0.70^{cB}
	10	12.28 ± 1.72^{aA}	7.99 ± 0.62^{bA}	7.78 ± 0.12^{bA}	7.52 ± 0.1b^{cA}	5.37 ± 0.79^{cA}	7.48 ± 0.23^{bcA}	6.29 ± 0.63^{bcA}
	15	6.59 ± 0.33^{aB}	6.00 ± 0.32^{aB}	5.85 ± 0.31^{aB}	5.57 ± 0.68^{aB}	3.57 ± 0.75^{bB}	6.06 ± 0.08^{aB}	3.80 ± 0.08^{bB}
	20	5.53 ± 0.11^{aBC}	5.51 ± 0.4^{aB}	5.14 ± 0.37^{aB}	4.98 ± 0.18^{aB}	3.55 ± 0.17^{bB}	5.23 ± 0.38^{aC}	3.51 ± 0.33^{bB}
TBARs (mg malonalde-hyde/100 g of sample)	0	2.72 ± 0.32^{aD}	2.81 ± 0.32^{aD}	2.42 ± 0.22^{abD}	2.84 ± 0. 28^{aD}	1.97 ± 0.04^{bD}	2.90 ± 0.17^{aD}	2.68 ± 0.35^{abD}
	5	6.66 ± 0.21^{aB}	5.60 ± 0.25^{bC}	5.57 ± 0.47^{bB}	5.99 ± 0.22^{abB}	4.48 ± 0.39^{cC}	5.45 ± 0.37^{bC}	5.74 ± 0.34^{abBC}
	10	9.63 ± 1.07^{aA}	9.37 ± 0.41^{abA}	9.74 ± 0.57^{aA}	8.31 ± 0.37^{abcA}	7.02 ± 0.64^{cA}	7.51 ± 0.95^{bcA}	7.62 ± 0.56^{bcA}
	15	6.82 ± 0.60^{aB}	6.60 ± 0.43^{aB}	6.55 ± 1.37^{aB}	6.63 ± 0.36^{aB}	5.64 ± 0.07^{aB}	6.47 ± 0.28^{aAB}	6.34 ± 0.17^{aB}
	20	4.95 ± 0.08^{aC}	4.78 ± 0.05^{aC}	4.89 ± 0.50^{aB}	4.88 ± 0.00^{aC}	4.73 ± 0.0^{aBC}	4.67 ± 1.15^{aCD}	4.88 ± 0.00^{aC}
FFA (% of oleic acid)	0	2.80 ± 0.14^{aD}	2.71 ± 0.29^{aE}	2.61 ± 0.21^{aE}	2.52 ± 0.37^{aD}	2.33 ± 0.21^{aC}	2.75 ± 0.16^{aD}	2.42 ± 0.08^{aD}
	5	4.77 ± 0.84^{aC}	4.07 ± 0.50^{abD}	3.37 ± 0.28^{bD}	3.41 ± 0.21^{bC}	3.13 ± 0.16^{bB}	3.27 ± 0.29^{bD}	3.27 ± 0.40^{bCD}
	10	6.82 ± 0.21^{aB}	5.19 ± 0.24^{bC}	4.95 ± 0.21^{bC}	3.65 ± 0.24^{cC}	3.51 ± 0.24^{cB}	4.95 ± 0.35^{bC}	3.74 ± 0.49^{cC}
	15	8.18 ± 0.21^{aA}	7.47 ± 0.29^{abB}	6.82 ± 0.08^{bcB}	5.42 ± 0.32^{deB}	4.86 ± 0.40^{eA}	6.07 ± 0.21^{cdB}	5.75 ± 0.24^{dB}
	20	9.16 ± 0.45^{aA}	9.12 ± 0.42^{aA}	7.57 ± 0.14^{bA}	6.40 ± 0.08^{cA}	5.51 ± 0.29^{dA}	6.87 ± 0.14^{bcA}	7.01 ± 0.24^{bcA}
Total carbonyl (nmol/mg)	0	1.42 ± 0.24^{aD}	1.33 ± 0.24^{aD}	1.28 ± 0.05^{aD}	1.24 ± 0.04^{aB}	1.04 ± 0.22^{aC}	1.35 ± 0.07^{aC}	1.17 ± 0.07^{aB}
	5	2.76 ± 0.00^{aC}	1.92 ± 0.17^{bCD}	1.40 ± 0.15^{cD}	1.32 ± 0.16^{cB}	1.22 ± 0.23^{cBC}	1.38 ± 0.05^{cBC}	1.30 ± 0.07^{cB}
	10	2.86 ± 0.30^{aC}	2.64 ± 0.09^{aC}	2.63 ± 0.08^{aC}	1.98 ± 0.38^{bcB}	1.47 ± 0.04^{cBC}	2.04 ± 0.08^{bBC}	1.56 ± 0.07^{bcB}
	15	3.86 ± 0.11^{aB}	3.60 ± 0.09^{abB}	3.62 ± 0.45^{abB}	2.12 ± 0.77^{cB}	1.67 ± 0.35^{cB}	2.31 ± 0.77^{bcB}	1.74 ± 0.30^{cB}
	20	4.96 ± 0.52^{aA}	4.72 ± 0.52^{abA}	4.47 ± 0.08^{abA}	3.93 ± 0.07^{bA}	2.98 ± 0.13^{cA}	3.99 ± 0.15^{bA}	2.88 ± 0.35^{cA}

Abbreviations: TVB-N, total volatile basic nitrogen; FFA, free fatty acid; PV, peroxide value; TBARs, thiobarbituric reactive substance.

$^{a–d}$Different lowercase letters in the same row indicate significant differences ($p < 0.05$).

$^{A–D}$Different uppercase letters in the same column indicate significant differences ($p < 0.05$).

[1]Date is expressed as the mean ± SD ($n = 3$).

due to the higher speed of hydroperoxides production as compared to its breakdown. As time proceeds, hydroperoxides react with other metabolites such as ketones, hydroxy compounds, aldehydes, epoxides and proteins (Ozogul et al., 2017). A similar pattern was reported in hydroperoxide content in ground beef patties within 20-day storage (Amiri et al., 2019). During the storage time, the samples coated with chitosan nanoemulsion containing ZEO and BEO had lower PV than control samples. The samples treated with CNE + ZEO 1% were the most effective treatment and decreased the lipid decomposition compared toother treatments. Similarly, Ozogul et al. (2017) reported that lipid oxidation was reduced in nanoemulsion-treated samples during the storage period. As the droplet size of nanoemulsion reduces, its oxidative stability improves. Therefore, advancement of preliminary oxidation stage and peroxide formation is decelerated (Amiri et al., 2019). The treatments containing CNE + ZEO 1% and CNE + BEO 1% were more effective compared to the samples covered with CNE + ZEO 0.5% and CNE + BEO 0.5%. The results indicated that application of EOs at high levels may result in an additional antioxidant effect. Therefore, due to the higher concentrations of the antioxidant compounds such as phenolics, lipids are well protected against degradation.

3.6 | Changes in TBARs

TBARs is a technique for measuring the level of secondary metabolites produced from the fatty acid oxidation of meat (Ehsani, Hashemi, et al., 2019). TBARs value in high quality products must be lower than 3 mg MDA/kg, while in accepted quality material it should not exceed 5 mg MDA/kg (Kilinc et al. (2009). TBARs levels ≥5 mg MDA/kg in meat include the threshold for distinguishing off-odors and off-taste for humans. As shown in Table 1, TBARs values of the samples (mg MDA/kg) ranged from 1.97 ± 0.04 in CNE + ZEO 1% to 2.72 ± 0.32 in CON at zero time. TBARs values of the control sample were the maximum and reached 6.66 ± 0.21 mg MDA/kg at 5th day. In CON and other treatments, TBARs values were increased until days 5 and 10, respectively, and a decrease was observed until 20th day of storage. This trend occurred similarly to what reported previously in chicken breast meat and could be related to MDA formation (Chouliara et al., 2008) and degradation during the later stages of storage (Jasour et al., 2015). After 5 days of the storage, the TBARs values for CON and CNE + ZEO 1% were determined to be 6.66 ± 0.21 and 4.48 ± 0.39, respectively, whereas in other groups this value was found to be less than 5. The results of the present study are confirmed by values reported in other studies (Chouliara et al., 2008). Due to the antioxidant ability of chitosan, lipid oxidation was inhibited in the samples coated with chitosan. Residual amino groups of chitosan can produce a fluorosphere constant with volatile aldehydes such as malondialdehyde which are from the byproducts of lipid oxidation and degradation. The antioxidant ability of chitosan may be related to this structural and biochemical property (Pabast et al., 2018).

3.7 | Changes in FFA

FFA content shown in Table 1 is an indicator to express the development of lipid hydrolysis in the turkey meat fillets. FFA formation decreases the nutritional quality of meat by affecting proteins denaturation and lipid oxidation. Generally, the FFA concentrations at the beginning of the storage did not differ significantly. Increasing the FFAs levels during short-term chill storage may result from lipid decomposition of meat tissue via hydrolyzing enzymes such as lipase and phospholipase, in which recorded results were in line with Ehsani et al. (2020). *Pseudomonas* spp. plays a key role in the FFA production in food via lipase and phospholipase (Ehsani et al., 2020). The FFA concentration is directly correlated with *Pseudomonas* spp. This result is in close agreement with the findings of our prior study (Keykhosravy et al., 2020). In all the samples, a progressive enhancement was observed in the FFA contents. For example, the primary value of FFA (2.33−2.80) improved to the highest levels (5.51–9.16) at the final day of storage. Similarly, FFA content was enhanced during chill storage (Ehsani, Naghibi, et al., 2019). The comparison of FFA levels between control and the treatments proved decreasing effects of chitosan nanoemulsion coating containing EOs on FFA production via deactivation of the related enzymes.

3.8 | Fatty acid composition

Due to the limited published evidence considering the fatty acid profile of turkey meat, researchers are interested in this field. The analysis of lipid profile of turkey meat indicated that both domestic and wild birds contained 21 fatty acids. As shown in Tables 2 and 3, in turkey meats the percentage of unsaturated fatty acids (UFA) were superior to the saturated fatty acids (SFA). Evaluation of fatty acid profile, quantitatively and qualitatively, revealed that turkey meat lipid fractions are predominantly composed of SFA such as palmitic (C16:0) and stearic acid (C18:0), monounsaturated fatty acid (MUFA) such as oleic (C18:1 ω-9) and palmitoleic acid (C16:1 ω-7) and polyunsaturated fatty acid (PUFA) such as linoleic (C18:2 ω-6 cis) and arachidonic acid (C20:4 ω-6). During the storage of samples, the SFA and MUFA percentages were increased, and PUFA contents were decreased. Therefore, the PUFA/SFA was

TABLE 2 Fatty acid (FA) composition (% of total FAs) in turkey breast fillets at day 0 chilled storage (4 ± 1°C)[1]

	Day 0						
	CON	CH	NCH	NE + ZEO 0.5%	NE + ZEO 1%	NE + BEO 0.5%	NE + BEO 1%
C12:0	0.10 ± 0.02	0.12 ± 0.13	0.14 ± 0.04	0.05 ± 0.01	0.05 ± 0.01	0.13 ± 0.01	0.05 ± 0.01
C14:0	0.58 ± 0.07	0.89 ± 0.87	0.62 ± 0.03	0.59 ± 0.07	0.50 ± 0.06	0.55 ± 0.01	0.43 ± 0.05
C14:1ω5	0.13 ± 0.06	0.11 ± 0.05	0.18 ± 0.04	0.09 ± 0.02	0.06 ± 0.02	0.16 ± 0.01	0.06 ± 0.01
C15:0	0.10 ± 0.02	0.12 ± 0.10	0.15 ± 0.05	0.09 ± 0.02	0.09 ± 0.01	0.12 ± 0.01	0.09 ± 0.01
C16:0	27.55 ± 0.54	27.94 ± 0.15	29.38 ± 1.93	28.13 ± 0.25	26.34 ± 0.07	28.44 ± 1.02	26.05 ± 0.15
C16:1ω7	4.50 ± 1.93	3.45 ± 1.05	4.93 ± 2.65	4.51 ± 0.38	2.44 ± 0.24	5.09 ± 0.08	2.87 ± 0.24
C17:0	0.12 ± 0.04	0.13 ± 0.08	0.20 ± 0.08	0.11 ± 0.12	0.13 ± 0.02	0.14 ± 0.01	0.11 ± 0.03
C17:1	0.09 ± 0.05	0.07 ± 0.06	0.18 ± 0.06	0.09 ± 0.01	0.06 ± 0.01	0.09 ± 0.03	0.06 ± 0.01
C18:0	9.63 ± 2.43	10.36 ± 1.98	10.36 ± 0.58	9.47 ± 0.33	11.33 ± 0.11	8.84 ± 0.90	11.66 ± 0.18
C18:1ω9cis	0.17 ± 0.01	0.17 ± 0.24	0.14 ± 0.03	0.10 ± 0.03	0.04 ± 0.01	0.18 ± 0.05	0.05 ± 0.03
C18:1ω9tr	27.50 ± 2.70	28.86 ± 1.14	26.72 ± 0.61	22.90 ± 0.16	23.16 ± 0.06	24.97 ± 0.68	24.13 ± 0.16
C18:2ω6cis	23.81 ± 0.57	22.31 ± 2.50	20.94 ± 1.77	24.63 ± 0.37	25.66 ± 0.46	23.44 ± 0.21	25.01 ± 0.41
C18:3ω3	0.74 ± 0.17	0.62 ± 0.16	0.69 ± 0.13	0.67 ± 0.09	0.82 ± 0.19	0.54 ± 0.05	0.64 ± 0.08
C20:0	0.05 ± 0.05	0.07 ± 0.05	0.34 ± 0.10	0.06 ± 0.01	0.03 ± 0.02	0.05 ± 0.01	0.05 ± 0.04
C20:1ω9	0.16 ± 0.04	0.12 ± 0.01	0.16 ± 0.03	0.11 ± 0.01	0.22 ± 0.06	0.08 ± 0.01	0.12 ± 0.01
C20:2	0.40 ± 0.16	0.38 ± 0.14	0.63 ± 0.24	0.50 ± 0.01	0.66 ± 0.06	0.55 ± 0.05	0.60 ± 0.06
C20:3ω3	0.07 ± 0.03	0.17 ± 0.08	0.36 ± 0.06	0.16 ± 0.05	0.17 ± 0.06	0.16 ± 0.04	0.10 ± 0.01
C20:4?6	2.96 ± 1.39	2.74 ± 0.38	2.47 ± 1.46	5.38 ± 0.28	5.64 ± 0.32	3.87 ± 1.33	5.43 ± 0.11
C20:5ω3	0.93 ± 0.58	0.95 ± 0.03	0.72 ± 0.33	1.60 ± 0.18	1.82 ± 0.08	1.58 ± 0.28	1.72 ± 0.34
C22:5ω6	0.21 ± 0.08	0.20 ± 0.01	0.36 ± 0.10	0.38 ± 0.06	0.45 ± 0.04	0.36 ± 0.15	0.27 ± 0.07
C22:6ω3	0.12 ± 0.06	0.13 ± 0.03	0.22 ± 0.03	0.32 ± 0.09	0.27 ± 0.08	0.32 ± 0.14	0.15 ± 0.06
SFA	38.12 ± 2.28^{a}	39.62 ± 3.08^{a}	41.21 ± 1.64^{a}	38.49 ± 0.26^{a}	38.46 ± 0.13^{a}	38.26 ± 0.46^{a}	38.44 ± 0.32^{a}
MUFA	32.53 ± 3.88^{a}	32.78 ± 0.26^{a}	32.31 ± 2.22^{b}	27.81 ± 0.35^{b}	25.98 ± 0.25^{c}	30.57 ± 0.64^{ab}	27.28 ± 0.34^{abd}
ω-6 PUFA	23.31 ± 1.03^{a}	25.25 ± 2.87^{a}	23.76 ± 3.23^{a}	30.39 ± 0.16^{ab}	31.74 ± 0.20^{ac}	27.67 ± 1.03^{a}	30.70 ± 0.04^{a}
ω-3 PUFA	1.87 ± 0.49^{b}	1.87 ± 0.19^{b}	2.00 ± 0.46^{b}	2.74 ± 0.18^{ab}	3.08 ± 0.14^{a}	2.60 ± 0.43^{ab}	2.62 ± 0.40^{ab}
PUFA	29.24 ± 1.65^{a}	27.50 ± 3.15^{a}	26.39 ± 3.85^{a}	33.63 ± 0.15^{b}	35.49 ± 0.37a	30.82 ± 0.84^{b}	33.92 ± 0.28^{b}
PI	0.77 ± 0.02^{a}	0.70 ± 0.13^{a}	0.64 ± 0.12^{a}	0.87 ± 0.00^{b}	0.92 ± 0.01^{b}	0.81 ± 0.02^{ab}	0.88 ± 0.00^{b}

Abbreviations: MUFA, monounsaturated fatty acid; PI, polyene index; PUFA, polyunsaturated fatty acid.

[a–d]Different lowercase letters in the same row indicate significant differences ($p < 0.05$).

[1]Date is expressed as the mean ± SD ($n = 3$).

declined during the storage. The same pattern of changes was found in a previous study (Ceylan, Meral, et al., 2018). The polyene index (PI), which is the ratio of polyunsaturated to saturated FAs, is used as an indicator to determine lipid oxidation during the storage. The ω-6 and ω-3 PUFAs, the most preferred fatty acids for nutritional purposes, were maximum at the start of the storage duration. The contents of ω-3 and ω-6, which were 23.31–31.74 and 1.87–3.08 on the first day of storage, was measured to be minimum on day 20.

3.9 | Protein oxidation

Protein carbonyl content determination is suggested as an approach for the measurement of protein oxidation (Soyer et al., 2010). Protein oxidation degrades the color and texture of the meat and is responsible for decreasing the essential amino acids and digestibility of proteins (Guyon et al., 2016). Table 1 presents the protein carbonyl content of the turkey meat fillets. In this study, the level of protein oxidation in treated meat slices decreased as compared to that of estimated for the control groups. Phenolic compounds of EOs have antioxidant activity and can reduce lipids and proteins. In the treated samples, the phenolic compounds containing free hydroxyl groups inhibited the oxidation of sulfhydryl (-SH) group of proteins (Bazargani-Gilani et al., 2015). The results indicated that in the samples treated with CNE + ZEO 1% and CNE + BEO 1%, the carbonyl content is less than 2 nmol/mg after 15 days of storage. Therefore, it suggests the limitation of protein oxidation in turkey meat fillets. The amounts of protein carbonyl components

TABLE 3 Main muscle fatty acid (FA) composition (% of total FAs) in turkey breast fillets at day 20 chilled storage (4 ± 1°C)[1]

	Day 20						
	CON	CH	NCH	NE + ZEO 0.5%	NE + ZEO 1%	NE + BEO 0.5%	NE + BEO 1%
C12:0	0.07 ± 0.04	0.10 ± 0.02	0.21 ± 0.03	0.49 ± 0.60	0.07 ± 0.01	0.16 ± 0.01	0.08 ± 0.01
C14:0	0.62 ± 0.03	0.73 ± 0.23	0.72 ± 0.05	0.78 ± 0.17	0.56 ± 0.04	0.61 ± 0.07	0.44 ± 0.14
C14:1ω5	0.14 ± 0.02	0.12 ± 0.04	0.20 ± 0.09	0.09 ± 0.07	0.05 ± 0.01	0.21 ± 0.02	0.07 ± 0.01
C15:0	0.08 ± 0.02	0.15 ± 0.05	0.17 ± 0.05	0.08 ± 0.02	0.10 ± 0.01	0.13 ± 0.02	0.09 ± 0.03
C16:0	27.87 ± 0.87	28.52 ± 0.06	29.19 ± 0.59	29.34 ± 1.12	26.87 ± 0.21	28.81 ± 0.41	26.26 ± 1.46
C16:1ω7	5.55 ± 0.29	4.42 ± 0.17	4.25 ± 0.09	4.88 ± 1.31	2.53 ± 0.13	6.25 ± 0.04	3.51 ± 1.06
C17:0	0.10 ± 0.01	0.13 ± 0.03	0.20 ± 0.05	0.11 ± 0.05	0.15 ± 0.03	0.14 ± 0.01	0.11 ± 0.01
C17:1	0.09 ± 0.02	0.09 ± 0.01	0.22 ± 0.11	0.10 ± 0.02	0.07 ± 0.02	0.10 ± 0.01	0.07 ± 0.02
C18:0	9.61 ± 0.87	10.85 ± 0.07	11.57 ± 0.39	9.73 ± 1.68	11.40 ± 0.12	8.86 ± 0.46	12.10 ± 0.52
C18:1ω9cis	0.16 ± 0.04	0.15 ± 0.00	0.22 ± 0.08	0.15 ± 0.03	0.05 ± 0.02	0.22 ± 0.00	0.14 ± 0.05
C18:1ω9tr	28.39 ± 0.35	29.47 ± 0.15	27.40 ± 0.59	26.14 ± 3.12	24.80 ± 0.17	25.97 ± 0.21	27.58 ± 3.40
C18:2ω6cis	22.23 ± 0.18	21.18 ± 0.16	20.84 ± 0.81	22.34 ± 0.55	25.53 ± 0.33	22.02 ± 0.15	23.41 ± 2.38
C18:3ω3	0.64 ± 0.10	0.45 ± 0.10	0.40 ± 0.06	0.60 ± 0.20	0.70 ± 0.05	0.49 ± 0.05	0.62 ± 0.18
C20:0	0.05 ± 0.00	0.08 ± 0.02	0.28 ± 0.20	0.07 ± 0.03	0.04 ± 0.02	0.10 ± 0.01	0.12 ± 0.09
C20:1ω9	0.14 ± 0.04	0.18 ± 0.01	0.23 ± 0.09	0.12 ± 0.01	0.13 ± 0.03	0.12 ± 0.01	0.15 ± 0.05
C20:2	0.41 ± 0.12	0.26 ± 0.00	0.41 ± 0.02	0.40 ± 0.04	0.46 ± 0.04	0.37 ± 0.03	0.40 ± 0.08
C20:3ω3	0.07 ± 0.04	0.12 ± 0.01	0.15 ± 0.04	0.10 ± 0.02	0.12 ± 0.02	0.14 ± 0.03	0.06 ± 0.01
C20:4ω6	2.59 ± 1.07	1.99 ± 0.11	2.24 ± 0.34	2.95 ± 0.77	4.27 ± 0.07	3.43 ± 0.16	3.24 ± 1.01
C20:5ω3	0.84 ± 0.04	0.66 ± 0.12	0.62 ± 0.21	1.08 ± 0.38	1.54 ± 0.07	1.22 ± 0.19	1.11 ± 0.12
C22:5ω6	0.17 ± 0.03	0.16 ± 0.01	0.27 ± 0.08	0.17 ± 0.11	0.35 ± 0.00	0.25 ± 0.03	0.16 ± 0.03
C22:6ω3	0.09 ± 0.00	0.06 ± 0.02	0.12 ± 0.02	0.18 ± 0.10	0.14 ± 0.02	0.24 ± 0.07	0.15 ± 0.02
SFA	38.40 ± 0.91^{adf}	40.56 ± 0.24^{bde}	42.34 ± 0.52^{bce}	40.61 ± 3.28^{abf}	39.19 ± 0.27^{f}	38.80 ± 0.14^{af}	39.21 ± 1.33^{abf}
MUFA	34.47 ± 0.50^{a}	34.47 ± 0.31^{a}	32.52 ± 0.95^{a}	31.48 ± 4.34^{abc}	27.64 ± 0.17^{b}	32.87 ± 0.20^{c}	31.52 ± 4.32^{abc}
ω-6 PUFA	24.99 ± 0.56^{a}	23.34 ± 0.23^{a}	23.36 ± 1.21^{a}	25.46 ± 1.21^{a}	30.15 ± 0.33^{b}	25.70 ± 0.16^{ac}	26.80 ± 3.03^{a}
ω-3 PUFA	1.64 ± 0.31^{bc}	1.29 ± 0.15^{c}	1.29 ± 0.24^{c}	1.96 ± 0.31^{ab}	2.50 ± 0.12^{a}	2.09 ± 0.12^{ab}	1.93 ± 0.10^{ab}
PUFA	27.04 ± 0.98^{ab}	24.89 ± 0.08^{a}	25.06 ± 1.42^{ab}	27.82 ± 1.43^{abd}	33.10 ± 0.27^{d}	28.16 ± 0.22^{b}	29.13 ± 3.04^{ab}
PI	0.71 ± 0/04^{abc}	0.61 ± 0/00^{a}	0.59 ± 0/04^{ac}	0.69 ± 0/04^{abc}	0.84 ± 0/01^{b}	0.73 ± 0/01^{c}	0.74 ± 0.06^{abd}

Abbreviations: MUFA, monounsaturated fatty acid; PI, polyene index; PUFA, polyunsaturated fatty acid.

[a–d]Different lowercase letters in the same row indicate significant differences ($p < 0.05$).

[1]Date is expressed as the mean ± SD ($n = 3$).

in the present study were comparable to those previously reported in chicken meat (Soyer et al., 2010) and turkey breast muscle (Mercier et al., 1998). As shown in Table 1, during chill storage the amount of protein carbonyls was increased significantly in all the samples. This increase was more pronounced in CON, CH, SCH samples than samples containing EOs.

It has been suggested that protein oxidation in muscle food takes place through different pathways. Primary and secondary metabolites of lipid oxidation process such as hydroperoxides and malonaldehyde can be utilized as substrates for protein oxidation. Therefore, initiation of lipid oxidation results in protein oxidation as well. In fact, as soon as the reactive oxygen species attack proteins, carbonyl compounds are generated and the loss of sulfhydryl groups is separated from the protein. Lipid oxidation, measured by TBARs number, is correlated with protein oxidation which is determined by carbonyl content in turkey meat ($r = 0.32$) during the storage, especially at day 10 ($r = 0.85$). Similarly, Soyer et al. (2010) and Ventanas et al. (2006) reported a correlation between lipid and protein oxidation in turkey meat during chill storage (Soyer et al., 2010).

3.10 | Sensory evaluation

The obtained results of the sensory evaluation of raw turkey meat samples are shown in Table 4. According to the suggestion of Fan et al. (2009), the sensory score of

TABLE 4 Sensory evaluations of raw turkey fillet during 20 days of storage [1]

Attributes	Sampling time (day)	Treatments						
		CON	CH	NCH	NE + ZEO 0.5%	NE + ZEO1%	NE + BEO 0.5%	NE + BEO 1%
Odor	0	8.50 (7, 9)^{abc}	8.00 (6, 9)^{c}	8.00 (6, 9)^{cd}	9.00 (7, 9)^{ab}	9.00 (7, 9)^{a}	8.50 (6, 9)^{abc}	9.00 (6, 9)^{ab}
	5	7.00 (5, 9)^{c}	7.00 (6, 9)^{bc}	8.00 (6, 9)^{bc}	8.00 (6, 9)^{ab}	9.00 (6, 9)^{a}	8.00 (5, 9)^{ab}	8.00 (6, 9)^{ab}
	10	2.00 (1, 5)^{c}	6.00 (4, 7)^{b}	6.00 (4, 7)^{b}	7.00 (6, 9)^{a}	7.00 (5, 9)^{a}	6.00 (6, 8)^{ab}	7.00 (6, 8)^{a}
	15	1.00 (1, 4)^{c}	4.00 (2, 7)^{b}	4.00 (1, 8)^{b}	6.00 (4, 8)^{a}	6.00 (5, 7)^{a}	6.00 (4, 8)^{a}	5.50 (4, 8)^{a}
	20	1.00 (1, 1)^{b}	3.00 (2, 7)^{a}	4.00 (2, 6)^{a}	4.50 (3, 6)^{a}	4.50 (2, 7)^{a}	4.00 (3, 6)^{a}	5.00 (2, 7)^{a}
Color	0	9.00 (7, 9)^{abc}	9.00 (8, 9)^{a}	9.00 (8, 9)^{ab}	8.00 (6, 9)^{c}	8.00 (5, 9)^{c}	8.00 (7, 9)^{bc}	8.00 (6, 9)^{c}
	5	8.00 (6, 9)^{a}	8.00 (5, 9)^{a}	8.50 (6, 9)^{a}	7.00 (7, 9)^{a}	8.00 (6, 9)^{a}	8.00 (5, 9)^{a}	8.00 (5, 9)^{a}
	10	4.00 (2, 7)^{b}	7.00 (5, 8)^{a}	7.00 (6, 9)^{a}	7.50 (5, 9)^{a}	8.00 (6, 9)^{a}	7.00 (5, 9)^{a}	7.50 (6, 9)^{a}
	15	2.00 (1, 6)^{b}	5.00 (3, 7)^{a}	5.00 (4, 7)^{a}	6.00 (3, 8)^{a}	6.00 (3, 8)^{a}	5.50 (3, 7)^{a}	6.00 (4, 8)^{a}
	20	1.00 (1, 1)^{b}	1.00 (1, 1)^{b}	5.00 (1, 7)^{a}	5.00 (3, 7)^{a}	5.00 (4, 7)^{a}	5.00 (3, 7)^{a}	5.00 (4, 7)^{a}
Texture	0	8.50 (6, 9)^{a}	8.00 (7, 9)^{a}	8.00 (7, 9)^{a}	8.00 (7, 9)^{a}	9.00 (6, 9)^{a}	8.00 (7, 9)^{a}	9.00 (8, 9)^{a}
	5	8.00 (6, 9)^{a}	8.00 (6, 9)^{a}	8.00 (6, 9)^{a}	8.00 (6, 9)^{a}	8.00 (6, 9)^{a}	8.00 (6, 9)^{a}	8.50 (6, 9)^{a}
	10	4.00 (1, 8)^{c}	6.50 (5, 8)^{b}	7.00 (6, 9)^{ab}	7.00 (6, 9)^{ab}	8.00 (6, 9)^{ab}	7.00 (5, 9)^{ab}	8.00 (6, 9)^{a}
	15	2.00 (1, 3)^{b}	6.00 (3, 8)^{a}	6.00 (4, 8)^{a}	6.00 (5, 8)^{a}	6.00 (5, 8)^{a}	6.00 (5, 7)^{a}	6.50 (5, 8)^{a}
	20	1.00 (1, 1)^{c}	4.00 (1, 7)^{b}	4.50 (3, 7)^{ab}	5.00 (4, 7)^{a}	5.50 (2, 7)^{a}	5.00 (3, 7)^{ab}	5.00 (4, 8)^{a}
Overall acceptability	0	9.00 (8, 9)^{a}	9.00 (6, 9)^{a}	8.50 (6, 9)^{a}	8.00 (7, 9)^{a}	9.00 (7, 9)^{a}	9.00 (5, 9)^{a}	9.00 (6, 9)^{a}
	5	8.00 (6, 9)^{b}	8.00 (6, 9)^{ab}	8.00 (7, 9)^{ab}	8.50 (7, 9)^{ab}	8.00 (7, 9)^{a}	9.00 (5, 9)^{ab}	8.00 (5, 9)^{ab}
	10	3.00 (1, 6)^{d}	6.50 (5, 8)^{bc}	6.00 (4, 9)^{c}	7.00 (6, 8)^{a}	7.00 (6, 9)^{a}	7.50 (6, 9)^{a}	7.00 (6, 8)^{ab}
	15	2.00 (1, 3)^{c}	5.00 (3, 8)^{b}	6.00 (3, 9)^{ab}	7.00 (5, 8)^{a}	7.00 (5, 8)^{a}	6.00 (5, 8)^{a}	6.50 (5, 8)^{ab}
	20	1.00 (1, 1)^{b}	4.00 (2, 7)^{a}	4.00 (1, 6)^{a}	5.00 (2, 7)^{a}	6.00 (2, 7)^{a}	5.00 (4, 6)^{a}	5.00 (2, 7)^{a}

[a–c]Different lowercase letters in the same row indicate significant differences ($p < 0.01$).

[1]Date is expressed as the median (min, max) ($n = 3$).

TABLE 5 Sensory evaluations of cooked turkey fillet at day 0 chilled storage (4 ± 1°C)[1]

Attributes	Treatments						
	CON	CH	NCH	NE + ZEO 0.5%	NE + ZEO 1%	NE + BEO 0.5%	NE + BEO 1%
Odor	8.00 (5, 9)[a]	8.00 (6, 9)[a]	8.00 (6, 9)[a]	8.00 (5, 9)[a]	7.00 (4, 9)[a]	7.00 (4, 9)[a]	7.00 (3, 9)[a]
Color	8.50 (6, 9)[a]	8.00 (7, 9)[ab]	8.00 (6, 9)[ab]	8.00 (5, 9)[ab]	7.50 (5, 9)[b]	8.00 (5, 9)[ab]	8.00 (6, 9)[ab]
Texture	8.00 (5, 9)[a]	8.00 (6, 9)[a]	8.00 (5, 9)[a]	8.00 (6, 9)[a]	7.00 (4, 9)[a]	8.00 (5, 9)[a]	8.00 (5, 9)[a]
Accept	8.00 (6, 9)[a]	8.00 (7, 9)[a]	8.00 (7, 9)[a]	7.00 (5, 9)[a]	7.50 (4, 9)[a]	7.50 (4, 9)[a]	8.00 (5, 9)[a]
Taste	8.00 (6, 9)[a]	8.00 (5, 9)[ab]	7.50 (5, 9)[ab]	7.50 (4, 9)[ab]	6.50 (4, 9)[b]	7.00 (4, 9)[ab]	7.00 (4, 9)[ab]

[a–b]Different lowercase letters in the same row indicate significant differences ($p < 0.01$).

[1]Date is expressed as the median (min, max) ($n = 3$).

meat samples is acceptable for human consumption until 4. After 5 days of storage, the symptoms of spoilage were observed in the control samples. In all sensory evaluations, the highest score belonged to the samples treated with CNE + ZEO 1%. Similarly, ZEO application was also reported to improve the sensory characteristics of chicken meat and enhanced its shelf life throughout the chilling period (Bazargani-Gilani et al., 2015). The essential oils decrease the oxidative deterioration and therefore the production of secondary metabolites of the lipid oxidation process in comparison to CON, CH and SCH samples. As the findings of the present study reveal that the turkey fillets covered with chitosan nanoemulsions coatings containing EOs acquired higher scores. The odor, color and overall suitability of these groups were improved compared to other treatments. The results also designated that the maximum color score at zero time was achieved for CH and SCH treatments in comparison to other treatments and can be correlated with glazed appearance of chitosan solution. But these samples did not reach a high odor score at the beginning of the storage time. This is probably due to the undesirability of the strong flavor of chitosan (like fishy odor) by the panelists. The results also showed that integration of essential oil into chitosan nanoemulsion covering reduced the fishy odor of chitosan, enhanced its acceptability and prolonged the shelf life of turkey meat (Ozogul et al., 2017). Besides, samples coated with chitosan nanoemulsions containing EOs earned poor color score at zero time. The milky appearance of nanoemulsions may be the reason for obtaining the lower score by the panelists.

The obtained findings of the sensory evaluation of cooked turkey meat slices at zero time are given in Table 5. The results obtained from CON, CH and SCH samples revealed that the coverings were imperceptible, and treating meat samples with coating emulsions at certain concentrations did not lead to creating unwanted sensory traits. Nanoemulsions treatments decreased organoleptic quality of turkey breast fillets especially high concentrations (1%) of *Zataria multiflora* Boiss and *Bunium persicum* Boiss which gave a disagreeable taste.

4 | CONCLUSION

In this study, the oxidative stability of turkey meat was maximized with chitosan-loaded nanoemulsion coating, which contained *Zataria multiflora* Boiss and *Bunium persicum* Boiss. The TVB-N level for samples did not surpass the acceptability level (28–29 mg N/100 g). Lipid oxidation (TV and TBARs values) was increased progressively until day 10 of storage, and afterward it was decreased gradually. The primary value of FFA (2.33−2.80) improved to

the highest levels (5.51–9.16) at the final day of storage. The findings of the present study confirm that protein oxidation, measured as carbonyl content, is closely related to lipid oxidation ($r = 0.32$). Nanoemulsions treatments, especially high concentrations (1%) of *Zataria multiflora* Boiss and *Bunium persicum* Boiss which gave a disagreeable taste, decreased organoleptic quality of turkey breast fillets. This study showed that chitosan-loaded nanoemulsion coating which contained *Zataria multiflora* Boiss and *Bunium persicum* Boiss essential oils could be used as a covering material to decrease and postpone chemical deterioration in turkey meat fillets.

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CONFLICT OF INTEREST

The authors declare no conflict of interests.

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