Effect of novel bioactive coating enriched with nanoemulsion of mustard essential oil on the quality of turkey meat

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Summary

The effect of nano-emulsified mustard (*Brassica juncea*) essential oil (NME) alone and combined with gelatin/hydroxypropyl-β-cyclodextrin (FNME) investigated in comparison with a synthetic packaging polymer on weight loss, pH, total volatiles, total volatile basic nitrogen value (*TN*), thiobarbituric acid reactive substances value (*TR*), microbiological and sensorial characteristics of turkey breast during 20 days storage at 4 ± 1 °C. Results showed that pH, *TN*, *TR*, yeasts, moulds, total mesophilic and psychrotrophic bacteria of FNME samples were significantly lower than the same parameters of other samples during storage time ($p < 0.05$). The use of FNME significantly improved sensory attributes especially the odour and overall acceptability in comparison with NME ($p < 0.05$). In FNME samples, the shelf life of turkey meat was prolonged to 10–15 days. FNME coating was effective at improvement of the overall quality and extended the shelf life of turkey meat during cold storage.

Keywords

gelatin; coating; nanoemulsion; *Brassica juncea*; essential oil; turkey meat

The production and consumption of poultry meat have increased continuously during the last decades in many parts of the world. The presence of low levels of cholesterol and fat, high content of protein, high protein/energy ratio as well as high growth rate have led poultry meat and especially turkey meat preferred to red meat. On the other hand, due to its nature and composition, turkey meat is susceptible to the growth of pathogenic microorganisms, lipid oxidation and deterioration reactions, which may lead to a decrease in nutritional quality, undesirable organoleptic changes and great economic losses even during cold storage [1].

Considering the disadvantages of synthetic polymers, edible films have been proposed as an alternative to food packaging to improve the quality and shelf life of meat products. Bioactive edible films and coatings are biodegradable, non-toxic, non-pollutant and may be used as a carrier of natural preservative compounds. Gelatin is used extensively in preparing edible coatings and films to extend the shelf life and maintaining safety and freshness of various meat products but it suffers from poor biological characteristics and the lack of antioxidant as well as antimicrobial properties [2]. Nowadays, there is a growing demand for natural antimicrobial agents to be used in food instead of synthetic preservatives [3]. Mustard (*Brassica juncea)* is one of the most valuable plants from the Brassicaceae family growing in the south of Iran and has long been used to prepare ethnic foods

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like Mahvah. Mustard essential oil represents an interesting source of natural antimicrobials, in particular allyl isothiocyanate, and antioxidants for food preservation. United States Food and Drug Administration (FDA) classified this substance as generally recognized as safe (GRAS) [4]. Consequently, it is a good choice for use in antimicrobial food packaging [5].

Nanoemulsion preparation by the ultrasonic high-energy method is one of the potential strategies for incorporating essential oils into food products. It can overcome the limitations such as low water-solubility and bioavailability, poor chemical stability and the volatile nature of essential oils. Nanoemulsions containing essential oils can be used to form bioactive films and coatings with functional properties. The antimicrobial activity of nanoemulsions of essential oils was reported previously by CHANG et al. [6]. Also, the essential oil of aromatic plants can be encapsulated in hydroxypropyl-β-cyclodextrin (HP-βC). This compound is a water-soluble cyclodextrin derivative. Cyclodextrins (CD) are categorized as GRAS, non-toxic and biodegradable cyclic oligosaccharides [7, 8]. The three-dimensional structure and a hydrophobic cavity in the molecule facilitate formation of non-covalent host-guest inclusion complexes with some type of CD with various molecules including additives and essential oils. As a consequence, they can blend with polymers appropriately, solubilize lipophilic molecules, bind certain bitter materials or flavours and, therefore, diminish their perception by the senses of taste and odour, masking unpleasant odours, provide sustained release and targeted delivery of bioactive compounds, especially in nano-scale [9]. To the best of our knowledge, this is the first report describing the application of Iranian mustard essential oil in a new bioactive coating for turkey meat packaging.

The objective of this novel study was to evaluate and assess the preservative effects of gelatin/HP-βC coating enriched with nanoemulsion of mustard essential oil, as a bioactive coating, on the shelf life and quality of fresh turkey meat during cold storage.

MATERIALS AND METHODS

Materials

Raw turkey breast (without skin and bones) from B.U.T. breed purchased from a local market in Karaj (Alborz province, Iran) was transferred immediately to a standard laboratory under hygienic conditions in an ice box at 4 ± 1 °C. The mustard (*Brassica juncea*) seed was obtained from regions of southern Iran namely Larestan (Fars province, Iran, N 27° 40‘ 26.906“, E 54° 20‘ 8.824“) in 2018. Edible gelatin (180 Bloom) was obtained from Taramehr (Taramehr, Tehran, Iran) and HP-βC was obtained from Shandong Binzhou Zhiyuan Biotechnology (Shandong, China). All the used media, solvents, chemicals and biological reagents were of analytical grade and were obtained from Merck (Darmstadt, Germany).

Extraction and analysis of mustard essential oil

The mustard essential oil was extracted by hydrodistillation at 70 °C during 3 h in a Clevenger-type apparatus (Jahan Shimi Gostar, Tehran, Iran) according to the method of YU et al. [10]. Analysis of essential oil compounds was performed using a gas chromatography–mass spectrometry (GC-MS) system Agilent 7890B (Agilent, Santa Clara, California, USA) equipped with a 5977A mass selective and triple-axis detector, as well as with a split-splitless injector (1 : 10 split ratio). The capillary column was a fused silica HP-5MS (30 m × 0.25 mm inner diameter, 0.25 μm film thickness). The carrier gas was helium with a flow rate of 1.1 ml·min^{-1}. A volume of 1 μl of the mustard essential oil was injected for analysis. The injector and the detector temperature was set at 250 °C. The column temperature was set at 65 °C for 2 min, then increased to 170 °C at 10 °C·min^{-1} and held for 5 min, then increased to 250 °C at 25 °C·min^{-1} and held for 7 min [11].

Preparation of the coating nanoemulsion solution

The nanoemulsion of mustard essential oil was formulated using the extracted essential oil, Tween 80 (25 % w/w in the essential oil) as an emulsifier and deionized water, which was treated by high speed mechanical homogenizer Wisetis-HG-15D (Daihan Scientific, Seoul, South Korea) for 5 min and then subjected to ultrasonic emulsification using a 20 kHz, 70 W sonicator (Bandelin Sonoplus, Berlin, Germany) at 25 ± 2 °C several times until nanoparticles were produced [12]. The gelatin/HP-βC enriched with nanoemulsion of mustard essential oil was prepared by mixing 4 g of gelatin, 6 g·l^{-1} HP-βCD and distilled water, the obtained mixture being stirred on a magnetic stirrer/hot plate at 70 °C for 30 min, which resulted in a clear and smooth solution. After cooling, glycerol (30 % w/w with respect to gelatin) was added as a plasticizer to the mixture and it was stirred for 10 min at room temperature. The gelatin/HP-βC enriched with nanoemulsion of mustard essential oil (1.5 % v/v) was used for coating turkey meat [13].

Preparation and treatment of turkey meat samples

The turkey breast was washed, drained and cut into pieces weighing approximately 30 ± 5 g by the method of Fernández-Pan et al. [14]. The samples were divided into four separated groups, namely:

1. control samples that were left untreated (marked as B),
2. samples wrapped with food grade Sun wrap cellophane of Powerwrap, Cheongju, South Korea (marked as CE),
3. samples coated with nanoemulsion of mustard essential oil (marked as NME), and
4. samples coated with gelatin/HP-βC enriched with nanoemulsion of mustard essential oil (marked as FNME).

The treated samples were completely immersed in individual coating solutions for 2 min under hygienic and sterile conditions. After completion of the dip coating, the prepared meat samples were removed from the solution, allowed to drain sufficiently in the cold air and dried for 45 min. Then, all samples were individually placed in sterile trays of polypropylene in the refrigerator at 4 ± 1 °C. The evaluation of physico-chemical, microbiological specification as well as sensory properties was carried out at 0, 5, 10, 15 and 20 days.

Analysis of turkey meat samples

Weight loss

The weight loss (*WL*) was calculated through weight differences of turkey meat samples in accordance with the following equation and expressed as percentage [15].

$$WL = \frac{W_1 - W_2}{W_1} \times 100 \quad (1)$$

where W_1 is the weight of turkey meat sample before storage, W_2 is the weight of turkey meat sample after storage period (expressed in grams).

pH

An amount of 25 g of turkey meat sample was homogenized completely with 225 ml of distilled water for 1 min and then the pH value measured using a calibrated digital pH meter Eutech pH 5+ (Oakton Instruments, Vernon Hills, Illinois, USA) at 25 ± 2 °C [1].

Determination of total volatile basic nitrogen

Total volatile basic nitrogen (TVB-N) values were determined using a Kjeldahl nitrogen apparatus (Duran, Mainz, Germany) according to Gharibzahedi and Mohammadnabi [16]. In the step of steam distillation, 10 g turkey meat sample, 2 g magnesium oxide and 300 ml were water added to the Kjeldahl balloon. The distilled solution was collected in 2% boric acid containing methyl red reagent and titrated with 0.01 mol·l^{-1} HCl. The value of TVB-N (*TN*) was calculated based on the consumption of HCl using the following equation and expressed in milligrams N per kilogram:

$$TN = \frac{V \times M \times 14}{W} \times 1000 \quad (2)$$

where V is volume of HCl used expressed in millilitres, M is the concentration of HCl expressed in moles per litre and W is the weight of the sample expressed in grams.

Determination of thiobarbituric acid reactive substances

The thiobarbituric acid reactive substances (TBARS) value as a criterion of lipid oxidation was measured by a colorimetric method according to Feng et al. [15]. Briefly, 1 ml of the homogenized turkey meat with butylated hydroxyanisole and deionized distilled water was transferred to a test tube, sulfanilamide (10 g·l^{-1}, 20 μl) was added and mixed. After 5 min, 2 ml of thiobarbituric acid reagent (15 mmol·l^{-1} thiobarbituric acid in 15% trichloroacetic acid) was added. The mixture was centrifuged at 2500 ×g for 15 min at 4 °C. The TBARS value (*TR*) was calculated according to Eq. 3 based on the absorbance of the resulting supernatant solution at 531 nm against the blank as the amount of malondialdehyde (MDA) in milligrams per kilogram of meat:

$$TR = \frac{50 \times (A_s - A_b)}{200} \quad (3)$$

where A_s is absorbance of the sample and A_b is absorbance of the blank.

Microbiological analysis

An amount of 25 g of minced turkey meat was added to 225 ml of 0.1% sterile peptone water and homogenized in a sterile stomacher bag equipped with a filter (Seward, London, United Kingdom) for 1 min. Then, serial dilutions prepared and 0.1 ml of the diluted sample was spread on the surface of differential media under aseptic conditions. Colonies of the indicator bacteria were enumerated after the incubation time of 72 days at 30 °C, 10 days at 7 °C, and 3–5 days at 25 °C for mesophilic bacteria, psychotrophic bacteria and fungi, respectively. The obtained results were expressed as decadic logarithm of colony forming units per gram of sample [17].

Sensory evaluation

The sensory evaluation of turkey meat samples was performed by the quality index method (QIM) [18]. The quality criteria, namely, appearance, lack of the surface slime on meat, colour, odour, texture and overall acceptance were measured using a 9-point descriptive scale by a panel of eleven. On the scale used, scores between 7.0 and 9.0 indicated extremely like, scores between 4.0 and 6.9 indicated like, and 3.9 was the limit of acceptability.

Statistical analysis

All the experimental results were performed in triplicate. Analysis of variance (ANOVA) was carried out using SPSS 21.0 (SPSS, Chicago, Illinois, USA) and the results were expressed as mean ± standard deviation. Comparison of means was performed by the least significant difference (LSD) and Duncan's multiple range tests at P value of 0.05.

RESULTS AND DISCUSSION

Analysis of mustard essential oil

The extracted essential oil was found to be composed mainly of allyl isothiocyanate (80.0 %), 9-octadecenoic acid (*Z*)-phenyl methyl ester (7.9 %), *cis*-vaccenic acid (4.6 %), and pyrrolo [1,2-a] pyrazine-1,4-dione, hexahydro-3-(2-methylpropyl) (1.0 %). The chemical composition of mustard essential oil was described in detail in our previous study [5].

Weight loss

Weight loss of NME and FNME samples in comparison with samples wrapped in cellophane during storage at 4 ± 1 °C is presented in Fig. 1. During storage, the weight loss of all samples increased while, for CE and FNME samples, it was lower than for control samples ($P < 0.05$). The highest weight loss was observed at 3.3 % for the control sample on day 20 and the lowest weight loss was 0.2 % on day 5 in the sample wrapped in cellophane. The weight loss in control and NME samples was always significantly higher than weight loss for FNME and cellophane samples ($P < 0.05$). These results showed that FNME and CE were effective against water loss, which was attributed to the protective layer against water evaporation created on the surface by coating, as the weight loss of turkey meat resulted from the release of water during storage. The gelatin coatings act effectively as water vapour barriers and decrease water loss in fresh meat products during the entire storage period. This result is in accordance with results of other studies [19–22].

pH value

The average pH values of NME and FNME samples, in comparison with samples wrapped in cellophane, during storage at 4 ± 1 °C are presented in Fig. 2. Based on the obtained results, the initial pH value of all samples immediately after coating was 5.9. The observed changes in the pH value of the treated samples showed the same trend of values decreasing on day 5 of storage and then increasing significantly. The decrease in pH was attributed to production and accumulation of lactic acid by anaerobic glycolysis and increase in solubility of CO_2 resulting from the growth and activity of aerobic microorganisms. The increase in

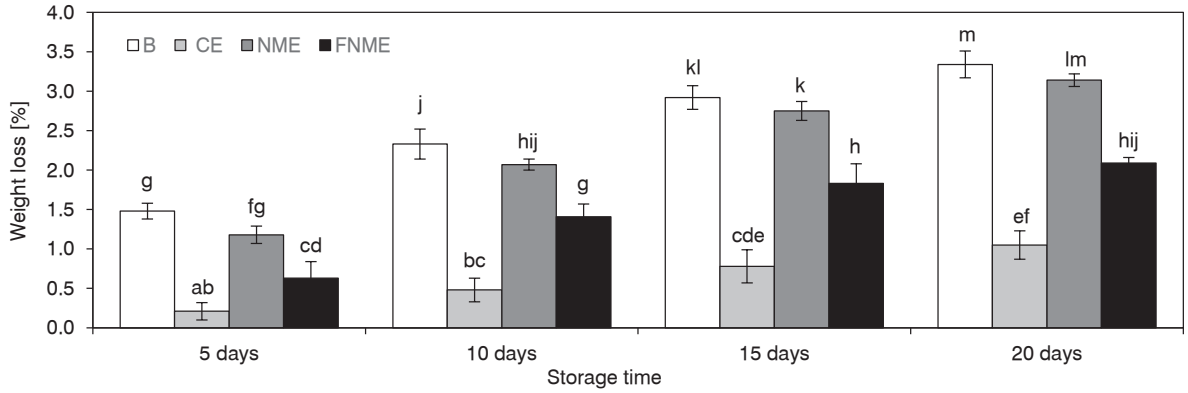

Fig. 1. Weight loss of turkey meat samples during storage at 4 ± 1 °C.

Values represent mean ± standard deviation.
B – control without coating, CE – wrapped in cellophane, NME – coated with nanoemulsion of mustard essential oil, FNME – coated with gelatin/hydroxypropyl-β-cyclodextrin enriched with nanoemulsion of mustard essential oil.

pH values may result from the formation of alkaline substances, such as ammonia, biogenic amines or trimethylamines, caused by spoilage microorganisms and endogenous enzymes [16, 21, 22]. The initial pH values of samples had no significant differences ($P > 0.05$). The FNME sample showed significantly lower pH value compared with other samples on day 15. The pH values of NME and FNME samples on day 20 of storage were 6.65 ± 0.02 and 6.28 ± 0.02, respectively. Compared to the control and CE samples, the delay in pH increase observed in NME and FNME was due to the presence of allyl isothiocyanate as a natural antimicrobial compound in mustard essential oil. Allyl isothiocyanate could reduce the growth of spoilage microorganisms and restrain generation of alkaline substances. HUANG et al. [21] reported that a packaging film with allyl isothiocyanate effectively inhibited protein decomposition, controlled the pH value and thus increased the water retention capability of the muscle. The obtained results are in agreement with the previous studies [21–24].

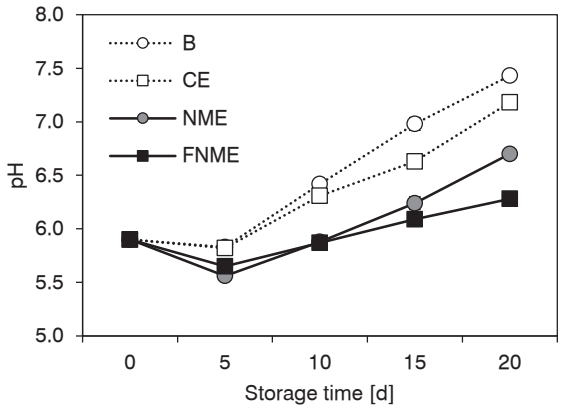

Fig. 2. pH values of turkey meat samples during storage at 4 ± 1 °C.

Values represent mean ± standard deviation.
B – control without coating, CE – wrapped in cellophane, NME – coated with nanoemulsion of mustard essential oil, FNME – coated with gelatin/hydroxypropyl-β-cyclodextrin enriched with nanoemulsion of mustard essential oil.

Total volatile basic nitrogen

Fig. 3 shows the TVB-N values (*TN*) of NME and FNME samples in comparison with the samples wrapped in cellophane during storage at 4 ± 1 °C. TVB-N is an important quality indicator for assessing meat freshness [21]. The highest acceptable limit of *TN* is proposed to be 280–290 mg·kg^{-1} for poultry meat products [22]. As shown in Fig. 3, TVB-N increased during storage time in all treatments ($P < 0.05$). There were no significant differences among the initial *TN* of all samples ($P > 0.05$). At day 10 of storage, *TN* of control sample (331.2 mg·kg^{-1}) was above the standard value of fresh or frozen poultry meat. At the day 15 day of storage, the highest *TN* belonged to control samples (438.4 mg·kg^{-1}), while the lowest *TN* was observed for FNME (225.6 mg·kg^{-1}). According to the obtained results on *TN*, the preservation effect of gelatin/HP-βC coating enriched with nanoemulsion of mustard essential oil on turkey meat was superior to the control sample and cellophane. The results indicated the inhibitory effect of mustard essential oil against spoilage bacteria and endogenous enzymes, and against degradation of protein and non-protein nitrogen-containing compounds [20]. Our results are similar to those previously reported by other researchers [20, 22]. These findings suggest that gelatin/HP-βC coating enriched with nanoemulsion of mustard essential oil can inhibit the increase in *TN* and extend the shelf life of turkey meat samples to 15 days.

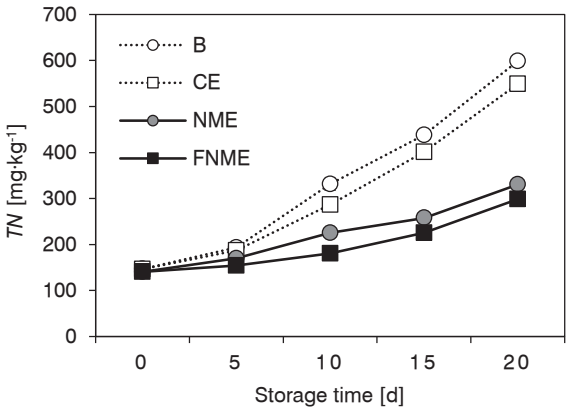

Fig. 3. Total volatile basic nitrogen values of turkey meat samples during storage at 4 ± 1 °C.

Values represent mean ± standard deviation.
TN – total volatile basic nitrogen values (expressed in milligrams N per kilogram of meat).
B – control without coating, CE – wrapped in cellophane, NME – coated with nanoemulsion of mustard essential oil, FNME – coated with gelatin/hydroxypropyl-β-cyclodextrin enriched with nanoemulsion of mustard essential oil.

Thiobarbituric acid reactive substances

Changes in TBARS values (*TR*) of NME and FNME samples in comparison with samples wrapped in cellophane during storage at 4 ± 1 °C are presented in Fig. 4. TBARS is an important indicator to measure the amount of MDA as a secondary product of the oxidative degradation of polyunsaturated fatty acids in the poultry meat during storage [24]. As shown in Fig. 4, the initial *TR* (expressed as MDA) was 0.26 mg·kg^{-1} in the control sample. *TR* of 1 mg·kg^{-1} is the threshold

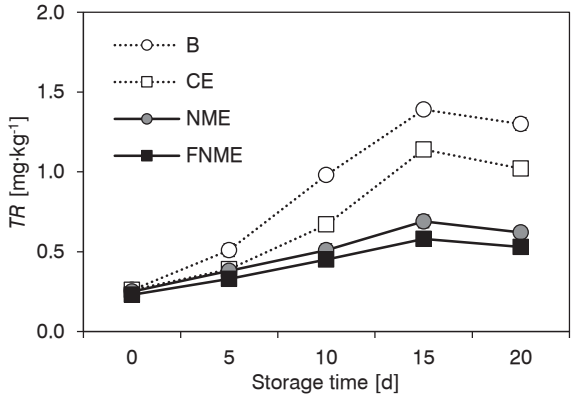

Fig. 4. Thiobarbituric acid reactive substances values of turkey meat samples during storage at 4 ± 1 °C.

Values represent mean ± standard deviation.
TR – thiobarbituric acid reactive substances value (expressed in milligrams of malondialdehyde per kilogram of meat.
B – control without coating, CE – wrapped in cellophane, NME – coated with nanoemulsion of mustard essential oil, FNME – coated with gelatin/hydroxypropyl-β-cyclodextrin enriched with nanoemulsion of mustard essential oil.

of sensory evaluation of oxidative rancidity in meat, percepted as off-flavour. *TR* of all samples stored for 10 days did not exceed this threshold, which could be related to the moderately low fat in turkey meat [25]. *TR* of all samples increased during storage significantly ($P < 0.05$). This seemed related to accumulation of the degradation products of unsaturated fatty acids [25]. However, it should be noted that the rate of increase in *TR* for control and cellophane-wrapped samples was significantly higher than that of the samples treated with mustard essential oil ($P < 0.05$). At day 15 of storage, the highest *TR* was observed in the control sample (1.39 mg·kg^{-1}) and the lowest one belonged to samples in a coating containing mustard essential oil, in particular FNME sample (0.58 mg·kg^{-1}). Compared to the control and CE samples, TBARS increased less in NME and FNME ($P<0.05$) probably due to the presence of phenolic and phytochemical compounds with antioxidant activity in mustard essential oil. The key mechanism is their free radical-scavenging activity to form relatively stable inactive products [26].

Lipid oxidation was delayed or inhibited by the coating of food. The reason was the protective function of gelatin/HP-βC coating enriched with nanoemulsion of mustard essential oil on the surface of turkey meat samples, which restricted effectively access to air and retarded the oxidation of unsaturated fatty acids in turkey meat. The decrease of TBARS in samples occured at the end of the storage period probably due to the formation of secondary oxidation products that do not react with the thiobarbituric acid reagent or due to the reaction of MDA with proteins by Maillard reaction or by other chemical reactions of MDA with constituents of turkey meat. Also, MDA might have been metabolized by microorganisms [27]. These results are in accordance with previously reported results of Wu et al. [2]. Lee et al. [26] demonstrated that the extract of *B. juncea*, as a natural antioxidant, was very effective to prevent lipid oxidation compared to the synthetic antioxidants such as butylated hydroxyanisole or butylated hydroxytoluene.

Microbiological effects

Changes in aerobic mesophilic, psychrotrophic bacteria, yeasts and moulds of NME and FNME samples, in comparison with samples wrapped in cellophane, during storage at 4 ± 1 °C are shown in Tab. 1. As presented, counts of aerobic mesophilic bacteria, psychrotrophic bacteria, yeasts and moulds in NME and FNME samples were significantly lower than in control and CE samples ($P < 0.05$). The changes in psychrotrophic bacteria as the specific spoilage organisms in meat or meat products during chilled storage, as well as in the yeasts and moulds, showed the same trend with the counts of mesophilic bacteria. The obtained results revealed that gelatin/HP-βCD coatings enriched with nanoemulsion of mustard essential oil had good antimicrobial activity in the turkey meat samples during storage. The maximum acceptable limit of microbial counts in meat is 7.00 log CFU·g^{-1}, which is considered the expiry point and the beginning of spoilage, chemical modification and undesirable odour in meat [28]. In the current study, in the case of mesophilic bacteria, counts for control sample and CE until day 5, the NME sample until day 10 and the FNME sample until day 15 did not exceed the maximum acceptable limit.

Our results are in accordance with those of previous studies [9, 20, 29], which reported the inhibitory effect of mustard species on spoilage and pathogenic microorganisms in food products. Yu et al. [9] reported the high value and antimicrobial activity of *B. juncea* essential oil against various microorganisms. Kumar and Tanwar [30] stated that incorporation of mustard powder into chicken nuggets decreased the counts of Enterobacteriaceae, yeasts and moulds until 15 days. Chen and Liu [31] also found that films with mustard essential oil showed great antimicrobial activity against *Escherichia coli, Staphylococcus aureus*, and lower for *Bacillus subtilis* and *Aspergillus niger*. Allyl isothiocyanate, a predominant detected

Tab. 1. Microbiological quality of turkey meat samples during storage at 4 ± 1 °C.

Sample	Storage time				
	0 days	5 days	10 days	15 days	20 days
Mesophilic bacteria [log CFU·g^{-1}]					
B	4.43 ± 0.21^{ab}	6.09 ± 0.11^{de}	7.96 ± 0.17^{fg}	8.43 ± 0.21^{g}	8.98 ± 0.17^{hi}
CE	4.36 ± 0.18^{ab}	5.68 ± 0.27^{cd}	7.12 ± 0.17^{f}	8.04 ± 0.12^{g}	8.45 ± 0.15^{h}
NME	4.25 ± 0.14^{a}	5.12 ± 0.14^{bc}	6.35 ± 0.21^{e}	7.07 ± 0.17^{f}	7.80 ± 0.25^{g}
FNME	4.21 ± 0.16^{a}	4.88 ± 0.16^{b}	5.26 ± 0.18^{c}	6.20 ± 0.14^{de}	7.28 ± 0.08^{c}
Psychrotrophic bacteria [log CFU·g^{-1}]					
B	3.64 ± 0.10^{ab}	6.92 ± 0.15^{e}	8.29 ± 0.19^{g}	8.97 ± 0.21^{h}	9.46 ± 0.18^{i}
CE	3.59 ± 0.18^{ab}	6.87 ± 0.14^{e}	8.08 ± 0.22^{g}	8.86 ± 0.13^{h}	9.39 ± 0.24^{i}
NME	3.27 ± 0.18^{a}	5.32 ± 0.20^{cd}	6.33 ± 0.26^{de}	7.23 ± 0.16^{f}	7.87 ± 0.17^{g}
FNME	3.09 ± 0.13^{a}	5.13 ± 0.17^{c}	5.97 ± 0.21^{h}	6.48 ± 0.17^{g}	7.50 ± 0.12^{f}
Yeasts and moulds [log CFU·g^{-1}]					
B	3.35 ± 0.19^{a}	4.65 ± 0.23^{cd}	7.29 ± 0.15^{h}	8.01 ± 0.15^{i}	8.36 ± 0.15^{i}
CE	3.30 ± 0.12^{a}	4.46 ± 0.19^{c}	6.35 ± 0.18^{f}	7.05 ± 0.29^{gh}	7.29 ± 0.12^{h}
NME	3.31 ± 0.21^{a}	4.12 ± 0.13^{bc}	6.03 ± 0.17^{f}	6.82 ± 0.19^{g}	7.16 ± 0.19^{h}
FNME	3.32 ± 0.21^{a}	3.79 ± 0.16^{b}	5.48 ± 0.27^{e}	6.32 ± 0.14^{f}	6.56 ± 0.20^{g}

Values represent mean ± standard deviation. Values with different letters in superscript are significantly different ($P < 0.05$).
B – control without coating, CE – wrapped in cellophane, NME – coated with nanoemulsion of mustard essential oil, FNME – coated with gelatin/hydroxypropyl-β-cyclodextrin enriched with nanoemulsion of mustard essential oil.

Tab. 2. Sensory assessment of turkey meat samples during storage at 4 ± 1 °C.

Sample name	Storage time				
	0 days	5 days	10 days	15 days	20 days
Colour					
B	8.72 ± 0.46^{j}	6.90 ± 0.94^{gh}	4.81 ± 0.75^{c}	3.27 ± 1.19^{b}	1.81 ± 0.87^{a}
CE	8.72 ± 0.46^{j}	7.36 ± 0.67^{hi}	6.27 ± 0.78^{eg}	5.09 ± 1.37^{cd}	3.18 ± 1.07^{b}
NME	8.72 ± 0.46^{j}	6.81 ± 0.87^{gh}	5.09 ± 1.04^{cd}	4.36 ± 0.92^{c}	1.18 ± 0.40^{a}
FNME	8.90 ± 0.30^{j}	7.72 ± 0.78^{i}	6.90 ± 1.04^{gh}	5.81 ± 0.98^{de}	5.00 ± 1.00^{c}
Odour					
B	8.72 ± 0.46^{k}	6.18 ± 1.25^{gh}	2.09 ± 0.94^{bc}	1.09 ± 0.30^{a}	1.00 ± 0.00^{a}
CE	8.27 ± 0.46^{jk}	7.27 ± 1.55^{i}	4.90 ± 1.13^{f}	2.54 ± 0.93^{cd}	1.90 ± 0.83^{bc}
NME	7.81 ± 0.98^{ij}	6.09 ± 0.70^{gh}	3.18 ± 0.40^{de}	2.09 ± 0.70^{bc}	1.63 ± 0.50^{ab}
FNME	8.72 ± 0.90^{k}	8.27 ± 0.64^{b}	6.45 ± 0.93^{h}	5.63 ± 0.80^{g}	3.81 ± 1.07^{e}
Appearance					
B	8.72 ± 0.46^{g}	7.81 ± 0.98^{ef}	4.90 ± 1.13^{c}	2.54 ± 0.93^{ab}	2.27 ± 0.78^{a}
CE	8.72 ± 0.46^{g}	8.27 ± 0.78^{fg}	6.45 ± 0.82^{d}	5.09 ± 0.83^{c}	3.09 ± 0.70^{b}
NME	8.72 ± 0.64^{g}	7.90 ± 1.04^{f}	5.63 ± 0.80^{c}	4.90 ± 1.04^{c}	3.09 ± 0.94$_{b}$
FNME	8.90 ± 0.30^{g}	8.45 ± 0.82^{fg}	7.27 ± 1.00^{e}	6.36 ± 1.02^{d}	5.18 ± 0.75^{c}
Texture					
B	9.00 ± 0.00^{h}	8.90 ± 0.30^{h}	3.27 ± 1.00^{d}	1.27 ± 0.46^{a}	1.00 ± 0.00^{a}
CE	9.00 ± 0.00^{h}	8.45 ± 0.93^{h}	5.36 ± 1.36^{ef}	3.18 ± 1.07^{cd}	2.09 ± 0.53^{b}
NME	9.00 ± 0.46^{h}	8.72 ± 0.46^{h}	5.72 ± 0.90^{fg}	3.27 ± 0.90^{d}	2.54 ± 0.82^{bc}
FNME	9.00 ± 0.00^{h}	8.90 ± 0.30^{h}	6.18 ± 1.07^{g}	5.63 ± 1.20^{fg}	4.81 ± 1.07^{e}
Overall acceptance					
B	8.72 ± 0.46^{h}	5.81 ± 0.98^{f}	2.54 ± 1.03^{cd}	1.45 ± 0.68^{ab}	1.09 ± 0.30^{a}
CE	8.81 ± 0.40^{h}	7.09 ± 0.94^{g}	3.27 ± 0.90^{d}	3.09 ± 0.60^{d}	2.09 ± 0.53^{bc}
NME	8.63 ± 0.50^{h}	6.00 ± 1.00^{f}	4.54 ± 0.52^{e}	3.18 ± 0.75^{d}	1.81 ± 0.60^{b}
FNME	8.90 ± 0.30^{h}	8.45 ± 0.68^{h}	7.27 ± 1.34^{c}	6.27 ± 1.34^{fg}	4.18 ± 0.98^{e}

Values represent mean ± standard deviation. Values with different letters in superscript are significantly different ($P < 0.05$).
B – control without coating, CE – wrapped in cellophane, NME – coated with nanoemulsion of mustard essential oil, FNME – coated with gelatin/hydroxypropyl-β-cyclodextrin enriched with nanoemulsion of mustard essential oil.

compound in mustard essential oil, is a natural antimicrobial component. According to the previous researches [5, 20], packaging with allyl isothiocyanate has an inhibitory effect on the growth of pathogenic microorganisms in meat. There are some proposed mechanisms for the antimicrobial action of allyl isothiocyanate including interaction with the cell wall or membrane that leads to increased uptake of other antimicrobials, prevention of oxygen absorption, alteration of proteins and inhibition of protective enzymes, which lead to a prolonged lag phase of bacterial populations [21, 30, 31].

The conversion of the essential oil to nanoemulsion enhanced its antimicrobial activity due to the easier access of antimicrobial compounds to the bacterial cells [32]. On the other hand, the nanoemulsions have non-specific and a broad-spectrum of antimicrobial activity against bacteria and fungi, which reduced the appearance of resistant strains [33]. It is noteworthy that encapsulation of the essential oils in cyclodextrins can protect their active compounds from environment, which can increase their functionality. It was reported that encapsulation in HP-βCD increased the antibacterial activity of black pepper essential oil 4-fold against *Staph. aureus* and *E. coli* [34].

Sensory evaluation

Results on sensory evaluation including colour, odour, appearance, texture and overall acceptability of turkey meat samples during storage at 4 ± 1 °C are presented in Tab. 2. Statistical analysis and mean values of obtained results for sensory evaluation revealed that there was a significant difference between treatment and storage time ($P < 0.05$). There were no significant differences between quality criteria including colour, appearance, texture and overall acceptance values of treated and control samples before the day 5 of storage. At the beginning of storage, the odour of NME samples gained low scores, which was probably due to the lower dissolution of the noticeable pungent sulphur odour of mustard essential oil especially because of the low fat content of turkey meat. The results of our research are in line with previous reports about the negative effects of high concentration of mustard seed essential oil on the sensory properties of various foods [29, 35]. Over the storage time, the preservative compounds of mustard essential oil prevented the growth of spoilage microorganisms, breakdown of peptides, reduced oxidation changes and formation of undesirable aromatic compounds such as ammonia, dimethylamine or trimethylamines, and so the sensory scores of the such treated samples increased compared to control. Since day 5, the FNME samples had higher overall acceptability scores during the rest of storage ($P < 0.05$). According to the results, odour, texture and overall acceptability of control and CE samples received unacceptable scores after the day 5, whereas NME and FNME samples received scores "unacceptable" after day 10 and 15, respectively (Fig. 5). It seems that in FNME sample, the extracted mustard essential oil had little irritating odour of allyl isothiocyanate due to the complexing and embedding effects of HP-βC.

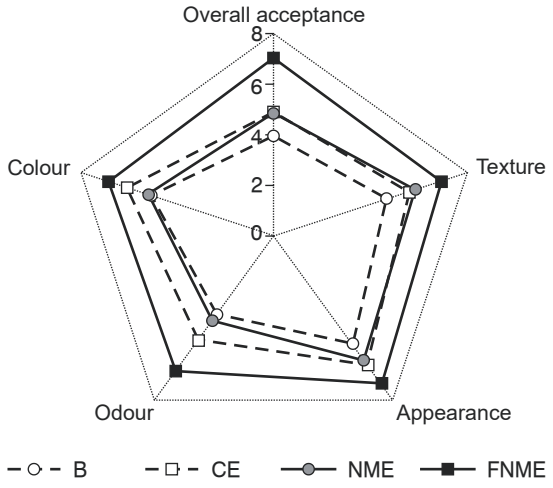

Fig. 5. Radar plot of hedonic sensory evaluation of turkey meat samples.

B – control without coating, CE – wrapped in cellophane, NME – coated with nanoemulsion of mustard essential oil, FNME – coated with gelatin/hydroxypropyl-β-cyclodextrin enriched with nanoemulsion of mustard essential oil.

Overall, FNME samples gained the highest sensory scores and this coating could be considered a way to retard the deterioration of turkey meat. Based on the results of this research, the gelatin/HP-βC coating enriched with nanoemulsion of mustard essential oil formed an attractive surface and was reflected by high acceptance. This novel coating extended the shelf life of NME and FNME samples by approximately 10 and 15 days, respectively. There was a correlation between the sensory evaluation results and results of chemical and microbiological analysis.

CONCLUSIONS

Results of this study demonstrated that coating of turkey meat samples with gelatin/HP-βC enriched with a nanoemulsion of mustard essential inhabited lipid oxidation, delayed microbial

contamination, retard spoilage and prolonged the shelf life of turkey meat samples by approximately 5–10 days compared to the control and cellophane packaging during storage at 4 ± 1 °C. This novel packaging can be considered promising from the aspect of antimicrobial effects regarding spread of spoilage and pathogenic microorganisms by not only meat products but also by other food products. Further investigations on applicability of this bioactive coating on other parts, breeds and meat types and the effects of this coating enriched with other essential oils on meat shelf life are proposed.

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