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Antimicrobial and antioxidant effects of an edible coating of *Lepidium sativum* seed mucilage and *Satureja hortensis* L. essential oil in Uncooked lamb meat

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ABSTRACT

The current research aimed to fabricate an active edible coating, *Lepidium sativum* seeds mucilage (LSSM) loaded with *Satureja hortensis* essential oil (SHEO) (0, 0.5, 1, and 1.5 % (w/w)) for further extension of the shelf life of refrigerated lamb meat during storage for 18 days at (4 °C). The control and the coated lamb meat samples were continually analyzed for microbiological (total count, psychrotrophic count, yeast and mold), chemical (pH, moisture content, PV, and TBA), and sensory characteristics. Consistent with the microbiological analysis, the LSSM incorporated with 1, and 1.5% SHEO caused a significant shelf-life extension of the lamb meat by 15 and 18 days, respectively. These results suggested that (LSSM+1.5%S) sufficiently hindered the overall bacterial growth in the lamb meat sample since the shelf life in this treatment was 12 days more in comparison to the control. Hence, LSSM containing SHEO is very useful as an active packaging in order to preserve the quality and to prolong the lamb meat shelf life at 4 °C.

1. Introduction

Foodborne diseases are globally among the most severe and expensive public concerns, and bacteria tend to be the most widespread reasons for these types of poisonings and infections (Nyachuba, 2010). In addition to pathogenic bacteria, reactive oxygen species (ROS) take part in the emergence and development of many diseases such as cancer (Ashok & Ali, 1999; Bhattacharyya, Chattopadhyay, Mitra, & Crowe, 2014; Ercolano, De Cicco, & Ianaro, 2019). Most of these ROS-associated and harmful compounds are formed by food oxidation in the high-value product such as meat (Gupta, et al., 2014; X. Huang & Ahn, 2019; Ribeiro et al., 2019). Fresh meat is among the most sensitive foods that can be immediately exposed to microbial and chemical degradation when stored because they contain valuable proteins, various vitamins, a suitable pH, and high moisture content (Pereira & Vicente, 2013). Studies show that various methods like using many synthetic additives used to protect and increase the shelf life of red meat cause side effects such as carcinogenesis and quality changes, due to this reason fresh meat offered to consumers is less accepted by people and the demand for natural food additives of plant origin has increased (Lorenzo, et al., 2018; Nikmaram et al., 2018). That is to say, the antimicrobial properties of plants have been considered from the past, and thriving plant remedies have been applied for many years as traditional medicines in different countries around the world. On the other hand, using modern methods has made it possible to identify these plants' therapeutic effectiveness (Cowan, 1999; Swamy, Akhtar, & Sinniah, 2016). In the present study, *Satureja hortensis* essential oil was used to increase the shelf life of meat. *Satureja hortensis* L., famous as the summer savory, is a part of the Lamiaceae family. The phenolic compounds of several plants belong to this genus have outstanding antimicrobial and antioxidant activity (Fierascu, et al., 2018). The direct application of Essential oils onto the meat surface reduces their efficacy and may create undesirable organoleptic (Adorjan & Buchbauer, 2010). With this in consideration, the use of films and edible coatings as a carrier of antimicrobial substances like essential oils and extracts are of great interest, and the best results are related to using them (Ganiari, Choulitoudi, & Oreopoulou, 2017; Sánchez-González, Vargas, González-Martínez, Chiralt, & Chafer, 2011). The use of biopolymers as active packaging materials containing antimicrobials is beneficial not only because they are edible, biodegradable, preserving nutritional value, non-toxic and inexpensive, but they may also increase control during release and stability of bioactive compounds of essential oils (Cutter, 2006; Hassan, Chatha, Hussain, Zia,

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& Akhtar, 2018). The *Lepidium sativum*, universally known as "Garden Cress", is a part of the Brassicaceae family. It has seeds that are valuable sources of nutrients and phytochemicals. In addition to several therapeutic properties, many researchers have explored the functional properties of crude hydrocolloid extraction (Doke & Guha, 2014). The functions, physical, and chemical characteristics of *Lepidium sativum* seed mucilage have made it one of the excellent options for biofilms and edible coatings (Razmkhah, Mohammadifar, Razavi, & Ale, 2016). To date, no study has been directed toward LSSM edible coating merged with SHEO to ameliorate the shelf-life of lamb meat (thighs).

2. Materials and methods

2.1. Materials

The utilized culture medium and chemicals in the analytical grade were supplied from Merck Co. Germany and Sigma-Aldrich, USA. *S. hortensis* essential oil was procured from Barij Essence Pharmaceutical Company in Kashan, Iran, and the mucilage powder of *Lepidium sativum* seeds was supplied from the Food Hydrocolloid Co. in Mazandaran, Iran.

2.2. Determination of the chemical composition of the SHEO

The quantities of the main constituents and the other bioactive properties of SHEO were specified by Gas Chromatography/Mass Spectrophotometer (TRACE MS, Thermo Quest-Finnigan) (Küçükbay, Kuyumcu, Azaz, Arabacı, & Yücetürk, 2014).

2.3. Content of total phenolic and antioxidant potential of the SHEO

The Folin-Ciocalteau technique determined the total phenolic compound content (Singleton, Orthofer, & Lamuela-Raventós, 1999), and the method of Brand-William et al., (1995) with DPPH was utilized for the calculation of the antioxidant potential of SHEO (Brand-Williams, Cuvelier, & Berset, 1995).

2.4. Antimicrobial activity of the SHEO in vitro

The antimicrobial activity was specified using the agar diffusion technique (well and disc) based on the CLSI protocol against four microbial strains, including *Escherichia coli* ATCC 25922, *Pseudomonas fluorescens* OS8, *Staphylococcus aureus* ATCC 25923, and *Alternaria alternata* PTCC 5224. To determine the minimum inhibitory concentration (MIC), the broth microdilution method was used in a sterilized 96-well plate (Wayne, 2011). The MBC/MFC defines the lowest level of SHEO as an antimicrobial agent that results in microbial death (Mihajilov-Krstev, Radnović, Kitić, Stojanović-Radić, & Zlatković, 2010).

2.5. Preparation of lamb meat and coating the meat samples

The studied lamb meat (thigh) was bought from a resident market (Mashhad, Khorasan Razavi, Iran) and transported to the laboratory of industrial microbiology. First, it was sliced into equal pieces, weighing about 50 g. These thighs were thoroughly washed with water that was previously sterilized and cooled to reduce its microbial load while removing the waste. Next, the coating process was performed with the LSSM. So, the edible coating solution of LSSM was prepared from a mixture of 5 g of powder made from the LSSM with 1.84 g of Tween 80. After preparing and cooling the solution, the antimicrobial essential oil was inserted into the solution with a range of concentrations (0, 0.5, 1, and 1.5% w/w). The slices of meat were divided into five sets at random: a control sample, mucilage-coated meat sample (LSSM), mucilage+0.5% SHEO (LSSM+0.5%S), mucilage-coated meat sample+1% SHEO (LSSM+1%S), and mucilage-coated meat sample + 1.5% SHEO (LSSM+1.5%S). Each of the meat samples was immersed in the solution at ambient temperature for 1 min and then removed. After there were no more droplets, the solution was hung from a sterile plate and was exposed to mild airflow. One sample was considered to be the control sample. After drying, the samples were transferred to a refrigerator for various chemical, microbiological, and sensory characteristics of lamb meat samples and stored at 4 °C for 18 days (Alizadeh Behbahani & Imani Fooladi, 2018).

2.6. Measurements of the chemical composition of LSSM and lamb meat

The measurements of moisture content, ash, protein, and fat of lamb meat and carbohydrates of LSSM were performed according to the AOAC official methods (1990) (AOAC, 1990).

2.7. Microbiological analysis

Five grams of each meat sample was homogenized by grinding in sterile conditions with 45 ml of peptone water 0.1% for 1 min. Then, other dilutions were formulated in tubes containing peptone water 0.1%, and from each dilution, the medium was cultured on plates with the use of the pour plate method. The growth and count of total viable bacteria, psychotropic bacteria count, mold and yeast, *Escherichia coli* and *Staphylococcus aureus* were carried out based on the logarithms of the number of colony-forming unit per gram (LogCFU/g) (Roberts & Greenwood, 2008).

The media and condition of microbial tests as follows.

a. Plate count agar for total viable bacteria count (incubation at 37 °C for 24 h).
b. Plate count agar for psychrotrophic count (at 7 °C for 10 days).
c. Sabouraud dextrose agar for mold and yeast count (incubation at 27 °C for 72 h).
d. Eosin methylene blue for *Escherichia coli* count (incubation at 37 °C for 24 h).
e. Manitol salt agar for *Staphylococcus aureus* count (incubation at 37 °C for 24 h) (Jouki, Yazdi, Mortazavi, Koocheki, & Khazaei, 2014).

2.8. pH and moisture content measurements

Following the method of AOAC official methods (1990), the pH and moisture content of each treatment was measured.

2.9. Peroxide value (PV) and 2-thiobarbituric acid (TBA) measurements

To measure of PV (meq oxygen/kg lipid) and TBA values (mg malonaldehyde/kg beef) of the lamb meat, the method of Egan, Kirk, and Sawyer (1981), was exploited (Egan et al., 1981).

2.10. Sensory evaluation

The lamb meat samples sensory characteristics (color, odor, and overall acceptance) were evaluated by a 5-person panel trained using 9-point hedonic scale (1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, 9 = like extremely). Sensory evaluation was achieved with similar temperature and light conditions (Fan, et al., 2009).

2.11. Statistical design and data analysis

Statistical analysis was performed in a randomized design with factorial arrangements. The results were analyzed using one-way ANOVA followed by Duncan's multiple tests ($p \leq 0.05$) using the SPSS 20.0 statistical software. The correlation coefficients (r) were obtained between various characteristics of lamb meat samples. All experiments were done on days 0, 3, 6, 9, 12, 15, and 18 in triplicates.

3. Results and discussion

3.1. The composition of essential oil

The result of analysis of SHEO by GC-MS is presented in Fig. 1. According to the analysis of SHEO, 16 compounds were identified, and the major constituents are *Isopropyl Myristate* (59.14%) and *Carvacrol* (37.83%) as shown in Table 1. In addition, other main compounds including *Para*-Cymene (0.44%), *Thymol* (0.33%), *Isopropyl Dodecanoate* (0.1%) and *Limonene* (0.1%) were dominant compounds. The variableness in the volatile compositions of the essential oil from one another could be attributed to many different factors like genetic and ecological factors that can affect the antimicrobial and antioxidant potential of therapeutic plants (Sefidkon, Abbasi, & Khaniki, 2006).

3.2. Antioxidant activity and TPC

The total phenolic compounds in SHEO were 253.95 mg/ml GAE. DPPH free radical scavenging activity reflects the ability of SHEO oil in hydrogen donation. The radical scavenging capacity of SHEO was presented as IC50, equal to 11.638 μg/ml. Regarding the results, by increasing the total phenolic compounds in SHEO, the IC50 decreases, and antioxidant activity increases (Alizadeh, et al., 2010).

3.3. Antimicrobial activity "in vitro."

3.3.1. Antimicrobial effect of S.hortensis EO through the DDA and WDA method

The comparison of results between the WDA and DDA method is described briefly. The average zone of inhibition in the DDA method for Gram-negative bacteria, *Staphylococcus aureus*, and *Alternaria alternata* was equal to 9.7, 12.3, and 10.76 mm, and for Gentamycin, Vancomycin, and Amphotericin B, as a positive control, was equal to 13, 16.25, and 11.3 mm, respectively. The average zone of inhibition in the WDA method for Gram-negative bacteria, *Staphylococcus aureus*, and *Alternaria alternata* was equal to 35.87, 14.11, and 10.49 mm, respectively. No significant differences were detected between the results of the WDA and the DDA method. However, the average inhibition zone for DDA was lower compared to the WDA method. Gram-positive bacteria's highest sensibility in comparison with Gram-negative is because of the difference in their cell wall, which many researchers (L. Huang et al., 2012).

Table 1
Compounds identified using gas chromatography mass spectrometry (GC-MS).

NO	Compound name	%	KI[a]
1	α-Pinene	0.04	934
2	Camphene	0.02	950
3	p-Cymene	0.44	1026
4	Limonene	0.1	1030
5	1,8-Cineol	0.8	1033
6	Terpinene (gamma)	0.04	1059
7	p-Allylanisole	0.87	1204
8	Thymol	0.33	1305
9	Carvacrol	37.83	1322
10	Spathulenol	0.07	1584
11	Isopropyl dodecanoate	0.1	1628
12	Tridecanoic acid	0.04	1727
13	Isobicyclogermacrenal	0.04	1743
14	Isopropyl Myristate	59.14	1838
15	n-Nonadecane	0.02	1898
16	Isopropyl Palmitate	0.12	1024

[a] KI: The Kovats retention indices relative to n-alkanes were determined on DB5column capillary column.

3.3.2. Microbial inhibition and bactericidal/fungicidal by single antimicrobials

According to our preliminary findings, the lowest concentration of the SHEO on *Escherichia coli, Pseudomonas fluorescens, Staphylococcus aureus,* and *Alternaria alternata* was respectively equal to 2, 1, 0.5, and 1 mg/ml. Also, the results showed that SHEO at concentrations of 4, 2, 1, and 1 mg/ml had a bactericidal and fungicidal effect on *Escherichia coli, Pseudomonas fluorescens, Staphylococcus aureus,* and *Alternaria alternata*, respectively.

3.4. Microbial properties

3.4.1. Total viable count (TVC)

Changes in the value of TVC of the lamb meat in different groups during refrigerated storage (18 days) are presented in Fig. 2A.

The TVC initial value was low (3.71 log CFU/g), pointing to acceptable quality. Similar low enumerations were reported (Behbahani

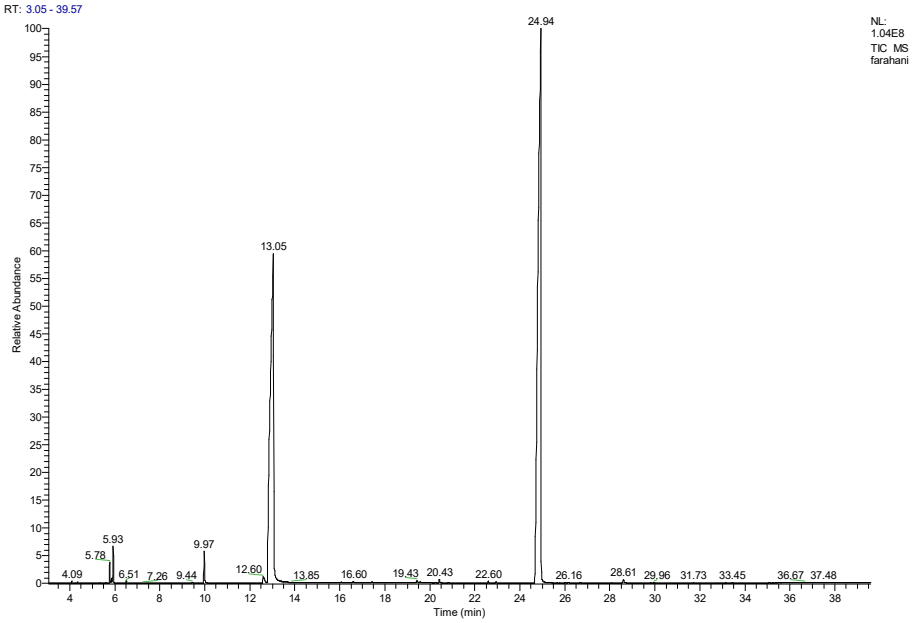

Fig. 1. Chromatography of the *Satureja hortensis* essential oil.

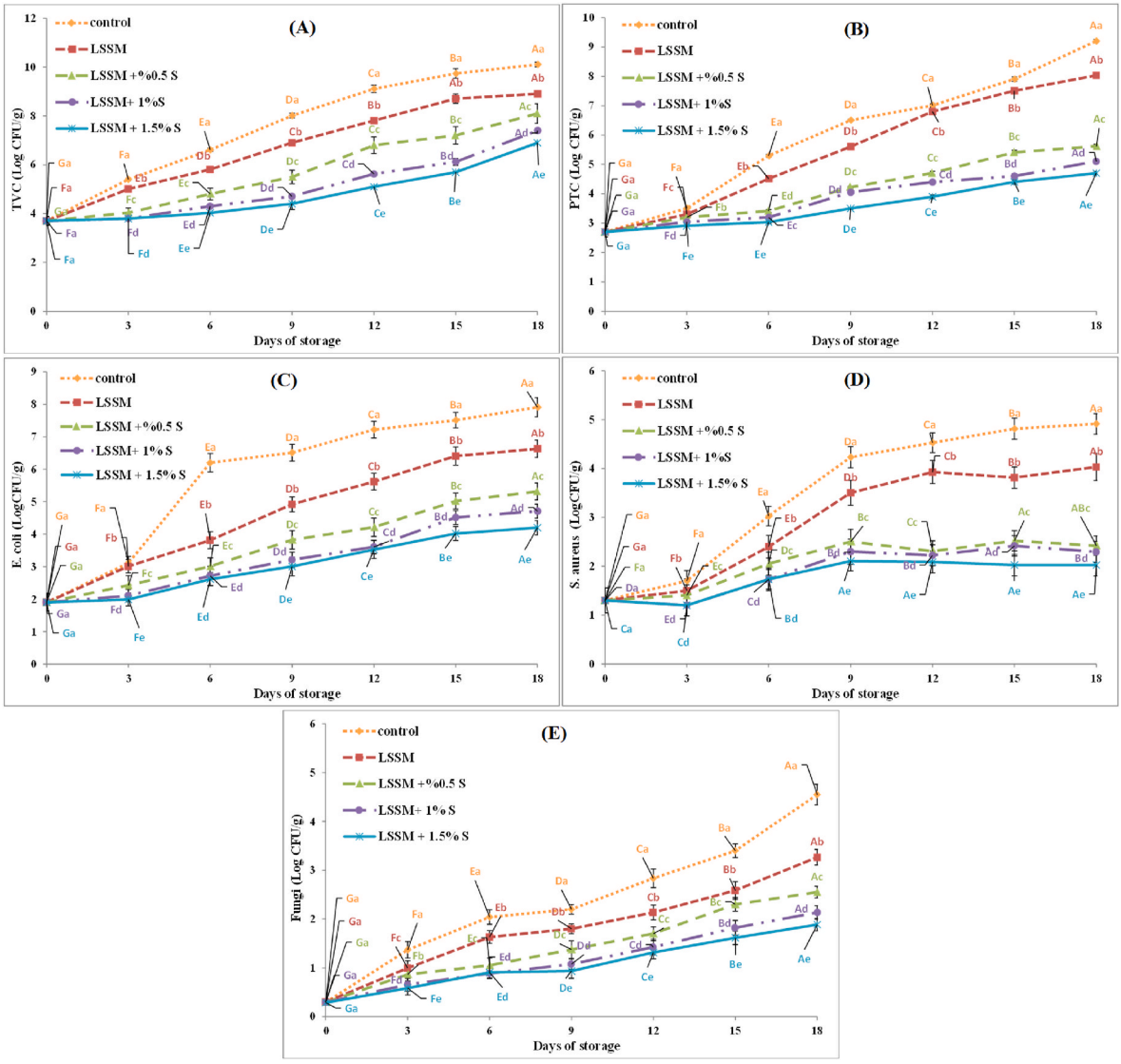

Fig. 2. Total viable count (A), psychrophilic bacterial count (B), *Escherichia coli* (C), *Staphylococcus aureus* (D), and Fungi (E) of lamb meat samples during storage at (4 °C) for 18 days. (Control: uncoated sample, LSSM: samples coated with LSSM, LSSM + S: samples coated with LSSM and incorporated with various concentrations of *S.hortensis* essential oil). Means with the different lowercase letters in the same day and uppercase letters in the same treatment are significantly different according to ANOVA test ($p < 0.005$).

and Fooladi, 2018). Microbial load gradually increased with storage time. The statistical analysis of the TVC specified that there was a significant difference observed among all samples (LSSM, LSSM+0.5%S, LSSM+1%S, LSSM+1.5%S) compared to the control during 18 days of storage. The 9th day of storage results showed that TVC in the control sample was higher than the maximum acceptable limit (7 log CFU/g) of fresh meat; thus, the microbial shelf-life of the control was about six days (ICMSF, 1978). Generally, the edible antimicrobial coating grounded on LSSM, including diverse concentrations of SHEO (LSSM+0.5%S, LSSM+1%S, LSSM+1.5%S) significantly inhibited bacterial growth and prolonged the shelf-life of refrigerated fresh lamb meat treatments compared to the control. However, in the lamb meat samples coated with 1.5% of *S.hortensis* (LSSM+1.5%S), there was a noteworthy reduction of total viable counts, and it did not exceed the International Commission of Food Microbial Standard's acceptable limit of 7 log CFU/g during the entire storage (ICMSF, 1978). The maximum shelf-life of the lamb meat samples (LSSM+0.5%S) (LSSM+1%S) and (LSSM+1.5%S) was equal to 12, 15, and, 18 days, respectively. The obtained results were following other studies (Siripatrawan & Noipha, 2012; Vásconez, Flores, Campos, Alvarado, & Gerschenson, 2009).

3.4.2. *Psychrotrophic count*

Variations in the value of the Psychrotrophic count (PTC) of the lamb meat in different groups during refrigerated storage (18 days) appear in Fig. 2B. As expected, by increasing the meat storage time, bacterial growth in all treatments increased significantly ($p < 0.05$). This increase was more severe in the control sample so that the primary psychrotrophic bacteria counts were 2.71 log CFU/g, and on the 6th and 18th days of storage, psychrotrophic bacteria counts were 5.3 and 9.2, respectively. An increase in the microbial growth in the other treatments had a slower slope than the control sample. The results indicated that the higher concentration of SHEO (1.5%) in LSSM coating, was also the most efficient for the inhibition of the growth of psychrophilic bacteria in a lamb meat sample over the storage time, and this was consistent with other studies (Andevari & Rezaei, 2011; Zengin & Baysal, 2015).

Pseudomonas spp. are strictly aerobic microorganisms which are not capable of surviving without oxygen. LSSM, as oxygen barriers inhibit the growth of *Pseudomonads*. McMillin (2008) reported that high oxygen content in the package increases *Pseudomonas* bacteria's growth rate. *Pseudomonads* reduce meat quality by producing extracellular lipase and protease. By decreasing the oxygen penetration into the surface layers of

lamb meat coated with mucilage, the growth of psychrotrophic bacteria cells has been primarily controlled (McMillin, 2008).

3.4.3. *Escherichia coli and Staphylococcus aureus count*

The initial count of *E. coli* and *S. aureus* were approximately 1.9 and 1.3 log CFU/g, and as it was expected, it was gradually amplified to 7.9 and 4.9 log CFU/g on the 18th day, respectively Fig. 2C and 2D. The statistical analysis determined that incorporating the *S.hortensis* essential oil into LSSM coating may enrich the antimicrobial and antioxidant properties of the coating and this is a promising means of controlling *E. coli* and *S. aureus* growth on lamb meat samples during refrigerated storage.

3.4.4. *Total yeast and mold (fungi) counts*

These changes are revealed in Fig. 2E. The statistical analysis shows that the fungi growth on lamb meat throughout the storage period in the control sample was the highest and had a significant variation compared to other treatments ($p < 0.05$). The initial count of the total fungi was very low and equal to 0.3 log CFU/g, which increased throughout storage and went to 4.4, 3.4, 2.6, 2.1, and 1.9 logs CFU/g in the control and the lamb meat coated with (LSSM), (LSSM+0.5%S), (LSSM+1%S), and (LSSM+1.5%S) on the 18th day, respectively.

3.5. *Chemical properties*

3.5.1. *Chemical composition of LSSM and lamb meat*

Based on the results, the moisture content, protein, fat and total ash were equal to 72.71, 18.6, 4.51, and 1.6% for lamb meat and 3.88, 7.5, 2.5, and 18 as well as 68.12% total carbohydrate for the seeds mucilage, respectively. The results were, in part, correlated with the results of other researchers (Arsenos, et al., 2007; Karazhiyan et al., 2011).

3.5.2. *pH*

Fig. 3A portrays the variations of pH values. Throughout the storage period, the pH value is influenced by the changes in the nitrogen compounds and bacterial activity. The maximum acceptable pH for fresh meat is 5.2–5.8. The initial pH of the meat samples (0 days) was equal to 5.7. This value increased to 6.93 on the 18th day. The results suggested that pH changes during the storage period had a growing trend that was chiefly because of microbial and enzymatic activity. The results revealed that the pH of samples (LSSM), (LSSM+0.5%S), (LSSM+1%S), and (LSSM+1.5%S) after 18 days of storage in the refrigerator was 6.2, 5.9, and 5.6, respectively. These results are attributed to the antimicrobial properties of SHEO and the coating based on LSSM.

Gill (1983) stated that after consuming the stored glucose, bacteria's use of amino acids derived from protein degradation and ammonia accumulation results in this pH increasing (Gill, 1983). Moreover, it was stated that the meat pH is a significant and effective factor in the essential oil activity so that low pH improves the hydrophobicity of the essential oils (Caetano, Hessel, Tondo, Flôres, & Cladera-Olivera, 2017Caetano, Hessel, Tondo, Flôres, & Cladera-Olivera, 2017; Chen, Lin, Lin, & Jen, 2018; da Silva, Bernardes, Pinheiro, Fantuzzi, & Roberto, 2021). Consequently, the essential oil exhibits a stronger antimicrobial activity in meat (Djenane, Yangüela, Montañés, Djerbal, & Roncalés, 2011). The carbon dioxide was produced by meat respiration and its microbial activity. The presence of some essential oils and plant extracts in the film and edible coatings reduces or enhances the dissolution of carbon dioxide in the film or coatings, affecting their permeability to this gas. The presence of SHEO in the edible mucilage reduces the permeability. Consequently, with an increase in the concentration of carbon dioxide, the pH is reduced, which also affects the reduction of microbial flora (Bifani, et al., 2007).

3.5.3. *Peroxide value*

Fig. 3B displays the variations of PV values of the lamb meat samples.

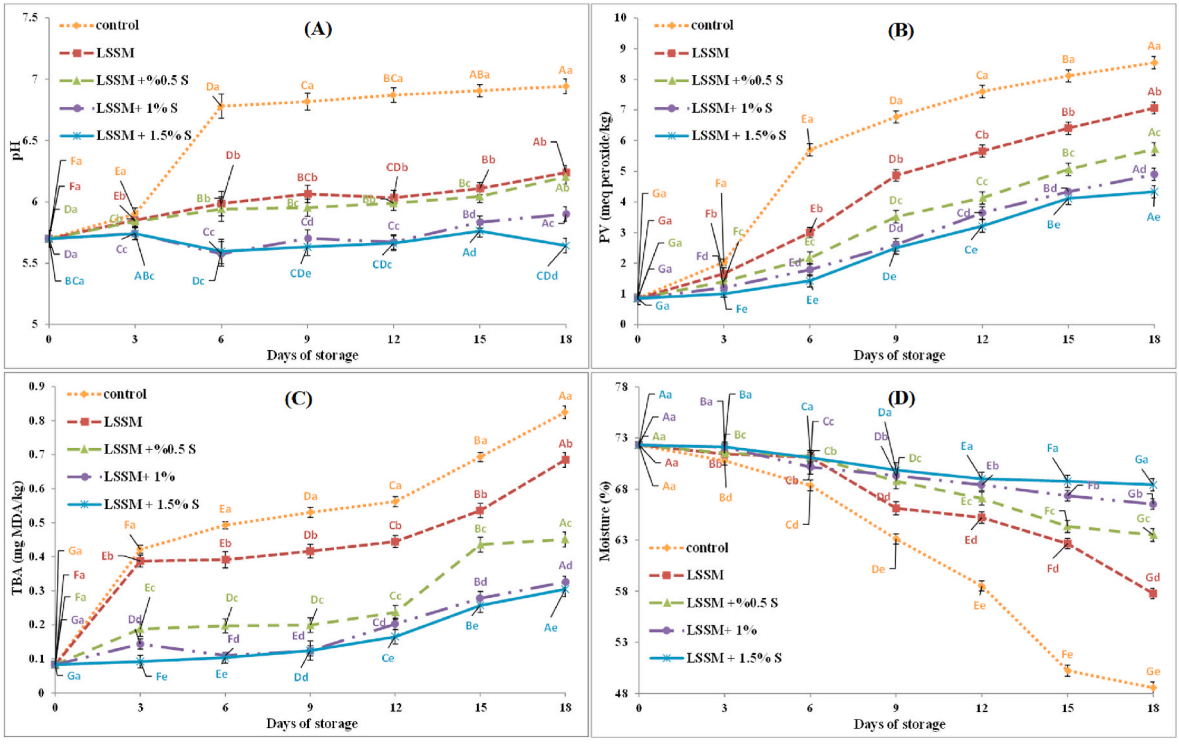

Fig. 3. Changes in pH (A), Peroxide values (B), TBA values (C), and Moisture content (D) of lamb meat samples during storage at (4 °C) for 18 days. (Control: uncoated sample, LSSM: samples coated with LSSM, LSSM + S: samples coated with LSSM and incorporated with various concentrations of *S.hortensis* essential oil). Means with the different lowercase letters in the same day and uppercase letters in the same treatment are significantly different according to ANOVA test ($p < 0.005$).

The initial PV in the analyzed lamb meat samples was equal to 0.85 meq peroxide/kg meat sample. Increasing the essential oil supply might decrease oxygen in the area. Subsequently, the contact between its surrounding air and fatty substance will decrease. As a result, lipid oxidation decreases. The sample comprising 1.5% essential oil had the lowest peroxide values, and 1.5% of SHEO in lamb meat coated with (LSSM+1.5% S) was the lowest PV, 4.33 meq peroxide/kg.

Based on the phenolic compounds and the antioxidant activity of SHEO and LSSM, there is a delay in the oxidation of meat samples throughout the storage period (18 days) can be ascribed to their phenolic content. These results were in line with other studies (Hasanzati Rostami, Motallebi, Khanipour, Soltani, & Khanedan, 2010; Kang et al., 2007).

3.5.4. Thiobarbituric acid (TBA)

Fig. 3C presents the variations of TBA values of the lamb meat. According to the International Standard for Food, the threshold value for thiobarbituric acid in meat is 1 mg MDA/Kg. TBARS in control increased from an initial level of 0.083–0.82 mg malonaldehyde/kg on the 18th day. This was significantly higher than the other treatments ($p < 0.05$). In this study, generally lower production of TBA index in the lamb meat coated with (LSSM), (LSSM+0.5% S), (LSSM+1% S), and (LSSM+1.5% S) may be related to 1) Existence of phenolic compounds in SHEO and their potent antioxidant and free radical scavenging activities which disrupt free radical propagation advance. 2) Proper oxygen barriers of coating based on LSSM to oxygen permeation. As expected, the lowest TBA level was for the lamb meat coated with (LSSM+1.5% S) during storage and equal to 0.30 mg malonaldehyde/kg on the 18th day. Duo to the high percentage of SHEO (1.5%), it has been able to delay the production of secondary oxidation products and lessen the slope of TBA changes compared to the other treatments (Madsen, Andersen, Christiansen, Brockhoff, & Bertelsen, 1996). The free radicals scavenging activity, decreasing lipoxygenase, and the metal chelating activity are all influenced by the phenolic compounds of SHEO. This coincided with other results (Madsen, et al., 1996).

3.5.5. Moisture content

Fig. 3D presents the variations of moisture values of the lamb meat. Fresh meat has about 68–78% moisture content. The initial moisture content of the meat sample was 72.3%. This was about 48.5% on the 18th day of storage, and it was 57.7%, 63.5%, 66.5%, and 68.4% in other lamb meat coated samples with (LSSM), (LSSM+0.5%S), (LSSM+1%S), and (LSSM+1.5%S), respectively. As can be seen in the results of the analysis of variance, there were significant differences ($p < 0.05$) in moisture content between control and the other coated treatments. The pH changes, meat tissue decomposition by microorganisms, and other changes have an active role in reducing the meat's ability to maintain moisture. Regarding the results, the lower decrease in moisture content in the treatments (LSSM, LSSM+0.5%S, LSSM+1%S, LSSM+1.5%S) over time can be attributed to the presence of the mucilage coating of *Lepidium sativum* seeds and the presence of effective compounds in SHEO. This is a promising means of controlling moisture by restraining water evaporation from the surface and prolonging the shelf-life (Singh, Langowski, Wani, & Saengerlaub, 2010). Also, the essential oil has a significant effect in reducing weight loss by increasing the resistance to water vapor permeability. Vascons et al. (2009) evaluated and compared the weight loss in salmon coated with chitosan film compared with a control sample. They stated that the coated Salmon meat samples stored moisture and compared to the control sample reduced the weight loss from 17.8% in the control sample to 12.4% in the coated samples (Vásconez, et al., 2009).

3.6. Sensory evaluation

The organoleptic qualities of lamb meat samples are displayed in Fig. 4. At first and on the zero-day, the results here indicated that the sensory characteristics of meat (color, odor, and overall acceptance) were superior to other groups. On the 6th day, all three indexes

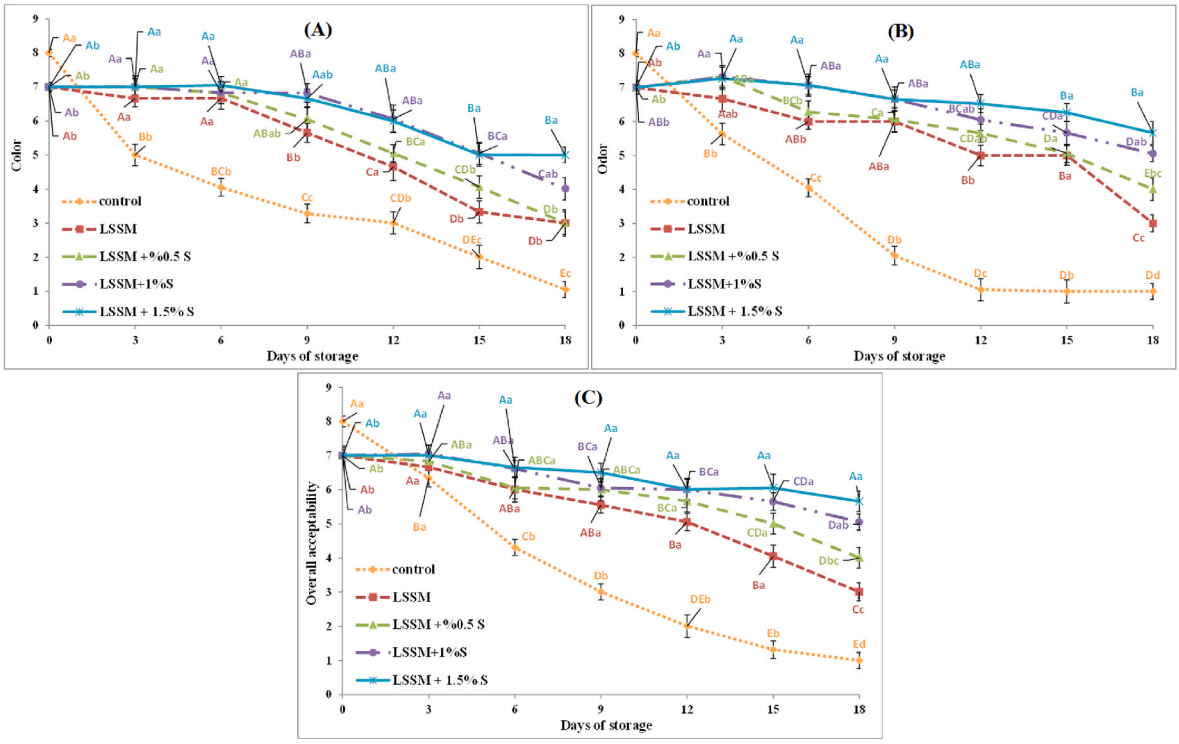

Fig. 4. Evaluation of lamb meat color (A), odor (B), and overall acceptability (C) of lamb meat samples during storage at (4 °C) for 18 days. (Control: uncoated sample, LSSM: samples coated with LSSM, LSSM + S: samples coated with LSSM and incorporated with various concentrations of *S.hortensis* essential oil). Means with the different lowercase letters in the same day and uppercase letters in the same treatment are significantly different according to ANOVA test ($p < 0.005$).

attenuated in the control sample, which is consistent with the increase in microbial growth and corruption indexes on this day. The decline continued with an increasing trend on the 9th, 12th, 15th, and 18th days so that all three sensory factors in this group were less than acceptable (Behbahani, Shahidi, Yazdi, Mortazavi, & Mohebbi, 2017; Jouki, Mortazavi, Yazdi, Koocheki, & Khazaei, 2014). Therefore, based on the results obtained from overall acceptability, the maximum shelf-life of the control and the covered lamb meat samples (LSSM), (LSSM+0.5%S), (LSSM+1%S), and (LSSM+1.5%S) was equal to 6, 15, 15, 18, and 18 days. According to the findings, it seems that intensifying the SHEO concentration from 0.5 to 1.5% in the LSSM-coated samples is desirable for the referees. Furthermore, the results of the sensory tests (odor) demonstrated that the lamb meat coated with (LSSM+1%S) and (LSSM+1.5%S) were extremely favorable by the panelists. This is due to the suitable concentration of SHEO in the lamb meat samples, which not only adds a favorable aroma of essential oil but also provides results that are in great accordance with the oxidative and microbial results (Cutter, 2006). By increasing the storage time, the treatments' sensory scores were reduced, but what is noteworthy in this study is that the referees gave acceptable sensory scores throughout the maintenance period to the coated treatments (containing essential oils). Using LSSM in combination with the SHEO, in addition to postponing the microbial and chemical degradation of meat and increasing its shelf-life, increased the sensory properties of meat and led to durability and acceptance of samples (LSSM+1%S and LSSM+1.5%S) for 18 days. Latoa et al., (2014) reported that chicken fillets coated with chitosan, packed in a modified atmosphere, retained sensory properties at an acceptable level for up to 14 days (Latou, Mexis, Badeka, Kontakos, & Kontominas, 2014). Vasilatus et al., (2013) reported the effect of chitosan and rosemary essential oils on increasing turkeys' shelf life in refrigeration temperature, improved sensory properties such as flavor and odor (Vasilatos & Savvaidis, 2013).

3.7. Correlation between chemical, microbial, and organoleptic properties of lamb samples

According to the results in Fig. 5, it was found that the linear correlation among all the variables has a fair number. The linear relationship between the sensory test variables (color, odor, and overall acceptance) and moisture content, with the other variables, was negative as shown in the heatmap analysis. This indicates an inverse relationship among these variable with the others.

4. Conclusion

Our results display the considerable antimicrobial and antioxidant potential of the SHEO. Based on the chemical compounds distinguished in the SHEO, these components can be utilized as an essential cost-effective source in chemical and pharmaceutical industries. This study revealed that the LSSM is containing SHEO boosted the lamb meat shelf-life at 4 °C by inhibiting microbial spoilage and lipid oxidation and preserving the quality. The results exhibit that the effect of LSSM+1.5% S covering on the lamb was to preserve the meat's worthy characteristics. This was backed by the findings in microbiological, chemical, and sensory evaluation.

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CRediT authorship contribution statement

Mina Farahani: Methodology, Data curation, Writing – original draft, preparation. **Fakhri Shahidi:** Conceptualization, Supervision, Formal analysis. **Farideh Tabatabaei Yazdi:** Project administration, Resources, Validation. **Abdurrahman Ghaderi:** Software, Writing – original draft.

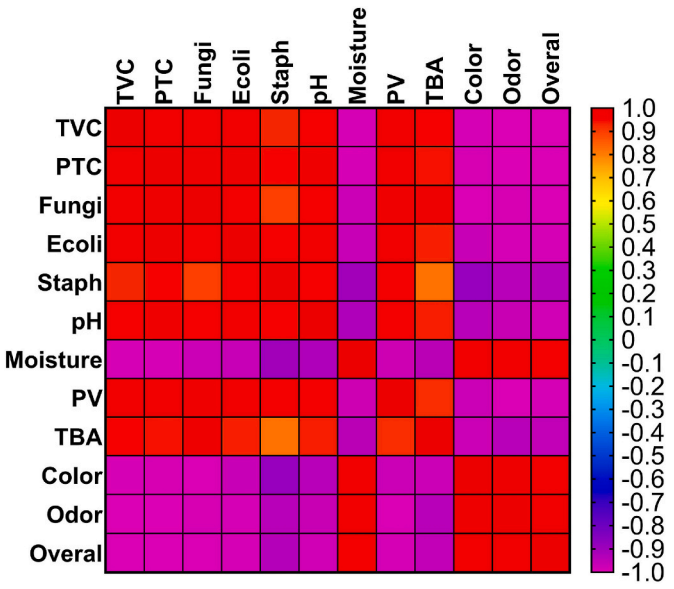

Fig. 5. Heatmap of correlation analysis (Pearson) among microbiological, physicochemical and sensory attributes.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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