

Chemical, Microbiological, and Sensory Analysis Benefits Leading to Shelf-Life Extension of Minced Beef Meat Using Essential Oil of Oregano Contained in Xanthan Gum and Guar Gum Edible Coating

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Abstract:

In the present study, the effect of oregano essential oil, which is contained in xanthan gum and guar gum edible coating, was investigated in regard to its ability to assist with the preservation and the extension of the shelf life of minced beef meat when stored at 4 °C. Minced beef meat samples were coated with a mixture of xanthan gum and guar gum containing oregano essential oil at various levels (1?3%). The coated samples were compared with the control sample (uncoated) for bacteriological (i.e., total viable count, coliforms, and Enterobacteriaceae), physicochemical (pH), and sensorial properties (color and odor) on specific storage days (0, 3, 6, 9, and 12). There was greater microbial growth noted in the uncoated minced beef meat in comparison to the coated ones. Odor, color, and overall acceptability were significantly improved in the coated samples ($p < 0.05$). The chemical, bacteriological, and sensory analyses that were performed, evidenced the benefits that edible coating with oregano essential oil may have on the shelf life and quality of minced beef meat.

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Article

Chemical, Microbiological, and Sensory Analysis Benefits Leading to Shelf-Life Extension of Minced Beef Meat Using Essential Oil of Oregano Contained in Xanthan Gum and Guar Gum Edible Coating

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Abstract: In the present study, the effect of oregano essential oil, which is contained in xanthan gum and guar gum edible coating, was investigated in regard to its ability to assist with the preservation and the extension of the shelf life of minced beef meat when stored at 4 °C. Minced beef meat samples were coated with a mixture of xanthan gum and guar gum containing oregano essential oil at various levels (1–3%). The coated samples were compared with the control sample (uncoated) for bacteriological (i.e., total viable count, coliforms, and Enterobacteriaceae), physicochemical (pH), and sensorial properties (color and odor) on specific storage days (0, 3, 6, 9, and 12). There was greater microbial growth noted in the uncoated minced beef meat in comparison to the coated ones. Odor, color, and overall acceptability were significantly improved in the coated samples ($p < 0.05$). The chemical, bacteriological, and sensory analyses that were performed, evidenced the benefits that edible coating with oregano essential oil may have on the shelf life and quality of minced beef meat.

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1. Introduction

Minced beef meat is one of the most perishable food products. Therefore, an extension of its shelf life for a further 2–3 days would allow for a significant economic impact generated by a possible expansion of the market, as a result. Minced beef meat shelf life is generally shorter than that of the whole meat and is limited by several factors, such as discoloration or microbiological deterioration [1]. The minced meat shelf life can, however, be naturally increased by using an edible coating with the addition of essential oils—which is an efficient and eco-friendly method to maintain and enhance its quality and safety. Edible coating films are developed from proteins, polysaccharides, etc. and have proven to be excellent moisture barriers [2]. Edible proteins, such as gelatin films are used for the packaging of meat products [3–6]; this is because their use on meat products leads to minimizing effects related to moisture loss, lipid oxidation, discoloring, and water drippage [7]. Additionally, edible coatings using polysaccharides are generally very hydrophilic, thereby leading to poor water vapor and gas barrier properties; as such, coating films can prevent the exchange in the transfer of gasses (O₂ and CO₂) as well [8]. Nowadays, carrageenan and alginates are used for producing edible films and coatings for various meat products, such as in meat, poultry and fish, thereby utilizing their ability to improve the end product and consequently in satisfying the demanding consumer preferences [9]. Generally, polysaccharide films also have a structural stability advantage and adhesiveness, which is why researchers also direct great attention to other polysaccharide films, such as gums [10].

Guar gum is a water-soluble polysaccharide that is extracted from *Cyamopsis tetragonolobus*. It is characterized by its high viscosity in an aqueous solution even at low concentrations [11]. Xanthan gum is an exopolysaccharide, which is produced by *Xanthomonas campestris*, and is characterized by its high viscosity in cold and hot water at low concentrations; further, it presents high stability over a wide range of pH and temperatures. Additionally, it also presents a resistance to enzymatic degradation [12]. However, such edible coating films do not confer antimicrobial properties to the final product, therefore they do not extend its shelf life.

The addition of essential oils with antioxidant and/or antimicrobial properties in the edible coatings may maintain product quality [13,14]. Further, different edible coating films with extracts and/or essential oils (such as ginger, green tea, cloves, bilberry, etc.) have been used in meat and meat products (i.e., poultry, beef, fish, and sausages) with satisfactory results in terms of extending their shelf life [15–19]. The films that have been previously used presented high antimicrobial and antioxidant activity, therefore leading to an extended shelf life for the end products [20].

The antimicrobial activity of oregano essential oil against food-borne pathogens is due to its high content in phenolic compounds, such as thymol and carvacrol [21]. Oregano essential oil at various concentrations (0.05%, 0.5%, and 1%) may delay the growth of microorganisms and therefore minimize the microbial spoilage profile of the product [22].

The aim of this study was to evaluate the effect of coating with guar gum, xanthan gum, and oregano essential oil on the physicochemical, bacteriological, and sensorial changes in minced beef meat when it is stored at 4 °C. Further, the study aimed to also evaluate the possibility of these coatings extending the minced beef meat's shelf life. So far, there are studies related to edible coatings with various antimicrobial agents on various food products. However, there has not been as many for minced beef meat specifically or on the use of guar gum and xanthan gum as a coating material in combination with essential oils. As such, the contribution of this study is to highlight the use of a low cost, biodegradable, and antimicrobial coating, based on guar gum and xanthan gum with oregano essential oil, as an alternative to extending the shelf life of minced beef meat.

2. Materials and Methods

2.1. Materials

The guar gum and xanthan gum, used in this study, were purchased from Sigma-Aldrich Greece and the *Origanum vulgare* subsp. *hirtum* essential oil was purchased from Bioland Greece. The minced beef meat was purchased from a local market in the city of Karditsa in Thessaly, Greece and was stored at 4 °C.

Preparation of Coating Solution, Treatment, and Storage of Samples

The coating solution was prepared by dissolving 0.2% xanthan gum and 0.2% guar gum (*w/v*) in distilled water at 20 °C, while stirring at 800 rpm in a magnetic stirrer/hot plate at 60 °C for 5 min. Then, the coating solution was heated to 90 °C in a water bath for 30 min followed by cooling. Essential oil from *Origanum vulgare* subsp. *hirtum* was added into the solution at various concentrations of 1–3% (*v/v*).

The whole of the minced meat was divided into twenty portions of 50 g and stored individually in sterile, plastic Petri plates. Five portions were kept as control samples and each of the other portions were further dipped in the edible film with the appropriate volume of oregano essential oil, leading to three samples per concentration. The dipping process lasted 1 min and the final quantity of the formulation of edible coating was ~10 g. The coated samples were sealed with polyamide film and stored at 4 °C. All physicochemical and microbiological measurements were performed at equal time intervals over a period of 12 days (i.e., 0, 3, 6, 9, and 12 days).

2.2. Physicochemical Analysis

2.2.1. pH Value of Minced Beef

The pH value was measured by homogenizing a 10 g of sample with 100 mL distilled water for 1 min using an Ultra Turrax[®] T25 (IKA, Staufen, Germany) and measuring the pH by a Hanna pH-meter 211. The pH measurements were performed on days 0, 1, 3, 6, 8, 10, and 12 of the refrigerated storage samples.

2.2.2. Sensory Evaluation of Minced Beef

For the sensory evaluation (SE), 50 g of the previously prepared raw minced beef meat samples, which were stored at 4 °C, were assessed by 20 trained panelists—according to International Organization for Standardization (ISO) Standards, more specifically ISO 11037:2011 and ISO 5496:2006 [23,24]—in relation to color and odor assessment, respectively. The sensory analysis was performed in the Sensory Analysis Laboratory of the Food Technology Department of the University of Thessaly, which is designed according to ISO 8589:2007 [25]. The testing cabinet had a room temperature of 21 °C and cold light (daylight) with a color temperature of 5600–6200 kelvin. For each quality attribute according to certain descriptions, scores ranged from 0 to 5 on days 0, 3, 6, 9, and 12 of storage. Minced beef meat received a score between fresh (SE = 5) and completely deteriorated (SE = 1) [26]. Specifically, odor and color acceptability were evaluated immediately after opening the package by using a five-point scale as follows—for odor 1: very unpleasant, 2: unpleasant, 3: acceptable, 4: pleasant, and 5: very pleasant; and for color 1: pale pink, 2: pink, 3: pinkish red, 4: bright red, and 5: reddish brown [26].

2.2.3. Color Measurements

Color analysis was carried out using a colorimeter Konika Minolta CR410r (Konika Minolta, Tokyo, Japan) by assessing L*, a*, and b* values as defined by the Commission Internationale de l'Éclairage (CIE, International Commission on Illumination). The instrument was calibrated with black and white standard plates before the analysis. The lightness (L*, estimates from black to white on a 0–100-point scale), redness (a*, estimates positive values corresponding to red and negative values to green), and yellowness (b*, estimates positive values for yellow and negative values for blue) were recorded. The color parameters of the minced beef meat were measured in triplicate.

2.3. Microbiological Analysis of Minced Beef

Twenty-five (25) g of each sample was diluted in 225 mL sterile 0.1% peptone water and homogenized in a stomacher for 2.5 min at room temperature. A serial 10-fold dilution series was prepared in 0.1% peptone water. Total viable count (TVC) was determined on a plate count agar (PCA) after incubation at 35 °C for 48 h, according to ISO 4833-2:2013 [27]. Enterobacteriaceae were determined on violet red bile dextrose agar (VRBG) after incubation at 37 °C for 24 h, according to ISO 21528-2:2017 [28] and *E. coli* were determined on Chromocul[®] TBX agar after incubation at 44 °C for 18–24 h, according to ISO 16649-1:2018 [29]. Microbiological data were transformed into logarithms that represented the number of colony-forming units (CFU/g).

2.4. Statistical Analysis

Data are expressed as a mean value \pm standard deviation of three replicate analyses. One way analysis of variance (ANOVA) was used to determine the statistical significance of the differences between mean values using the Minitab 17 software (Minitab Inc., State College, PA, USA); further, statistical differences were declared at $p < 0.05$.

3. Results and Discussion

During refrigeration storage, the pH values increased in different degrees according to whether they were uncoated and coated minced beef samples due to endogenous enzymes, bacterial metabolites (such as hydrogen sulfides, organic sulfides, etc.), and other volatile

organic compounds, such as amines [30,31]. In the present study, the initial pH of the control increased from 5.58 to 7.67 by the end of storage, and the pH values of the coated samples also changed noticeably during storage (Figure 1). As such, the pH values showed a significant difference ($p < 0.05$) over the storage period. The statistical tests also showed that the bioactive-coated samples significantly affected the pH value ($p < 0.05$). The control sample was significantly different from the bioactive-coated samples, on average. Although the pH of the sample treated with a bioactive coating of 1% showed slightly lower values, the coated sample with 3% oregano essential oil showed the best pH value of 6.91, due to the antimicrobial activity that oregano essential oil has [32,33]. Moreover, during the storage period the pH value maintained at a safe level.

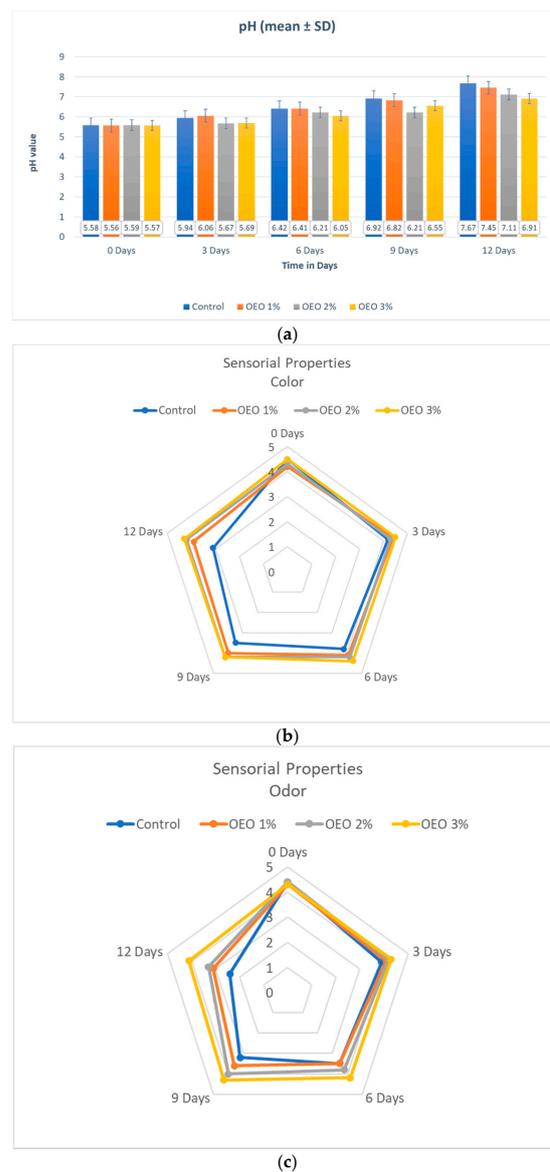


Figure 1. (a) pH values; (b) sensorial properties color scale: 5 reddish brown, 4 bright red, 3 pinkish red, 2 pink, 1 pale pink; and (c) sensorial properties odor scale: 1 very unpleasant, 2 unpleasant, 3 acceptable, 4 pleasant, 5 very pleasant on minced beef meat treated with edible coating stored at 4 °C for 12 days. OEO: Oregano essential oil.

According to the sensory analysis, all samples had an effect on the panelists in regard to odor. In particular, all 3% oregano essential oil coated samples had higher odor acceptability than the other coated samples, which showed intermediary odor values between them. The lowest acceptability was for the uncoated sample (control). Color is one of the main factors

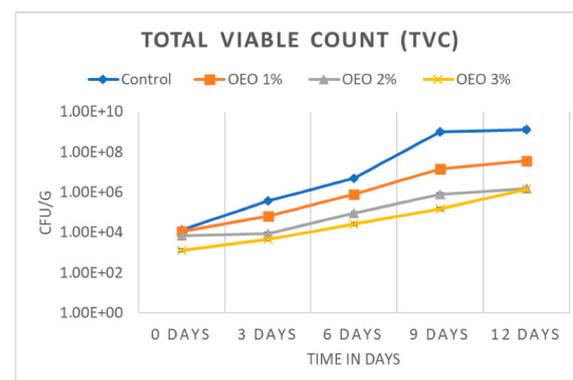
in determining meat quality. In Table 1, L*, a* and b* values of the samples are presented. During the storage time from 1 to 12 days, there was a significant increase ($p < 0.05$) in L* values, especially in the control sample as it became lighter. The samples coated with the edible biofilm were significantly darker at the end of storage period when compared with the control, and the best results were found in the samples with the edible film at 3% concentration of oregano essential oil. A significant decrease ($p < 0.05$) in a* value was also observed in the control sample as a result of the storage time. Further, the control samples became less red than the coated ones, due to the oxidation of oxymyoglobin to metmyoglobin [34]. It is also noteworthy to state that although the coated samples had initially higher b* values than the non-coated control due to the coating film, there was no significant change ($p < 0.05$) in b* values of the coated samples during storage; in contrast, the b* value of the control sample increased significantly from 5.9 to 17.32. The color change generally was confirmed also by the sensory analysis (Table 1). The panelists reported that the coated minced beef meat was significantly redder ($p < 0.05$) than the control at days 6, 9, and 12. The edible coating with the addition of oregano essential oil reduces color deterioration by acting as a barrier to oxygen. This is because oxygen is a promoter of oxidation, thus preventing exposure to oxygen we can maintain the color of minced beef meat. Regarding the odor, there was a significant difference ($p < 0.05$) among samples. At the beginning all scores are alike, but as the days passed, the scores decreased ($p < 0.05$) for the uncoated minced meat; however, this tendency did not show up in the bioactive-coated samples. The odor was maintained in acceptable to pleasant levels in bioactive-coated samples. In particular, the sample with the +3% concentration of oregano essential oil edible coating had the best results.

Table 1. Instrumental color assessment.

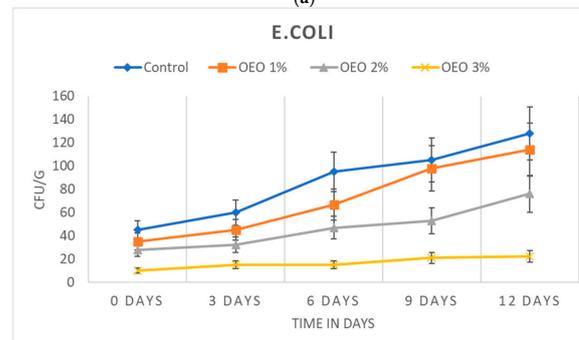
	L* (Lightness)	a* (Redness)	b* (Yellowness)
Control 0 days	36.10	18.70	5.90
OEO1% 0 days	37.50	23.70	12.15
OEO2% 0 days	38.10	25.62	8.93
OEO3% 0 days	36.90	26.15	11.56
Control 3 days	42.44	36.17	15.78
OEO1% 3 days	38.43	18.87	11.43
OEO2% 3 days	37.15	28.53	10.54
OEO3% 3 days	37.34	26.30	6.78
Control 6 days	52.60	18.32	12.75
OEO1% 6 days	44.56	22.87	13.76
OEO2% 6 days	42.67	26.54	13.65
OEO3% 6 days	38.65	28.76	14.56
Control 9 days	61.70	15.53	7.87
OEO1% 9 days	51.45	17.56	12.65
OEO2% 9 days	42.76	18.87	12.65
OEO3% 9 days	40.65	27.65	13.87
Control 12 days	69.10	11.54	17.32
OEO1% 12 days	56.32	15.32	14.50
OEO2% 12 days	49.68	22.45	9.32
OEO3% 12 days	43.36	26.32	12.56

Due to the importance of microbial growth in the quality decay of meat, coating them with antimicrobial activity films is a strategy that can be used to improve the shelf life of them [6]. A limitation in our study was that a coated sample with 0% oregano essential oil was not used in the experiments so that to assess the effects of the coating separately; however, the aim of the study was to assess the effect of the combination of coating with

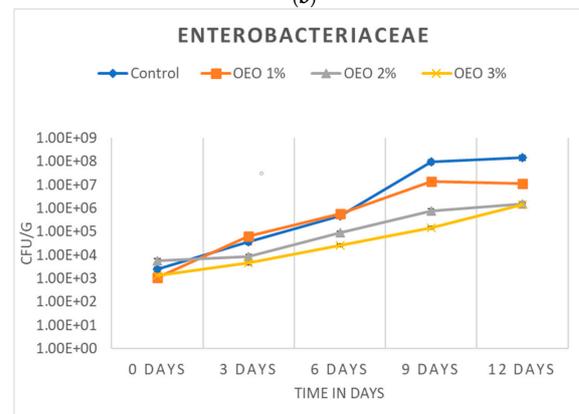
an active antimicrobial substance incorporated in it and not the effect of coating or the active antimicrobial substance separately. According to the microbiological results, which are shown in Figure 2, we can see the effect of the edible coatings loaded with different concentrations of oregano essential oil in minced meat during storage at 4 °C. The TVC increased in all samples during the storage time ($p < 0.05$); however, the control sample had the highest TVC increment (1.34×10^9 CFU/g) during storage, and the minced beef meat coated with edible film + 3% oregano essential oil presented the lowest increase in TVC (1.40×10^6 CFU/g). It is reported that 5×10^6 CFU/g is the maximum recommendation limit of TVC for minced beef meat according to EC regulation [35]. According to this same regulation, the samples coated with edible film + 2% and 3% oregano essential oil were within limits for the whole duration of storage (12 days). On the contrary, the bacteriologically acceptable shelf lives for the non-coated minced beef meat and for the coated sample with 1% oregano essential oil were reached at 6 days of storage.



(a)



(b)



(c)

Figure 2. (a) Total viable counts (TVC), (b) *E. coli* count, and (c) Enterobacteriaceae count in minced beef meat packaged with edible coating with the addition of oregano essential oil 1–3% and control sample without edible coating both at storage time 0, 3, 6, 9, and 12 days. OEO: oregano essential oil.

The Enterobacteriaceae and *E. coli* count in minced beef meat packaged with an edible coating, with the addition of oregano essential oil 1–3%, and the control sample without edible coating at storage time 0, 3, 6, 9, and 12 days are shown in Figure 2. The initial *E. coli* and Enterobacteriaceae counts in all samples were in the range of 10–45 and 1.12×10^3 – 5.75×10^3 CFU/g, respectively. All the coated samples showed a lower increase in the population of *E. coli* and Enterobacteriaceae compared to the control sample at the end of storage time ($p < 0.05$); further, the maximum count of *E. coli* (128 CFU/g) and Enterobacteriaceae (1.46×10^8 CFU/g) were found in the non-coated minced beef meat, and the coated sample with 3% oregano essential oil showed the lowest *E. coli* and Enterobacteriaceae count. Our findings agree with many studies demonstrating the potential of oregano essential oil in edible coating in order to control and inhibit the growth of microorganisms, as well as improve consumer acceptance [14,36–39]. However, regarding essential oil use in the food industry, it is important to always perform in vitro and in vivo toxicity research as well as bioaccessibility and bioavailability assays in order to understand behavior in the human body. In the case of oregano, the lack of toxicity has already been proven in doses much higher than those expected for the consumer to be exposed at, even in the worst-case scenarios [40].

4. Conclusions

In this study we analyzed the effect of an edible coating with three different percentages of oregano essential oil on the physicochemical and microbiological properties of minced beef meat.

The edible coating, which was based on xanthan gum and guar gum with the addition of oregano essential oil, effectively decreased the microbial growth in minced beef meat during cold storage. The coated minced meat also had a higher consumer acceptance compared to the control sample. Therefore, an edible coating with oregano essential oil has the potential to improve the characteristics of minced beef meat during storage and to extend the shelf life of it. This specific combination of edible coating and oregano essential oil shows the potential to be the focus of future studies for use in various meat products.

Author Contributions: Conceptualization, M.A. and E.M.; methodology, E.M.; formal analysis, M.A., G.V. and E.M.; resources, A.M.; data curation, M.A., G.V., A.M. and E.M.; writing—original draft preparation, M.A. and G.V.; writing—review and editing, E.M. and A.M.; supervision, E.M. All authors have read and agreed to the published version of the manuscript.

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References

1. Jayasena, D.D.; Jo, C. Essential oils as potential antimicrobial agents in meat and meat products: A review. *Trends Food Sci. Technol.* **2013**, *34*, 96–108. [\[CrossRef\]](#)
2. Kumar, N.; Neeraj. Polysaccharide-based component and their relevance in edible film/coating: A review. *Nutr. Food Sci.* **2019**, *49*, 793–823. [\[CrossRef\]](#)
3. Vukić, M.; Grujić, S.; Odzaković, B. Application of Edible Films and Coatings in Food Production. In *Advances in Applications of Industrial Biomaterials*; Pellicer, E., Nikolic, D., Sort, J., Baró, M., Zivic, F., Grujovic, N., Grujic, R., Pelemis, S., Eds.; Springer International Publishing: Cham, Germany, 2017; pp. 121–138.
4. Cardoso, G.P.; Dutra, M.P.; Fontes, P.R.; Ramos, A.d.L.S.; de Miranda Gomide, L.A.; Ramos, E.M. Selection of a chitosan gelatin-based edible coating for color preservation of beef in retail display. *Meat Sci.* **2016**, *114*, 85–94. [\[CrossRef\]](#)
5. Kaewprachu, P.; Osako, K.; Benjakul, S.; Rawdkuen, S. Quality attributes of minced pork wrapped with catechin-lysozyme incorporated gelatin film. *Food Packag. Shelf Life* **2015**, *3*, 88–96. [\[CrossRef\]](#)
6. Umaraw, P.; Munekata, P.E.S.; Verma, A.K.; Barba, F.J.; Singh, V.P.; Kumar, P.; Lorenzo, J.M. Edible films/coating with tailored properties for active packaging of meat, fish and derived products. *Trends Food Sci. Technol.* **2020**, *98*, 10–24. [\[CrossRef\]](#)
7. Vital, A.C.; Guerrero, A.; Monteschio, J.D.O.; Valero, M.V.; Carvalho, C.B.; de Abreu Filho, B.A.; Madrona, G.S.; do Prado, I.N. Effect of Edible and Active Coating (with Rosemary and Oregano Essential Oils) on Beef Characteristics and Consumer Acceptability. *PLoS ONE* **2016**, *11*, e0160535. [\[CrossRef\]](#)

8. Bourtoom, T. Edible films and coatings: Characteristics and properties. *Int. Food Res. J.* **2008**, *15*, 237–248.
9. Liu, L.; Kerry, J.F.; Kerry, J.P. Application and assessment of extruded edible casings manufactured from pectin and gelatin/sodium alginate blends for use with breakfast pork sausage. *Meat Sci* **2007**, *75*, 196–202. [[CrossRef](#)]
10. Rakshit, M.; Ramalingam, C. Gum acacia coating with garlic and cinnamon as an alternate, natural preservative for meat and fish. *Afr. J. Biotechnol.* **2013**, *12*, 406–413. [[CrossRef](#)]
11. Miyazawa, T.; Funazukuri, T. Noncatalytic hydrolysis of guar gum under hydrothermal conditions. *Carbohydr. Res.* **2006**, *341*, 870–877. [[CrossRef](#)] [[PubMed](#)]
12. Sworn, G. Gellan gum. In *Handbook of Hydrocolloids*, 2nd ed.; Phillips, G.O., Williams, P.A., Eds.; Woodhead Publishing Ltd: Cambridge, UK, 2009; pp. 204–227.
13. Guerrero, A.; Ferrero, S.; Barahona, M.; Boito, B.; Lisbinski, E.; Maggi, F.; Sañudo, C. Effects of active edible coating based on thyme and garlic essential oils on lamb meat shelf life after long-term frozen storage. *J. Sci. Food Agric.* **2020**, *100*, 656–664. [[CrossRef](#)] [[PubMed](#)]
14. Pateiro, M.; Muneke, P.E.S.; Sant’Ana, A.S.; Domínguez, R.; Rodríguez-Lázaro, D.; Lorenzo, J.M. Application of essential oils as antimicrobial agents against spoilage and pathogenic microorganisms in meat products. *Int. J. Food Microbiol.* **2021**, *337*, 108966. [[CrossRef](#)] [[PubMed](#)]
15. Abdou, E.S.; Galhoum, G.F.; Mohamed, E.N. Curcumin loaded nanoemulsions/pectin coatings for refrigerated chicken fillets. *Food Hydrocoll.* **2018**, *83*, 445–453. [[CrossRef](#)]
16. Bonilla Lagos, M.J.; Sobral, P.J.A. Application of active films with natural extract for beef hamburger preservation. *Ciência Rural.* **2019**, *49*, e20180797. [[CrossRef](#)]
17. Borella, T.G.; Peccin, M.M.; Mazon, J.M.; Roman, S.S.; Cansian, R.L.; Soares, M.B.A. Effect of rosemary (*Rosmarinus officinalis*) antioxidant in industrial processing of frozen-mixed hamburger during shelf life. *J. Food Process. Preserv.* **2019**, *43*, e14092. [[CrossRef](#)]
18. Cai, L.; Wang, Y.; Cao, A. The physiochemical and preservation properties of fish sarcoplasmic protein/chitosan composite films containing ginger essential oil emulsions. *J. Food Process Eng.* **2020**, *43*, e13495. [[CrossRef](#)]
19. Lima, J.C.d.C.; Pereira, J.d.C.N.; Andrade, M.F.d.; Góis, G.d.S.; Simões, I.T.d.A.; Silva, M.A.A.D.d.; Almeida, Y.M.B.d.; Vinhas, G.M. Study and influence of clove, cinnamon, and orange essential oils in the preparation of poly (lactic acid) films: Active packaging development. *Res. Soc. Dev.* **2021**, *10*, e41810414340. [[CrossRef](#)]
20. Hamann, D.; Putton, B.M.S.; Colet, R.; Steffens, J.; Ceni, G.C.; Cansian, R.L.; Backes, G.T. Active edible films for application in meat products. *Res. Soc. Dev.* **2021**, *10*, e13610716379. [[CrossRef](#)]
21. Proestos, C.; Zoumpoulakis, P.; Sinanoglou, V.J. Determination of Plant Bioactive Compounds. Antioxidant Capacity and Antimicrobial Screening. *Focus. Mod. Food Ind.* **2013**, *2*, 25–26.
22. Skandamis, P.N.; Nychas, G.J.E. Effect of oregano essential oil on microbiological and physico-chemical attributes of minced meat stored in air and modified atmospheres. *J. Appl. Microbiol.* **2001**, *91*, 1011–1022. [[CrossRef](#)]
23. International Organization for Standardization. Sensory Analysis—Guidelines for Sensory Assessment of the Colour of Products (ISO 11037:2011). Available online: <https://www.iso.org/standard/50112.html> (accessed on 9 September 2022).
24. International Organization for Standardization. Sensory Analysis—Methodology—Initiation and Training of Assessors in the Detection and Recognition of Odours (ISO 5496:2006). Available online: <https://www.iso.org/standard/44247.html> (accessed on 10 September 2022).
25. International Organization for Standardization. Sensory Analysis—General Guidance for the Design of Test Rooms (ISO 8589:2007). Available online: <https://www.iso.org/standard/36385.html> (accessed on 12 September 2022).
26. Mörlein, D. Sensory evaluation of meat and meat products: Fundamentals and applications. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *333*, 012007. [[CrossRef](#)]
27. International Organization for Standardization. Microbiology of the Food Chain—Horizontal Method for the Enumeration of Microorganisms—Part 2: Colony Count at 30 °C by the Surface Plating Technique (ISO 833-2:2013). Available online: <https://www.iso.org/standard/59509.html> (accessed on 15 September 2022).
28. International Organization for Standardization. Microbiology of the Food Chain—Horizontal Method for the Detection and Enumeration of Enterobacteriaceae—Part 2: Colony-Count Technique (ISO 21528-2:2017). Available online: <https://www.iso.org/standard/63504.html> (accessed on 15 September 2022).
29. International Organization for Standardization. Microbiology of the Food Chain—Horizontal Method for the Enumeration of Beta-Glucuronidase-Positive Escherichia Coli—Part 1: Colony-Count Technique at 44 °C Using Membranes and 5-Bromo-4-Chloro-3-Indolyl Beta-D-Glucuronide (ISO 16649-1:2018). Available online: <https://www.iso.org/standard/64951.html> (accessed on 16 September 2022).
30. Parrish, F.C., Jr.; Goll, D.E.; Newcomb II, W.J.; de Lumen, B.O.; Chaudhry, H.M.; Kline, E.A. Molecular Properties of Post-Mortem Muscle. 7. Changes in Nonprotein Nitrogen and Free Amino Acids of Bovine Muscle. *J. Food Sci.* **1969**, *34*, 196–202. [[CrossRef](#)]
31. Boakye, K.; Mittal, G.S. Changes in pH and water holding properties of Longissimus dorsi muscle during beef ageing. *Meat Sci.* **1993**, *34*, 335–349. [[CrossRef](#)]
32. Pavli, F.; Argyri, A.A.; Skandamis, P.; Nychas, G.-J.; Tassou, C.; Chorianopoulos, N. Antimicrobial Activity of Oregano Essential Oil Incorporated in Sodium Alginate Edible Films: Control of *Listeria monocytogenes* and Spoilage in Ham Slices Treated with High Pressure Processing. *Materials* **2019**, *12*, 3726. [[CrossRef](#)] [[PubMed](#)]

33. Sakkas, H.; Papadopoulou, C. Antimicrobial Activity of Basil, Oregano, and Thyme Essential Oils. *J. Microbiol. Biotechnol.* **2017**, *27*, 429–438. [[CrossRef](#)]
34. George, P.; Stratmann, C.J. The oxidation of myoglobin to metmyoglobin by oxygen. 2. The relation between the first order rate constant and the partial pressure of oxygen. *Biochem. J.* **1952**, *51*, 418–425. [[CrossRef](#)]
35. Microbiological Criteria for Foodstuffs. Commission Regulation (EC) No 2073/2005. 15 November 2005. Available online: <https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32005R2073> (accessed on 16 September 2022).
36. Catarino, M.D.; Alves-Silva, J.M.; Fernandes, R.P.; Gonçalves, M.J.; Salgueiro, L.R.; Henriques, M.F.; Cardoso, S.M. Development and performance of whey protein active coatings with *Origanum virens* essential oils in the quality and shelf life improvement of processed meat products. *Food Control* **2017**, *80*, 273–280. [[CrossRef](#)]
37. Badia, V.; de Oliveira, M.S.R.; Polmann, G.; Milkiewicz, T.; Galvão, A.C.; da Silva Robazza, W. Effect of the addition of antimicrobial oregano (*Origanum vulgare*) and rosemary (*Rosmarinus officinalis*) essential oils on lactic acid bacteria growth in refrigerated vacuum-packed Tuscan sausage. *Braz. J. Microbiol.* **2020**, *51*, 289–301. [[CrossRef](#)] [[PubMed](#)]
38. Tsigarida, E.; Skandamis, P.; Nychas, G.J. Behaviour of *Listeria monocytogenes* and autochthonous flora on meat stored under aerobic, vacuum and modified atmosphere packaging conditions with or without the presence of oregano essential oil at 5 °C. *J. Appl. Microbiol.* **2000**, *89*, 901–909. [[CrossRef](#)]
39. Govaris, A.; Solomakos, N.; Pexara, A.; Chatzopoulou, P.S. The antimicrobial effect of oregano essential oil, nisin and their combination against *Salmonella* Enteritidis in minced sheep meat during refrigerated storage. *Int. J. Food Microbiol.* **2010**, *137*, 175–180. [[CrossRef](#)] [[PubMed](#)]
40. Llana-Ruiz-Cabello, M.; Maisanaba, S.; Puerto, M.; Pichardo, S.; Jos, A.; Moyano, R.; Cameán, A.M. A subchronic 90-day oral toxicity study of *Origanum vulgare* essential oil in rats. *Food Chem. Toxicol.* **2017**, *101*, 36–47. [[CrossRef](#)]