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The Effect of Xanthan Gum-Based Edible Coating Incorporated with Ginger Essential Oil on the Physicochemical and Sensory Properties of Refrigerated Hamburger

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ABSTRACT: The present study evaluates the effect of a 1.5% xanthan gum edible coating, enriched with ginger essential oil (GEO) at concentrations of 3% and 4%, on the physicochemical and sensory characteristics of hamburgers during a 16-day refrigerated storage. In this study, the physicochemical properties, specifically pH, texture firmness, TVBN, TBA, and color indices (L*, a*, and b*), along with sensory attributes were assessed at days 0, 4, 8, 12, and 16. The findings indicated that the treatments containing GEO resulted in reductions in pH, TVBN, and TBA levels compared to the control sample ($p<0.05$). The firmness and color indices of xanthan gum-coated treatments incorporating GEO showed significantly higher amounts as compared to the control sample. Notably, the treatment utilizing 4% GEO exhibited the highest levels of firmness, brightness and redness. However, extending the storage period to day 16 resulted in a significant reduction in firmness and an elevation in pH, TVBN, and TBA levels in all hamburger samples ($p<0.05$), but this trend was observed to be less pronounced in the treatments that included GEO. Regarding the sensory evaluation, the treatment comprising 1.5% xanthan gum and 4% GEO achieved the most favorable scores across the parameters of color, flavor, odor, texture, and overall acceptability ($p<0.05$). The findings of the study suggest that the application of the xanthan gum edible coating incorporated with ginger essential oil enhances both the physicochemical and sensory characteristics of hamburgers. Moreover, this coating contributes to shelf-life extension of the product at refrigerated storage.

Keywords: Edible Coating, Ginger Essential Oil, Hamburger, Shelf-Life, Xanthan.

Introduction

Hamburger is widely regarded as one of the most popular meat products, esteemed for its significant nutritional value and convenience of consumption, thereby garnering a substantial following among consumers (Najafi *et al.*, 2023). Nevertheless, the inherent unprocessed characteristics of this product until the point of consumption render it susceptible to significant chemical spoilage. The predominant form of chemical spoilage in burgers is attributed to fat oxidation and the degradation of protein compounds.

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These processes adversely impact the physicochemical properties of the product, including pH, textural firmness, and shelf life (Mozaffari Nejad *et al.*, 2014). Although the use of refrigeration methods, especially freezing, is the most common way to preserve burgers, natural compounds such as essential oils and plant extracts can also be utilized to delay oxidative reactions and microbial changes, thereby extending the product's shelf life (Özvural *et al.*, 2016).

One of the natural compounds that has shown positive effects on food quality in numerous studies is ginger essential oil. This oil, extracted from the *Zingiber officinalis* plant, possesses significant antioxidant and protective properties due to its bioactive compounds such as camphene, zingiberene, and gingerol. These compounds are capable of reducing fat oxidation and preserving the physicochemical quality of products. Research indicates that the application of ginger essential oil or extract can diminish fat oxidation, enhance texture, and prolong shelf life in fish burgers, fish fillets, and camel meat (Mattje *et al.*, 2019). Nonetheless, plant-derived essential oils, such as ginger, encounter several constraints when it comes to direct applications. These limitations arise from their pronounced flavor and aroma, susceptibility to instability during processing, high volatility, and low solubility. Consequently, the implementation of contemporary techniques to harness the beneficial properties of essential oils while preserving the sensory attributes of the product is deemed essential. One such technique involves the application of natural edible coatings (Varmazyar *et al.*, 2024).

Edible coatings incorporated with bioactive compounds represent a viable strategy for preserving the quality and prolonging the shelf life of meat products. Among various hydrocolloids, xanthan gum is recognized as one of the most utilized thickeners in the food industry and has garnered substantial attention due to its advantageous physicochemical characteristics. Xanthan is classified as a heteropolysaccharide that exhibits solubility in water. It is synthesized via the bacterial fermentation process involving the organism *Xanthomonas campestris*. This gum has the ability to form viscous solutions at low concentrations, making it an effective stabilizer and thickening agent in a variety of food products (Azari *et al.*, 2020). Xanthan exhibits hydrophilic functional groups that facilitate moisture retention, mitigate staling, and prolong the shelf life of a diverse range of products. This compound is utilized in the food industry, especially in the formulation of meat products, where it functions as both a thickening and coating agent. Furthermore, xanthan gum significantly contributes to the enhancement of the physicochemical properties of various products, including burgers (Soltani *et al.*, 2022).

Research indicates that the application of edible coatings or films infused with plant extracts and essential oils can improve oxidative stability while preserving different food quality (Khamoushi *et al.*, 2021; Foromandi and Khani, 2023). For instance, the utilization of sodium caseinate-based edible coatings enriched with nanoemulsions incorporating ginger essential oil has been implemented to enhance the shelf life of chicken meat (Noori *et al.*, 2018). Furthermore, cellulose nanofiber coatings infused with ginger essential oil and citric acid have been employed to enhance the shelf life of grilled chicken. Additionally, bilayer agar-sodium alginate films infused with ginger essential oil have demonstrated efficacy in extending the shelf life of beef products (Zhang *et al.*, 2023). Considering the advantageous properties associated with ginger essential oil coatings and films in relation to meat products, the present study aims to examine the synergistic effects of xanthan gum-based edible coatings in conjunction with ginger essential oil on the physicochemical and sensory characteristics of hamburgers.

Materials and Methods

- *Materials*

In the formulation of the hamburger samples, a variety of ingredients were sourced from reputable suppliers in Iran. Fresh beef, specifically the blade and loin cuts, was procured from a local slaughterhouse in Tehran, Iran. The remaining components included table salt obtained from Golha Company (Tehran, Iran), spices provided by Sabzan Company (Tehran, Iran), onions sourced from Chahar Fasl Company (Tehran, Iran), whey powder from Ramak Dairy Company (Shiraz, Iran), wheat flour from Khosheh Fars Company (Shiraz, Iran), and breadcrumbs from Roshd Food Industries Company (Tehran, Iran). Additionally, xanthan gum was sourced from Niknam Trading Company (Tehran, Iran), and ginger essential oil was acquired from Barij Essence Company (Kashan, Iran). Table 1 presents the composition of ginger essential oil, which the respective supplier analyzed using Gas Chromatography–Mass Spectrometry (GC-MS). Furthermore, all requisite chemicals for the pertinent chemical analyses were procured from Merck Company (Germany).

- *Hamburger preparation*

For the preparation of hamburgers containing 60% meat, fresh beef cuts sourced from the flank and shoulder were utilized. The selected meat samples were positioned on designated cutting boards, where the muscle tissue and adipose material were meticulously disassociated from the skeletal elements. The samples were subsequently processed using a Moulinex model ME740 meat grinder (France), which features openings measuring 13 mm in diameter. Subsequently, additional ingredients were incorporated into the meat mixture, comprising fillers and binders, specifically breadcrumbs (14.8%), whey powder (4.5%), wheat flour (3%), onion (14%), and spices (2%). The ingredients were thoroughly blended for a duration of one hour to ensure a homogeneous mixture. Subsequently, the resulting mixture was subjected to further grinding using a meat grinder equipped with 2.5 mm openings. The ground burger mixture was subsequently formed into 100-gram portions utilizing a manual molding apparatus. Subsequent to the coating process, conducted in accordance with the

Table 1. Components of ginger essential oil analyzed by GC-MS

Row	Compound	Amount (%)	Row	Compound	Amount (%)
1	Alpha-Zingiberene	28.25	8	Trans-Citral	1.66
2	Beta-Seskophelandrene	15.65	9	Trans-Nuciferol	1.5
3	Alpha-Curcumene	15.23	10	Linalool	1.33
4	Trans-Gamma-Cadiene	11.88	11	Hinsole	1.2
5	Cis-Gamma-Cadiene	5.24	12	Alpha-Terpineol	1.18
6	Borneol	2.29	13	Cis-Citral	1.11
7	Spatholenol	2.98	14	Epi-Gamma-Iodosmol	1.60

preparation methods outlined in the following section, the samples were placed in polyethylene bags and stored in a refrigerator at 4ºC for a duration of 16 days. Following this storage period, the samples were subjected to physicochemical analyses and sensory evaluation.

- ***Preparation of coating solution and treatment***

In order to formulate a food coating utilizing xanthan gum, a solution was prepared by incorporating 1. 5% (w/v) xanthan gum into warm distilled water maintained at approximately 70ºC. Additionally, 30% (w/w) glycerol was included in the mixture as a plasticizing agent. The mixture was subjected to magnetic stirring at ambient temperature for a duration of three hours to facilitate thorough and uniform dissolution. Subsequently, ginger essential oil was incorporated into the coating solution at concentrations of 3% and 4% (v/v). For the purpose of coating, three distinct groups of hamburgers were individually immersed for a duration of 20 minutes in solutions comprising 1.5% xanthan gum (denoted as X), a combination of 1.5% xanthan gum and 3% ginger essential oil (designated as XG3), and a mixture of 1.5% xanthan gum and 4% ginger essential oil (designated as XG4). This process resulted in the establishment of three separate coating treatments. A control sample, devoid of any coating, was prepared through immersion in sterile distilled water. Subsequent to the removal of the hamburgers from the utilized solution, all samples were positioned beneath a fume hood (Jaal Company, Iran) for a designated duration, facilitating the drying process and the formation of the desired coating on the samples (Ovi and Rahman, 2019).

- ***Physicochemical tests***
- ***pH measurement***

In order to determine the pH level, a sample weighing 10 grams was dissolved in 100 milliliters of distilled water. Following a 20-minute incubation period, the pH measurement was obtained using a calibrated pH meter (Metrohm model 827, Switzerland) (INSO, 2020).

- ***Measurement of thiobarbituric acid (TBA)***

A 10-gram sample of homogenized hamburger was further homogenized through the addition of 35 milliliters of 4% perchloric acid and 1 milliliter of a 5% butylated hydroxytoluene solution in ethanol. The sample was subsequently subjected to filtration employing Whatman filter papers No. 4 were utilized to filter the solution, after which 5 milliliters of the filtered solution were combined with 5 milliliters of 0.02 M TBA solution in a sealed test tube. This mixture was subsequently incubated in a boiling water bath for a duration of one hour. Subsequent to the cooling phase, the optical absorbance of the samples was assessed utilizing a spectrophotometer (JENWAY model UV-Vis 6700, England) at a wavelength of 532 nanometers. The absorbance measurements were compared to a control solution comprising 5 milliliters of 4% perchloric acid and 5 milliliters of a 0.02 M thiobarbituric acid (TBA) solution. The results were expressed in terms of milligrams of malondialdehyde per kilogram of sample (Mattje *et al.*, 2019).

- ***Measurement of total volatile basic nitrogen (TVBN)***

The TVBN was quantified employing the micro-Kjeldahl distillation method, a standard technique utilized for the assessment of proteolytic degradation. The

TVBN value for each sample was determined and expressed in milligrams per 100 grams of the respective sample, utilizing Equation 1 for calculation (Ghadiri Amrei *et al.*, 2023).

$$TVBN = \frac{A - B \times 1 \cdot 4}{w} \times 100 \quad \text{Equation 1}$$

A= The titration volume for the tested sample (milliliters)

B= Volume of titration of the control sample (milliliters)

W= Sample weight (grams)

- ***Firmness measurement***

All samples subjected to testing were assessed in triplicate at ambient temperature utilizing a texture analyzer (Brookfield model CT3, USA). For each treatment, three samples measuring 20 mm x 20 mm were extracted from the center of each hamburger and were subjected to a two-stage compression testing protocol. The samples were subjected to a compression of up to 40% of their original height utilizing cylindrical balls with a circular cross-section measuring 6.35 mm in diameter, with a compression rate of 1 mm per second (Ghadiri Amrei *et al.*, 2023).

- ***Colorimetry***

The color was quantified employing a colorimeter (HunterLab model ColorFlex EZ, USA). The colorimetric properties, specifically L* (lightness), a* (redness), and b* (yellowness), were measured directly using a colorimeter. The calibration of the instrument was conducted utilizing a black and white calibration plate (Savadkoohi *et al.*, 2014).

- ***Sensory characteristics evaluation***

The sensory evaluation of hamburger samples, including texture, color, flavor, odor, and overall acceptability, was conducted after frying them in oil at a temperature of 148 ^{o}C for 7 minutes, using a 5-point hedonic scale (1 = inedible, 2 = unacceptable, 3 = acceptable, 4 = satisfactory, and 5 = very satisfactory). For this purpose, the samples were coded and provided along with a sensory evaluation form to 8 trained assessors (Jafarpour *et al.*, 2014).

- ***Data Analysis***

This study was conducted utilizing a factorial design grounded in a completely randomized framework, incorporating two factors: xanthan edible coating and ginger essential oil. The xanthan edible coating was applied at a singular level (1.5), while ginger essential oil was tested at three distinct levels (0, 3, and 4). This methodological approach yielded a total of four experimental samples. All experiments were conducted in triplicate, and the results were expressed as mean ± standard deviation (Mean ± SD). The data collected were subjected to analysis utilizing SAS software, and the significant effects of the independent variables were assessed through analysis of variance at a significance level of 5%. Furthermore, the comparative analysis of significant means was performed utilizing Duncan's multiple range test.

Results and Discussion

- ***pH Results***

The findings illustrated in Figure 1 indicate that the application of xanthan gum as a coating for hamburgers, particularly when combined with elevated concentrations of ginger essential oil (GEO), resulted in a significant reduction in pH levels. The treatment comprising 4% GEO demonstrated the lowest pH value of 6.03, in contrast to the control sample, which exhibited the highest pH value of 6.86 at the end of the storage period

($p<0.05$). As storage duration increased, a concomitant rise in pH was observed across all samples. Nevertheless, this trend was notably attenuated in the xanthan-coated treatments infused with GEO. This variation can be attributed to the antimicrobial properties of GEO and the reduced permeability to carbon dioxide associated with the xanthan coating.

The pH value serves as a significant indicator of meat product freshness, as it is intrinsically linked to bacterial activity and the subsequent accumulation of alkaline metabolites, including ammonia and amines (Zhang *et al.*, 2020). The accumulation of these compounds, resulting from protein degradation and lipid oxidation, gradually leads to an increase in pH (Kanatt, 2020). Xanthan gum and ginger extract are effective in mitigating protein degradation by inhibiting the proliferation of microorganisms. This, in turn, contributes to the preservation of the quality of the burger (Alizadeh-Sani *et al.*, 2020).

In the current investigation, the researchers documented that the incorporation of ginger essential oil into a two-layer film composed of sodium alginate and agar was associated with a reduction in pH levels in refrigerated beef treatments. Conversely, an extension of the storage duration was found to correlate with an increase in pH levels (Zhang *et al.*, 2023). A separate investigation demonstrated that the application of oregano essential oil within a chitosan coating significantly decreased the pH levels of burgers. Furthermore, it was observed that the storage duration exerted an influence on pH, aligning with the findings of the present study (Amadio *et al.*, 2019).

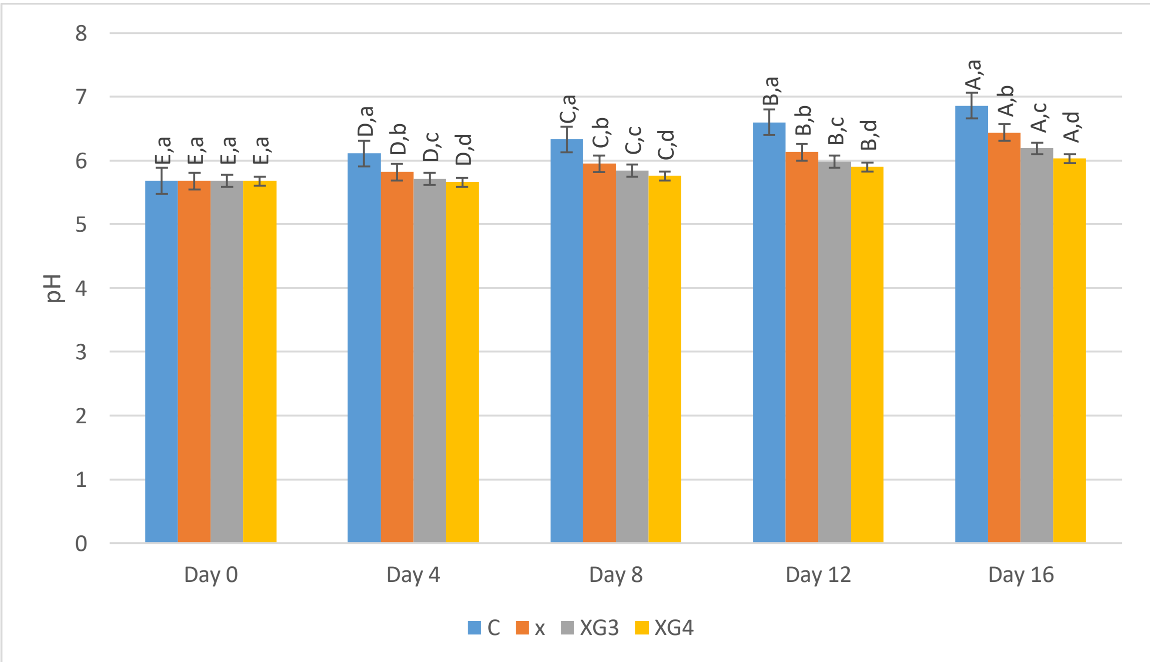

Fig. 1. The pH average of hamburger samples coated with xanthan containing ginger essential oil (Mean±SD) A-E: Different capital letters in each sample indicate significant differences between days of storage ($p<0.05$). a-d: Different lowercase letters in each day indicate significant differences between hamburger samples ($p<0.05$).

- - *TVBN results*

The findings presented in Figure 2 of the current study demonstrate that both the treatments applied and the duration of storage significantly influenced the total volatile basic nitrogen in the hamburger samples ($p<0.05$). On the initial day of assessment, no notable differences were observed among the samples. However, throughout the storage period, the TVBN values of all analyzed samples exhibited a significant increase ($p<0.05$). The rate of increase observed in samples coated with xanthan supplemented with GEO was significantly lower in comparison to the other samples. The elevation in TVBN levels observed throughout the storage period can be attributed to the accumulation of volatile nitrogenous compounds, which arise from the degradation of proteins by bacterial activity during the initial stages of meat spoilage. This biochemical process is concomitant with an increase in pH levels. This phenomenon, in turn, stimulated and enhanced the activity of enzymes such as cathepsin B and L, thereby accelerating the degradation and breakdown of proteins. Consequently, this led to a marked increase in TVBN levels (Zhang *et al.*, 2023).

On day 16, the control sample exhibited the highest concentration of TVBN. In contrast, the treatments incorporating 4% and 3% GEO demonstrated the lowest TVBN values, respectively, which had 23-28 mg/100 g less TVBN than the control. This phenomenon can be attributed to the inhibitory and bactericidal properties of ginger essential oil, which acts upon the bacteria located on the surface of hamburger samples. Consequently, this action effectively postpones the protein degradation process. This effect exhibited a positive correlation with the increasing concentration of GEO employed in the study. Another potential factor contributing to this phenomenon may be attributed to the hydrophilicity of the coating matrix formed. This property enhances the capacity of the surface of the hamburgers to absorb water, thereby resulting in a low water activity environment in proximity to the burger samples. This intervention may inhibit bacterial proliferation on surfaces, diminish the degradation of proteins and amino acids, and enhance the antibacterial efficacy of ginger essential oil (Zhang *et al.*, 2020). The findings of this study align with the results of previous research investigating the impact of rosemary essential oil on beef burgers, as well as with those pertaining to the effects of a dual-layer sodium alginate film infused with ginger essential oil on the physicochemical properties of refrigerated beef. These studies collectively demonstrate that the incorporation of both essential oils contributed to a significant reduction in TVBN in the treated samples (Zhang *et al.*, 2023; Mozafari et al., 2023).

The measurement of TVBN serves as an indicator of protein degradation resulting from enzymatic and microbial activities. This process ultimately gives rise to the formation of amines, including methylamine, dimethylamine, trimethylamine, and ammonia. This phenomenon leads to an undesirable flavor profile and a reduction in the nutritional quality of the product. Furthermore, it may function as an indicator for the identification and assessment of the freshness of meat products (Moghimi *et al.*, 2016). In accordance with the optimal threshold for TVBN levels in meat and meat products, which is established at 25 mg/100 g (Mehaya *et al.*, 2024), the treatment utilizing xanthan combined with 4% GEO maintained TVBN levels within acceptable limits for up to 12 days. In contrast, the xanthan treatment with 3% GEO sustained acceptable levels until day 8. The xanthan-coated treatment alone, as well as the control sample, exhibited acceptable TVBN levels solely until day 4.

- ***TBA results***

The findings presented in Figure 3 of the current study demonstrate that both the type of coatings employed and the duration of storage significantly influenced the levels of thiobarbituric acid (TBA) ($p< 0.05$). During the storage period, a significant increase in the TBA values of all samples was observed ($p<0.05$). Nevertheless, the rate of TBA increase in samples coated with xanthan incorporating ginger essential oil was significantly lower than that observed in the other samples. On day 16 of storage, the levels of TBA in samples treated with 3% and 4% GEO were found to be lower by 3.5 to 3.9 mg MDA/kg compared to the control sample. Notably, the control group exhibited the highest TBA levels on this day as well as on other days of storage.

TBA serves as an indicator of secondary oxidation products, including malondialdehyde (MDA), which are generated during the process of lipid oxidation. The observed reduction in thiobarbituric acid levels across the hamburger treatments can be attributed to the antioxidant properties of ginger essential oil. This oil not only demonstrates enhanced capability for distribution and dispersion within the fat phase but also provides protective effects through the coating that incorporates the essential oil surrounding the burger. The findings of the current investigation align with existing literature that demonstrates the beneficial impact of plant essential oils on mitigating lipid oxidation, thereby resulting in a reduction of TBA levels (Zhang *et al.*, 2021; Foromandi and Khani, 2023).

The optimal threshold for TBA has been established at 2 mg MDA/kg; values exceeding this limit are indicative of spoilage in meat products, manifesting primarily through the emergence of undesirable odors. In this context, the control sample demonstrated acceptable quality up to day 4. Conversely, the sample treated solely with xanthan maintained its acceptable status until day 8. Notably, the xanthan-coated treatments enriched with GEO remained within acceptable limits for an extended period, lasting until day 16. The treatment consisting of 1.5% xanthan and 4% GEO exhibited the most effective performance in inhibiting lipid peroxidation. This edible coating functions by decreasing the permeability of oxygen to the product, thereby delaying the progression of secondary lipid oxidation. This phenomenon is attributed to the antioxidant properties of the phenolic compounds contained within the essential oil (Sheikha *et al.*, 2022).

- ***Firmness results***

The analysis of variance revealed that the effects of coating treatment, storage duration, and the interaction between these variables significantly influenced the texture of the hamburger samples ($p<0.05$). The findings from the texture measurements (Figure 4) demonstrate that the application of xanthan coating on hamburgers, particularly when combined with elevated concentrations of ginger essential oil, significantly enhanced texture firmness. Specifically, the treatment that incorporated 4% GEO exhibited the greatest firmness, whereas the control sample displayed the lowest firmness throughout the storage period

($p<0.05$). Furthermore, an increase in storage duration was associated with a notable decline in the texture firmness of all samples analyzed. However, the rate of decrease in texture hardness in xanthan-coated samples infused with GEO was significantly less pronounced than that observed in the control sample ($p>0.05$).

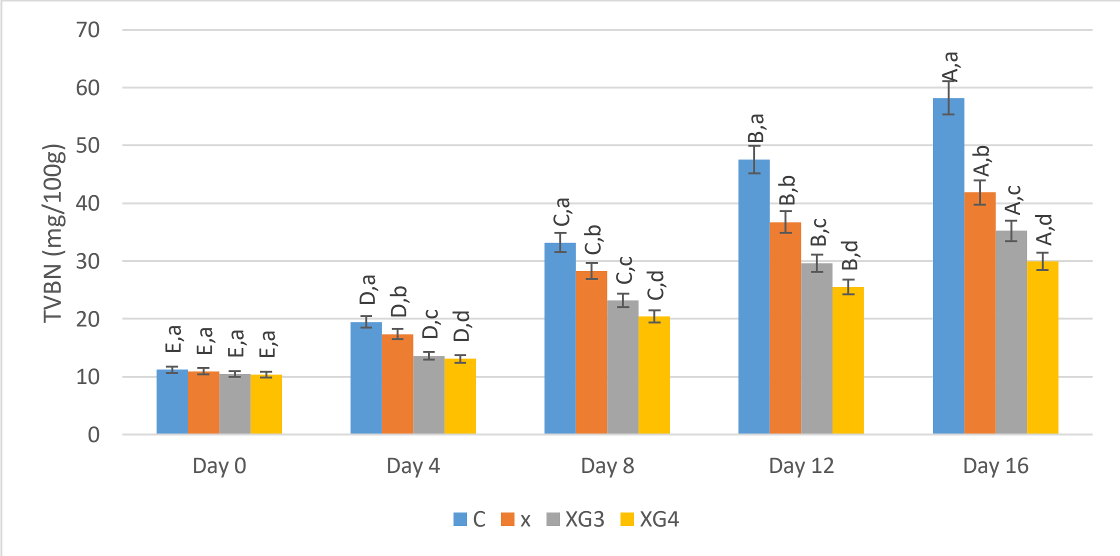

Fig. 2. The TVBN average of hamburger samples coated with xanthan containing ginger essential oil (Mean±SD)
A-E: Different capital letters in each sample indicate significant differences between days of storage ($p<0.05$).
a-d: Different lowercase letters in each day indicate significant differences between hamburger samples ($p<0.05$).

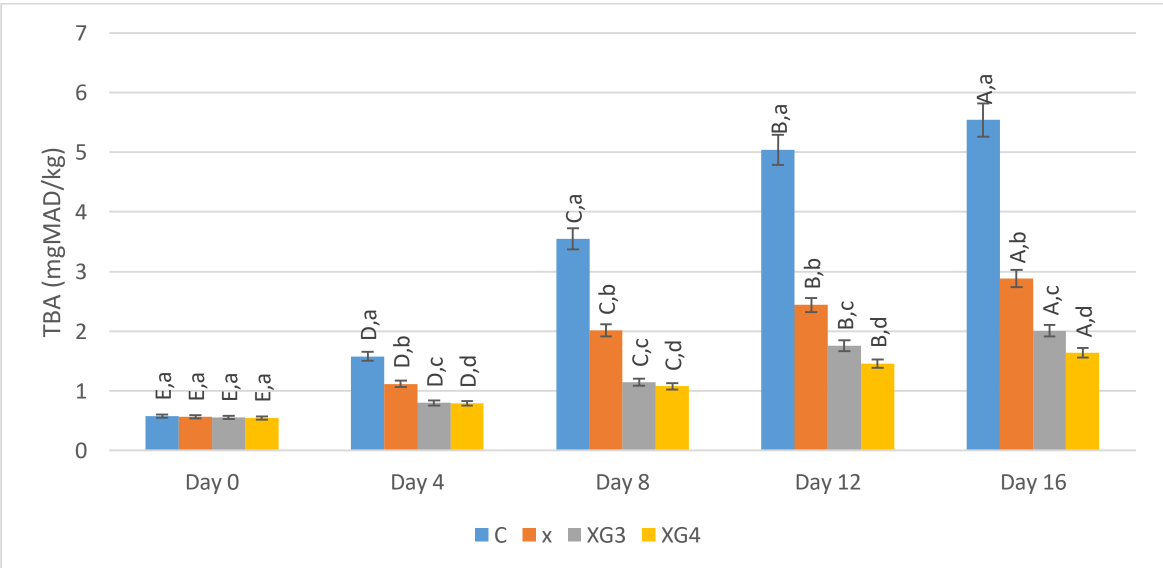

Fig. 3. The TBA average of hamburger samples coated with xanthan containing ginger essential oil (Mean±SD)
A-E: Different capital letters in each sample indicate significant differences between days of storage ($p<0.05$).
a-d: Different lowercase letters in each day indicate significant differences between hamburger samples ($p<0.05$).

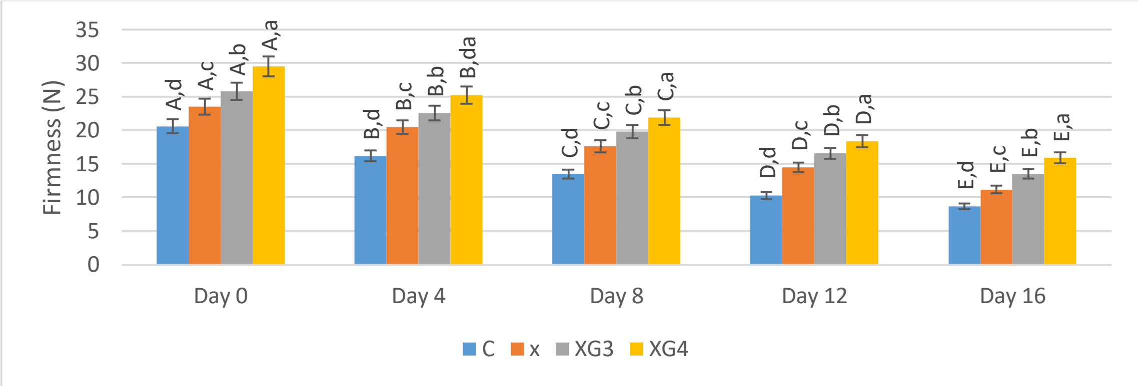

Fig. 4. The texture firmness of hamburger samples coated with xanthan containing ginger essential oil (Mean±SD)
A-E: Different capital letters in each sample indicate significant differences between days of storage ($p<0.05$).
a-d: Different lowercase letters in each day indicate significant differences between hamburger samples ($p<0.05$).

The texture of meat and meat products constitutes a significant attribute that influences consumer preferences, especially in terms of tenderness and chewiness.The observed decrease in firmness across all hamburger samples with prolonged storage duration may be attributable to microbial activity and the enzymatic degradation of meat caused by endogenous enzymes. Nonetheless, due to the antimicrobial properties exhibited by plant extracts, their application may effectively hinder the degradation of texture in the treated hamburger samples. In this context, a study investigated the impact of a sodium alginate-agar edible coating infused with ginger extract on meat quality. The findings revealed that the coated samples exhibited a more desirable and firmer texture in comparison to the control group (Zhang *et al.*, 2021). Furthermore, a study examining the impact of gelatin edible coatings infused with plant extracts on turbofish fillets indicated that the incorporation of plant extracts, particularly garlic extract, significantly postponed the degradation of texture in the fish samples (Xu *et al.*, 2017). This findings are consistent with the results obtained in the current study.

- ***Results of color indices (L*, a*, b*)***

Color serves as a fundamental indicator of both quality and consumer acceptance in meat products. The findings presented in Table 2 indicate that the effects of coating treatment, storage duration, and the interaction between these variables on the color indices of the hamburger samples were statistically significant ($p<0.05$). The color indices (L*, a*, b*) of the xanthan-coated hamburger treatments incorporating ginger essential oil exhibited a significant increase up to day 4 of storage, followed by a subsequent decrease by the end of the storage period ($p<0.05$). In contrast, the brightness of the control sample exhibited an initial increase until day 8, followed by a subsequent decrease. Conversely, the redness levels in both the control and xanthan-coated treatment (which did not contain GEO) declined consistently throughout the storage period. Notably, the brightness measurements on day 16 of storage were lower across all samples compared to those recorded on day one. The elevated brightness levels observed in the initial phases can likely be attributed to the xanthan coating, which enhances light reflection on the sample surface. The observed decrease in L* values may be attributed to the oxidation of myoglobin and the concomitant increase in metmyoglobin formation. Additionally, lipid oxidation over time is likely to enhance cell membrane permeability, resulting in a loss of water content within the product. The decrease in water content within the product may lead to a diminished capacity for light reflection, thereby contributing to a reduction in the product's overall brightness (Sayas-Barberá *et al.*, 2011).

The degree of redness in both the control sample and the xanthan-coated treatment without GEO, diminished throughout the storage period. The redness observed in the hamburger treatments incorporating GEO exhibited a slight increase until day 4, followed by a subsequent decline thereafter. The observed decrease in redness in the control sample and that devoid of GEO during refrigeration, as compared to the coated treatments, can be attributed to the oxidation of myoglobin within the hamburger tissue. In contrast, the coating that incorporates essential oil functions as a protective barrier separating the sample from oxygen present in the storage environment. Moreover, ginger essential oil possesses antioxidant properties that can effectively inhibit the oxidation of myoglobin, thereby extending its stability. Furthermore, the observed declining trend in the a* values can be ascribed to the progressive oxidation of myoglobin and the subsequent accumulation of metmyoglobin over time (Zhang *et al.*, 2023).

The yellowness index in the control sample and the treatments initially increased until day 4 and then decreased until the end of the storage period. The b* fluctuations largely depends on the food matrix, and it is clear that changes such as pH change, oxidation rate, water activity, etc. within the matrix, exerts a significant influence on this characteristic across numerous food products (Comi *et al.*, 2015).

The findings of the present study align with previous research indicating that the incorporation of a chitosan coating enhanced with oregano essential oil contributes to an improvement in the color quality of burger samples. Also, in the evaluation of burger treatments, an initial increase in color indices was recorded during the early days of storage, which was subsequently followed by a decline (Amadio *et al.*, 2019). In an alternative investigation, it was observed that the incorporation of ginger essential oil into tilapia fish burgers significantly improved their color characteristics (Mattje *et al.*, 2019). The findings of an additional study examining the impact of ginger powder on the quality of pork burgers suggest that the inclusion of ginger powder enhances the color intensity of these products. This observation aligns with the results of the present research (Mancini *et al.*, 2017).

- *Sensory characteristics results*

The findings presented in Table 3 indicate that both the coating treatment and the storage duration had a statistically significant impact on the sensory characteristics, including color, flavor, odor, texture, and overall acceptance of all hamburger samples examined ($p<0.05$). Furthermore, the interaction effect of the variables on the sensory characteristics of the samples, with the exception of odor and texture, was found to be statistically significant ($p>0.05$). On day zero, the sensory characteristics of the treatments did not exhibit a statistically significant difference when compared to the control group. However, on subsequent storage days, the treatments displayed a statistically significant difference (p<0.05). Moreover, throughout the 16-day storage period, there was a significant reduction in the sensory scores pertaining to color, flavor, odor, texture, and overall acceptance in all hamburger samples (p<0.05). Nonetheless, the treatments coated with xanthan gum and incorporating ginger essential oil exhibited a gradual decline in sensory characteristics at a slower rate.

Table 2. Color indices amounts of hamburger samples coated with xanthan containing ginger essential oil (Mean±SD)

Color index	Samples	Storage days 0	4	8	12	16
L*	C	37.42±0.16 Ca	39.72±0.03 Aa	40.81±0.08 Ba	36.21±0.04 Da	32.16±0.06 Ea
	X	38.73±0.05 Cb	42.30±0.05 Ab	41.60±0.08 Bb	38.59±0.05 Db	36.19±0.04 Eb
	XG3	40.03±0.12 Cc	43.32±0.06 Ac	42.03±0.07 Bc	39.81±0.04 Dc	37.41±0.04 Ec
	XG4	41.59±0.04 Cc	44.61±0.04 Ad	42.26±0.04 Bd	40.94±0.04 Dd	38.68±0.04 Ed
a*	C	11.36±0.01 Aa	8.93±0.05 Aa	7.32±0.06 Ca	6.72±0.04 Da	6.01±0.04 Ea
	X	11.37±0.01 Aa	9.14±0.03 Ab	7.91±0.03 Cb	6.94±0.04 Db	6.38±0.05 Eb
	XG3	11.41±0.01 Ba	12.37±0.04 Bc	10.70±0.11 Cc	8.38±0.05 Dc	7.55±0.04 Ec
	XG4	11.42±0.01 Ba	13.32±0.06 Bd	11.30±0.05 Cd	9.72±0.06 Dd	8.17±0.06 Ed
b*	C	7.29±0.04 Ca	8.17±0.03 Aa	7.88±0.02 Ba	7.28±0.04 Ca	6.54±0.59 Da
	X	7.97±0.02 Cb	8.61±0.03 Ab	8.06±0.06 Bb	7.94±0.04 Cb	7.72±0.04 Db
	XG3	8.33±0.09 Cc	8.90±0.08 Ac	8.20±0.04 Bc	8.02±0.05 Cc	7.82±0.06 Dc
	XG4	8.62±0.04 Cd	9.10±0,03 Ad	8.83±0.05 Bd	8.48±0.06 Cd	8.03±0.07 Dd

A-E: Different capital letters in each row indicate significant differences between days of storage (p<0.05).
a-d: Different lowercase letters in each column indicate significant differences between hamburger samples (p<0.05).
(C: control, X: coated with 1.5% xanthan gum, XG3: coated with 1.5% xanthan gum and 3% ginger essential oil, XG4: coated with 1.5% xanthan gum and 4% ginger essential oil t)

Table 3. Sensory evaluation scores of hamburger samples coated with xanthan containing ginger essential oil (Mean±SD)

Sensory property	Samples	Storage days 0	4	8	12	16
Color	C	5.0±0.00 Aa	4.0±0.0 Ba	3.3±0.4 Ca	2.3±0.4 Da	1.3±0.4 Ea
	X	5.0±0.00 Aa	4.3±0.4 Bb	3.8±0.4 Cb	2.8±0.4 Db	2.3±0.4 Eb
	XG3	5.0±0.00 Aa	4.8±0.4 Bc	4.0±0.0 Cc	3.3±0.4 Dc	2.8±0.4 Ec
	XG4	5.0±0.00 Aa	5.0±0.0 Bd	4.3±0.4 Cd	3.8±0.4 Dd	3.0±0.0 Ed
Flavor	C	5.0±0.00 Aa	3.8±0.4 Ba	2.3±0.4 Ca	1.8±0.4 Da	1.0±0.0 Ea
	X	5.0±0.00 Aa	4.3±0.4 Ba	2.8±0.4 Cb	3.0±0.0 Db	1.1±0.4 Eb
	XG3	5.0±0.00 Aa	4.5±0.0 Bc	3.8±0.4 Cc	3.3±0.4 Dc	2.3±0.4 Ec
	XG4	5.0±0.00 Aa	4.8±0.4 Bd	4.3±0.4 Cd	3.5±0.0 Dd	2.8±0.4 Ed
Odor	C	5.0±0.00 Aa	3.8±0.4 Ba	2.3±0.4 Ca	1.3±0.4 Da	1.3±0.0 Ea
	X	5.0±0.00 Aa	4.0±0.0 Bb	2.5±0.0 Cb	1.8±0.4 Db	1.3±0.4 Eb
	XG3	5.0±0.00 Aa	4.3±0.4 Bc	2.8±0.4 Cc	2.3±0.4 Dc	1.8±0.4 Ec
	XG4	5.0±0.00 Aa	4.8±0.4 Bd	3.3±0.4 Cd	2.8±0.4 Dd	2.0±0.0 Ed
Texture	C	5.0±0.00 Aa	3.5±0.7 Ba	2.3±0.4 Ca	1.3±0.4 Da	1.0±0.0 Ea
	X	5.0±0.00 Aa	4.3±0.4 Bb	2.8±0.4 Cb	2.0±0.0 Db	1.3±0.4 Eb
	XG3	5.0±0.00 Aa	4.8±0.4 Bc	3.3±0.4 Cc	2.3±0.4 Dc	1.8±0.4 Ec
	XG4	5.0±0.00 Aa	5.0±0.0 Bd	3.5±0.0 Cd	3.0±0.0 Dd	2.0±0.0 Ed
Overall Acceptability	C	5.0±0.00 Aa	4.0±0.0 Ba	2.8±0.4 Ca	1.8±0.4 Da	1.0±0.0 Ea
	X	5.0±0.00 Aa	4.3±0.4 Bb	3.3±0.4 Cb	2.8±0.4 Db	2.0±0.0 Eb
	XG3	5.0±0.00 Aa	4.5±0.0 Bc	3.8±0.4 Cc	3.5±0.0 Dc	2.8±0.4 Ec
	XG4	5.0±0.00 Aa	4.8±0.4 Bd	4.3±0.4 Cd	3.8±0.4 Da	3.0±0.0 Ed

A-E: Different capital letters in each row indicate significant differences between days of storage (p<0.05).
a-d: Different lowercase letters in each column indicate significant differences between hamburger samples (p<0.05).
(C: control, X: coated with 1.5% xanthan gum, XG3: coated with 1.5% xanthan gum and 3% ginger essential oil, XG4: coated with 1.5% xanthan gum and 4% ginger essential oil t)

The visual color of the hamburger treatment coated with xanthan and supplemented with 4% GEO was maintained at an acceptable level (≥ 3) throughout the storage duration, concluding on day 16. Conversely, the treatment with 3% GEO remained acceptable only until day 12. In contrast, both the xanthan-coated treatment devoid of GEO and the control sample exhibited acceptable quality solely until day eight. Despite this, the red-pink colors of all hamburger samples underwent a transformation to brownish during the refrigeration storage period.

The flavor of all hamburger treatments coated with xanthan incorporating GEO, as well as those devoid of essential oil, remained acceptable until day 12. In contrast, the control sample exhibited an acceptable sensory profile only until day four.

Regarding odor, the xanthan-coated hamburger treatment with 4% GEO demonstrated acceptable sensory attributes until day eight. In contrast, the other treatments, as well as the control sample, maintained acceptability only until day four.

In the context of sensory evaluation concerning texture, the treatment incorporating xanthan gum and 4% GEO remained deemed acceptable until day 12. Conversely, the treatment with 3% GEO was found to maintain acceptability only until day eight. Furthermore, the xanthan-coated treatment without GEO, along with the control sample, exhibited acceptable sensory attributes only up to day four.

With respect to overall acceptability, the hamburger treatment coated with xanthan incorporating 4% GEO was achieved scores exceeding 3 and deemed acceptable until day 16. In contrast, the treatment containing 3% GEO maintained acceptability until day 12, while the formulation devoid of GEO was acceptable up to day eight, and the control sample was rated acceptable only until day four.

The observed decline in scores for color, flavor, and odor over time may be attributed to several factors, including the formation of compounds stemming from fat oxidation, the generation of volatile compounds, and the proliferation of microbial organisms. Furthermore, the hydroxides generated may decompose into aldehydes and ketones; however, this process is somewhat mitigated in the samples subjected to coated treatments (Pirouz *et al.*, 2023).

Researchers examining the impact of thyme and rosemary essential oils on the organoleptic properties of chicken breast meat discovered that the application of these coating effectively improved the color and texture of the samples compared to control, but the taste and odor were not desired at the higher concentration of these essential oils (Piruz and Khani, 2022). Furthermore, a study investigating the impact of chitosan enriched with oregano essential oil on the quality of refrigerated meat burgers revealed that the application of this edible coating significantly enhanced sensory attributes, including color, flavor, odor, texture, and overall acceptance of the hamburger samples. Nonetheless, during the storage period, a decline in all sensory scores was observed. Notably, the treatments incorporating the coating and essential oil exhibited superior retention of sensory characteristics compared to the control group (Amadio *et al.*, 2019). The findings of the present research align with the existing literature in the field.

Conclusion

The findings of the present study suggest that treatments coated with xanthan gum and incorporating ginger essential oil exhibited significantly lower pH, total volatile basic nitrogen, and thiobarbituric acid values when compared to the control sample. The texture firmness and color indices (L*, a*, and b*) of the treatments incorporating ginger essential oil and xanthan gum exhibited superior and greater values as compared to the control group. Throughout the storage period, the treatment comprising 1.5% xanthan gum and 4% ginger essential oil exhibited the highest levels of brightness, redness, and yellowness. In contrast, the control sample demonstrated the lowest measurements for these attributes. The findings from the sensory evaluation indicated that the hamburger treatment coated with 1.5% xanthan gum containing 4% ginger essential oil received the highest scores in terms of color, flavor, odor, texture, and overall acceptance throughout the storage period. In contrast, the control sample received the lowest scores in these sensory attributes. Moreover, the storage duration extending to day 16 resulted in an elevation of pH, TVBN, and TBA levels. Concurrently, there was a notable reduction in texture firmness, as well as a decline in color indices and sensory evaluation scores across all hamburger samples. Nonetheless, the physicochemical and sensory characteristics exhibited a more gradual alteration in treatments coated with xanthan gum incorporating ginger essential oil. In light of the findings indicating that hamburgers treated with a xanthan gum coating containing 4% ginger essential oil maintained acceptable physicochemical characteristics until day twelve and sensory attributes until at least day eight, or potentially longer, it is advisable to employ this coating. This approach could not only enhance the physicochemical quality of hamburgers but also improve their sensory attributes, ultimately extending their shelf life by an estimated 4 to 8 days when stored under refrigeration.

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