Revista de Ciências Agroveterinárias
Universidade do Estado de Santa Catarina (UDESC)

Research Article

Effects of lemon peel essential oil (*Citrus latifolia* Tanaka) as a natural preservative in beef burgers on chemical composition, cooking characteristics, and microbiological quality

Efeitos do óleo essencial da casca do limão (Citrus latifolia Tanaka) como conservante natural em hamburguer bovino sobre a composição química, características cozimento e qualidade microbiológica

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Submission: June 14, 2024 | Acceptance: July 24, 2024

ABSTRACT

The search for healthy eating has sparked consumer interest not only in fast foods such as hamburgers, but also in more nutritious foods with fewer synthetic additives. In this sense, this study investigated the effect of applying lemon peel essential oil as a natural preservative in beef burgers on physical-chemical parameters, cooking characteristics, and microbiological quality. The essential oil was extracted from Tahiti lime peels and its chemical composition was determined, as well as yield (%) and density (g/L). Three hamburger formulations were produced: HC (without preservatives), HS (with added synthetic preservatives), and HE (with added essential oil). Physical-chemical analyses were performed, including the determination of moisture, lipids, proteins, and ash. In addition, the cooking characteristics of the hamburgers were also verified. The pH and color were monitored during storage at refrigeration temperature (5 °C) for five days and freezing (-18 °C) for 10 and 20 days. To assess microbiological quality, analyses were performed to identify *Salmonella* sp., quantify *Escherichia coli*, and identify mesophilic aerobic bacteria. The essential oil showed a satisfactory yield (1.74%) and characteristic density (0.881 g/L), containing d-limonene (45.67%) as the major compound. The addition of oil did not alter most of the physical-chemical parameters of the hamburger, except for a slight reduction in protein content. The pH (<5.8) and color remained stable in the HE formulation and showed no significant differences with the addition of essential oil compared to the control formulation (HC). The essential oil also did not affect the cooking characteristics. Microbiological analyses showed no contamination by pathogenic bacteria according to current legislation. Therefore, the addition of lemon essential oil as a natural preservative proved to be viable in beef burgers, maintaining the physicochemical characteristics, cooking characteristics, and microbiological quality of the beef burger.

KEYWORDS: Meat products. Citrus. Food additives.

RESUMO

A busca por uma alimentação saudável tem despertado o interesse dos consumidores não somente por alimentos de rápido preparo, como o hambúrguer, mas também alimentos mais nutritivos e com menos aditivos sintéticos. Nesse sentido, este estudo investigou o efeito da aplicação do óleo essencial da casca do limão como conservante natural em hambúrgueres bovinos sobre os parâmetros físico-químicos, características de cozimento e qualidade microbiológica. O óleo essencial foi extraído das cascas do limão Taiti e sua composição química foi determinada, bem como, rendimento (%) e densidade (g/L). Foram

produzidas três formulações de hambúrguer: HC (sem conservantes), HS (com adição de conservante sintético), HE (com adição do óleo essencial). As análises físico-químicas foram realizadas, incluindo a determinação da umidade, lipídios, proteínas e cinzas. Além disso, também foram verificadas as características de cozimento dos hambúrgueres. O pH e a cor foram monitorados durante o armazenamento em temperatura de refrigeração (5 °C) no tempo de cinco dias e congelamento (-18 °C) nos tempos de 10 e 20 dias. Para avaliação da qualidade microbiológica foram realizadas análises de identificação de *Salmonella* sp., quantificação de *Escherichia coli* e bactérias aeróbias mesófilas. O óleo essencial apresentou um rendimento satisfatório (1,74%) e uma densidade característica (0,881 g/L), contendo o d-limoneno (45,67%) como composto majoritário. A adição do óleo não alterou a maioria dos parâmetros físico-químicos do hambúrguer, com exceção de uma leve redução no conteúdo de proteínas. The pH (<5.8) and color remained stable in the HE formulation and showed no significant differences with the addition of essential oil compared to the control formulation (HC). O óleo essencial também não afetou as características de cozimento. As análises microbiológicas mostraram ausência de contaminação por bactérias patogênicas segundo a legislação vigente. Portanto, a adição do óleo essencial de limão como um conservante natural mostrou-se viável em hambúrgueres bovinos, mantendo as características físico-químicas, características de cozimento e a qualidade microbiológica do hambúrguer bovino.
PALAVRAS-CHAVE: Produtos cárneos. Citrus. Aditivos alimentares.

INTRODUCTION

The hamburger is one of the most popular meat products worldwide, consumed by all social classes. Because it is a protein-rich product that is quick and easy to prepare, its consumption has become increasingly common in the daily lives of Brazilians (VESSONI et al. 2019).

In Brazil, hamburgers are defined as “industrialized meat products obtained from ground meat from slaughtered animals, with or without added fat and other ingredients, molded and subjected to an appropriate technological process” (BRASIL 2000).

The high percentage of lipids and synthetic preservatives in hamburgers and other meat products raises concerns among many consumers about health and the development of chronic multifactorial diseases. For this reason, the food industry and research organizations are investing in the development of new industrialized products with improved nutritional value and reduced sodium, additives, and fat content (HUKERDI et al. 2019). Therefore, the search for natural additives with the potential to replace synthetic additives has intensified in recent years in order to ensure a healthy and natural diet for the population (BAZAN et al. 2020).

Another relevant aspect that has attracted consumers' attention is sustainable food production (DURÇO et al. 2020). In this scenario, citrus fruits such as Tahiti lemons stand out, as their industrial processing generates tons of peel and seed waste that could be used for the production and sale of essential oils, which have a very promising market in Brazil and abroad (BIZZO & REZENDE 2022).

Essential oils from citrus fruit peels are natural compounds rich in terpenes, specifically d-limonene, which have excellent bioactive properties, such as antioxidant, antifungal, and antibacterial properties. These oils have a wide range of applications in the food industry, as a natural preservative, in addition to improving sensory characteristics in terms of intensifying aroma and flavor (SINGH et al. 2021).

Recently, studies on the application of essential oils in meat products as substitutes for synthetic preservatives have revealed promising results regarding the potential of these oils in maintaining product shelf life, improving sensory characteristics and cooking properties (BAKHEET et al. 2024), and effectiveness in controlling the growth of microorganisms (LAGES et al. 2021, SHARAFATI CHALESHTORI & SHARAFATI CHALESHTORI 2017).

The use of lemon essential oil in beef burgers has been little explored, but studies in the literature point to its effectiveness as an antioxidant and antimicrobial agent in refrigerated beef cuts (BEN HSOUNA et al. 2017, LOTFY et al. 2023), cured sheep meat (XIN et al. 2022), and chicken meat (BUDIARTO et al. 2024).

Considering the bioactive and sustainable potential of lemon peel essential oil, the objective of this study was to evaluate the effect of applying Tahiti lemon peel essential oil (*Citrus latifolia* Tanaka) as a natural preservative in beef burgers on physicochemical parameters, cooking characteristics, and microbiological quality.

MATERIALS AND METHODS

The experiment was conducted at the Meat Technology Laboratory of the Federal Institute of Maranhão (Instituto Federal do Maranhão – IFMA) Maracanã Campus, São Luís, MA, Brazil. The essential oil from lemon peel (Tahiti) was extracted using the Clevenger system, by hydrodistillation (SANTOS et al. 2004). After oil extraction, the yield (dry basis) and density (kg/m^3) were determined.

The chemical composition of the essential oil was determined by Gas Chromatography coupled with Mass Spectrometry (GC-MS). The compounds detected in the samples were identified using the NIST105, NIST21, and WILEY139 mass spectrum databases. Chromatographic analyses were performed at the Analytical Center of the Federal University of São Paulo.

To prepare the hamburger meat, the *Semimembranosus* muscle (topside) was used, certified with the Federal Inspection Seal (SIF). Visible fat was removed, and the meat was then cut into cubes and weighed. The meat was then ground in an electric grinder (brand name), weighed, and divided into polyethylene trays. All ingredients used in the manufacture of the hamburgers were duly weighed (Table 1). The meat mixture, ingredients, and essential oil were homogenized manually, separated into 60g portions, and shaped into hamburgers. Subsequently, the hamburgers were wrapped in plastic wrap and frozen at -18°C. Three beef burger formulations were produced: control formulation (no preservatives added – HC), formulation 1 (synthetic preservative added – HS), and formulation 2 (0.5% essential oil added – HE).

The physical-chemical analyses of beef hamburgers were performed according to the methodology recommended by the Adolfo Lutz Institute, determining moisture (012/IV), ash (018/IV), proteins (036/IV), and lipids (032/IV) (INSTITUTO ADOLFO LUTZ 2008).

Table 1. Formulations of beef burgers without added preservatives (HC); with the addition of synthetic preservative (HS); and with the addition of lemon essential oil (HE).

Ingredients (%)	Beef Burger		
	HC	HS	HE
Pork belly	2.1	2.1	2.1
Meat	90.3	89.9	89.9
Salt	1.9	1.8	1.8
Garlic	0.3	0.3	0.3
Black pepper	0.3	0.3	0.3
Nutmeg	0.0	0.0	0.0
Onion	5.2	5.1	5.1
Lemon essential oil	0.0	0.0	0.5
Ascorbic acid	0.0	0.5	0.0
Curing salt (salt, sodium nitrate, and sodium nitrite)	0.0	0.005	0.0

pH analyses and color determination were performed during sample storage, when subjected to refrigeration in a refrigerator at 5°C (0 and 5 days) and freezing in a freezer at -10°C (10 and 20 days). The pH was determined using a solid-state pH meter (AKSO, Brazil) and the color was determined using a spectrophotometer (Delta Color, Brazil). The color analysis of the beef hamburger samples was determined using the CIELab system, where L* indicates lightness, a* indicates color from red (+a*) to green (-+a*), and b* indicates color from yellow (+b*) to blue (-b*), as recommended by the American Meat Science Association (AMSA 2012). The total color difference (ΔE) between the control sample (HC) and the HS and HE treatments was determined by equation (1).

$$\Delta E = \sqrt{(\Delta L)^2} + (\Delta a)^2 + (\Delta b^2) \quad (1)$$

Before cooking, the diameter of the raw hamburger (mm) was determined using a digital caliper. After cooking, the following were determined: weight loss due to cooking (%), moisture, lipids, moisture and lipid retention (%), diameter of the cooked hamburger (mm), and shrinkage factor (%) (SÁNCHEZ-ZAPATA et al. 2010). All analyses were performed in triplicate.

The hamburger samples from each formulation were cooked until they reached a temperature of 72 °C in the center of the hamburger. Weight loss due to cooking (1) and percentage shrinkage (diameter reduction-DR) (2) (AMSA 1978) were determined by the following equations:

$$PC = (H_{AC} - H_{DC} / \text{Raw hamburger patty}) * 100 \quad (1)$$

$$PE = (D_{ACC} - D_{DCC} / \text{Diameter of raw hamburger patty}) * 100 \quad (2)$$

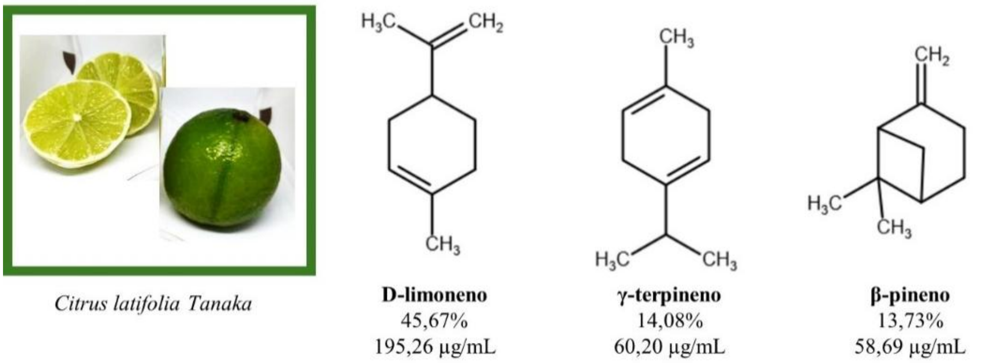
Microbiological analyses were performed according to the parameters established by Normative Instruction No. 161/2022 (BRAZIL 2022a) and the methodology recommended by APHA (2001), which include identification of *Salmonella* sp. and quantification of *Escherichia coli* and mesophilic aerobic bacteria.

The data were subjected to mean and standard deviation calculations using Microsoft Excel® software. Analysis of variance (ANOVA) and Tukey's test at a 5% significance level, used to compare means, were performed using the PROC GLM procedure of the SAS statistical program version 9.2 (SAS Institute, 2003).

RESULTS AND DISCUSSION

The essential oil extracted from lemon peel had an average yield of 1.74% (dry basis) and a density of 0.881 g/L. In addition, the oil had a clear, limpid color and a pleasant aroma characteristic of lemon. Previous studies have reported lower essential oil yields compared to this study. SIMAS et al. (2015) and PENTEADO et al. (2021) obtained a yield of 1.06% and 1.0% of essential oil from Tahiti lemon peel, respectively. BORGES et al. (2021) obtained a yield of 1.43% and a density of 0.857 g/L.

Terpenes were the major compounds found in the essential oil of Tahiti lemon peel, with D-limonene (45.67%), γ-terpinene (14.08%), and β-pinene (13.73%) being the compounds found in the highest concentrations (Figure 1). D-limonene is the main terpene found in lemon peel essential oil and can be considered a quality marker for this product. Similar results were found by BORGES et al. (2021) when they detected D-limonene (50.28%) as the major compound, followed by γ-terpinene (16.33%) and β-pinene (8.32%) in essential oil samples from Tahiti lemon peel. RUIZ-PÉREZ et al. (2016) also identified D-limonene (51.64%) as the major compound, followed by β-thujene (14.85%), β-pinene (12.79%), and γ-terpinene (12.8%) as the main components of *Citrus latifolia Tanaka*.



Source: www.chem-space.com.

Figure 1. Main terpenes found in the essential oil of Tahiti lemon (*Citrus latifolia Tanaka*) peel.

The physicochemical composition of beef burgers was similar in the three treatments and showed no significant differences, except for a slight reduction in protein observed for the HE formulation. These data demonstrate that the inclusion of essential oil and healing salt did not affect the composition of the formulations (Table 2).

Table 2. Physicochemical composition of beef burger formulations.

Parameters (%)	Beef burger			SEM	P-value
	HC	HS	HE		
Humidity	73.61±0.12[a]	73.23±0.32[a]	73.42±1.82[a]	0.313	0.909
Proteins	22.99±1.63[a]	21.48±0.17[ab]	19.27±1.00[b]	0.626	0.018
Lipids	6.11±0.05[a]	8.09±0.34[a]	8.16±0.79[a]	0.685	0.424
Ashes	2.34±0.19[a]	1.68±0.35[a]	2.22±0.15[a]	0.233	0.972

HC: Beef burger without added preservatives; HS: Beef burger with added synthetic preservatives; HE: Beef burger with added lemon essential oil. Averages followed by the same letters in the row do not differ from each other according to the Tukey test at a 5% probability level. SEM: Standard error of the mean.

According to the Technical Regulation on Quality and Identity of hamburgers, all samples are within the established limits for lipids (maximum limit of 25%) and proteins (minimum limit of 15%) (BRASIL 2022b).

LEITE et al. (2022) added 0.05% oregano essential oil as a natural antioxidant to beef burgers and found no significant differences between the control sample and the formulation containing the essential oil. The authors state that the addition of additives does not alter the chemical composition of the meat product. LOTFY et al. 2023 also found no significant variations in content of moisture (71-74.04%), protein (22.46-23.02%), ash (1.06-1.12%), and lipid (20.30-25.77%) content in ground beef treated with four essential oils as natural antioxidants, including lemon essential oil.

Table 3 shows the pH variations in the three beef hamburger formulations produced (HC, HS, and HE) evaluated at refrigeration temperatures of 5°C for five days and freezing temperatures of -18°C for 10 and 20 days. The results indicate that there were no significant differences between the HC and HE treatments, demonstrating that the addition of lemon peel essential oil did not interfere with the pH.

Significant differences were observed between the HS treatment and the other treatments evaluated. The HS sample showed the lowest pH values throughout the storage period, which is related to the addition of ascorbic acid, a synthetic antioxidant that caused the pH to decrease.

There was no interaction between storage days and treatment. These data show that the use of lemon peel essential oil preserved the pH value of beef burgers during storage at refrigeration and freezing temperatures, acting as a natural antioxidant in this product.

BEN HSOUNA et al. (2017) also found that when lemon essential oil was applied to ground beef at a concentration of 0.06%, the pH (5.52 to 6) did not show significant differences during four days of refrigerated storage (4°C). These results are consistent with previous studies showing that lemon essential oil applied to ground beef has a pH-preserving effect during refrigerated storage (LOTFY et al. 2023, XIN et al. 2022).

Table 3. pH values and color parameter evolution in beef hamburgers treated with synthetic preservative and lemon peel essential oil during storage at refrigeration temperature (5 °C) and freezing (-18 °C).

Treatment (T)	Day (D) 0	5	10	20	Average	SEM	P-value T	D	T*D
				pH					
HC	5.55	5.37	5.76	5.67	5.59 A	0.031	<.001	<.001	0.073
HS	5.26	5.20	5.47	5.42	5.34 B				
HE	5.65	5.34	5.68	5.68	5.59 A				
Average	5.49 b	5.30 c	5.63 a	5.59 a					
			L*						
HC	46.78	63.09	61.36	60.21	57.86	1.237	0.235	<.001	0.068
HS	46.96	61.59	67.04	61.54	59.28				
HE	46.91	65.64	63.27	60.55	59.09				
Average	46.88 c	63.44 ab	63.89 a	60.77 b					
			a*						
HC	13.43 b	13.75 b	20.58 a	15.34 ab	15.78 AB	0.653	0.001	<.001	0.015
HS	10.00 b	14.20 ab	15.63 ab	19.96 a	14.95 B				
HE	13.71 b	15.38 ab	20.69 a	21.35 a	17.78 A				
Average	12.38 b	14.44 b	18.97 a	18.88 a					
			b*						
HC	7.47 c	23.03 a	13.62 Bbc	19.71 ab	15.96 B	1.216	0.002	<.001	0.021
HS	12.55 b	22.94 a	24.34 Aa	25.22 a	21.01 A				
HE	8.83 b	23.91 a	26.34 Aa	27.71 a	21.70 A				
Average	9.62 b	23.29 a	21.10 a	24.21 a					

HC: Beef burger without added preservatives; HS: Beef burger with added synthetic preservatives (0.005% curing salt and 0.5% ascorbic acid); HE: Beef burger with 0.5% added lemon essential oil. SEM: Standard error of the mean. Capital letters represent the treatment and lowercase letters represent the day. Averages followed by the same letters in the row do not differ from each other according to the Tukey test at a 5% probability level.

The increase in pH is a consequence of meat deterioration caused by microorganisms that degrade proteins, producing free amino acids, NH3, and amines. ZHANG et al. (2023) found that the use of essential oils applied to beef cuts can slow down protein degradation in meat and better maintain its quality.

The results obtained for the L* parameter indicate that there was no significant difference for this parameter between treatments, only for storage time, with an increase in the L* value observed on days 5 and 10, and a slight reduction on day 20 of storage.

XIN et al. (2022) also observed an increase in brightness in cured meat with the addition of 0.150 uL/g during the 15-day storage period at 4 °C, ranging from 43.36 to 45.2. According to AMADIO et al. 2019, the increase in L* during the first days of storage may be related to myoglobin oxidation, increasing the concentration of metmyoglobin, while the decrease in L* may be related to lipid oxidation, increasing cell permeability and inducing fluid loss in the hamburger. The a* values did not differ significantly between the HE treatments, in which lemon essential oil was added, and HC, indicating that lemon peel essential oil did not affect the redness of the meat product. In contrast, HS treatment showed significant differences compared to the others, presenting the lowest a* value.

Regarding the storage period, there were no significant differences at times 0 and 5, when storage was at refrigeration temperature and the lowest a* values were obtained. In the 10 and 20 periods, when storage at freezing temperature was used, no significant differences were observed and the highest a* values were obtained.

However, significant differences were observed between time 5 and times 10 and 20, demonstrating that storage temperature influenced the a* value. These results are consistent with XIN et al. (2022), who found an increase in the a* value during refrigerated storage of cured meat using lemon essential oil.

The a* parameter is considered the main indicator of red color stability in meat and meat products (AMADIO et al. 2019). Therefore, the use of lemon peel essential oil in this study kept the red color of the product stable, which intensified during the storage period of up to 20 days at freezing temperature (Figure 2).

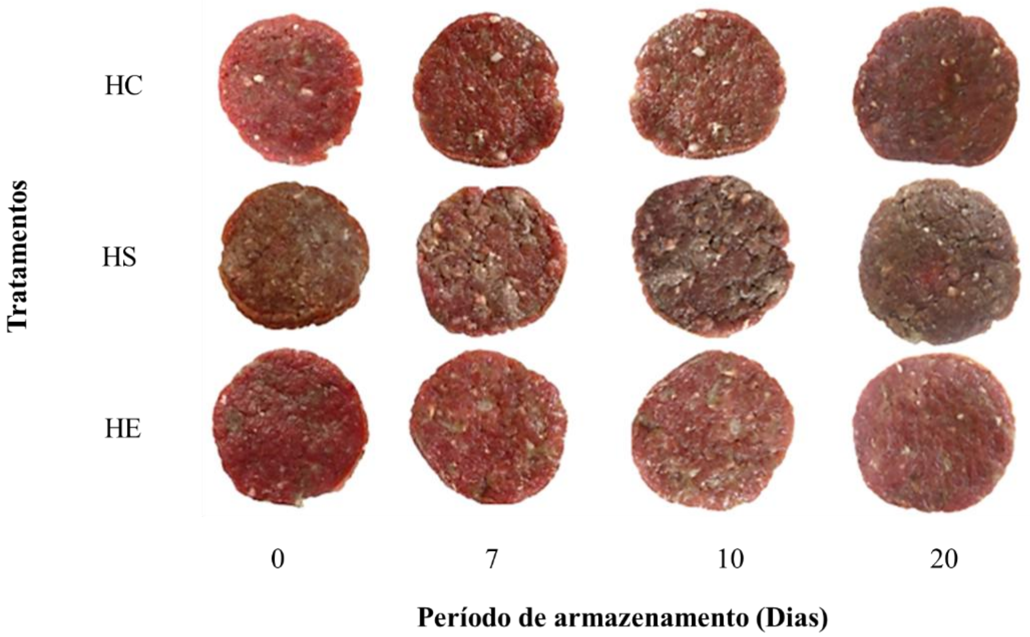


Figure 2. Color change in beef hamburgers subjected to different treatments (HC, HS, and HE) and storage periods.

The value of b* showed significant differences between the control treatment (HC) and the HS and HE treatments. There were no significant differences between the HS and HE treatments, indicating that the b* value increased similarly for both.

CARDOSO et al. (2022) evaluated color changes in beef hamburgers with 20% fat content with the addition of Goji Berry extract (3 and 6%) using the CIELAB system. These authors found that the preservation of the color of this meat product is related to the action of natural antioxidants present in this extract, which can inhibit or reduce the rate of myoglobin oxidation, as well as prevent the oxidative rancidity of the fats present in hamburgers.

The loss of weight during cooking (LWC) is one of the parameters that indicates water retention capacity (WRC); the higher the LWC, the lower the WRC. The results obtained for LWC showed that there was a significant difference between treatments, with an increase in water loss in the HS and HE treatments. These results show that the greatest water loss (>10%) occurred in the HS sample, while in the HE sample losses were less than 6%, demonstrating that the addition of this oil as a natural antioxidant in the hamburger promoted greater water retention than the formulation containing synthetic preservatives (Table 4).

Table 4. Loss of weight during cooking, moisture and lipid retention, raw and cooked diameter, and shrinkage of the three beef burger formulations.

Parameters	Beef Burger			SEM	p-value
	HC	HS	HE		
Weight loss due to cooking, %	20.95±0.82[a]	31.90±4.69[ab]	26.67±0.00[b]	1.769	0.008
Moisture retention, %	78.5±7.4[a]	70.1±2.99[a]	75.7±6.34[a]	2.098	0.283
Lipid retention, %	76.8±1.2[a]	67.8±4.4[a]	66.9±7.3[a]	11.507	0.204
Diameter of raw hamburger, mm	40.60±0.49[a]	41.91±1.05[a]	41.70±0.74[a]	0.307	0.179
Diameter of cooked hamburger, mm	37.10±1.56[a]	36.97±0.83[a]	37.89±1.14[a]	0.380	0.632
Shrinkage, %	8.65±2.95[a]	11.78±0.50[a]	9.13±3.05[a]	0.863	0.136

HC: Control hamburger without added preservatives; HS: Hamburger with added synthetic preservatives; HE: Hamburger with added lemon essential oil. Averages followed by the same letters in the row do not differ from each other according to the Tukey test at a 5% probability level.

Regarding the other parameters evaluated, there was no significant difference between the treatments for moisture retention, lipid retention, raw and cooked hamburger diameter, and hamburger shrinkage factor, demonstrating that the addition of essential oil had no effect on these characteristics of the hamburger before and after cooking.

Lipid retention and moisture retention are related to the ability of myofibrillar proteins to retain water and fat. The cooking process for meat products with high moisture content (>75%) is critical, as excessive water loss results in economic and nutritional losses and affects product acceptability (SÁNCHEZ-ZAPATA et al. 2010).

Similar results to those of this study have been found in the literature. SILVA et al. (2014), when producing beef hamburgers, found a LWC of 29.49%, shrinkage of 20.29%, and pH of 5.50. HAUTRIVE et al. (2008) found a LWC of 30.8% and pH of 5.63 for beef hamburgers. RODRIGUES & ANDRADE (2004) found a LWC of 30.7% and pH of 5.42 for beef loin cuts.

Table 5 shows the results of the microbiological analyses performed on the three hamburger formulations. The results show that there was no contamination by total coliforms, Salmonella sp., and Escherichia coli in the formulations analyzed. The quantification of mesophilic aerobic bacteria was verified in all samples and did not exceed the limits required by current legislation.

Table 5. Results of microbiological analyses performed on beef hamburger formulations after 10 days of storage at -18°C.

Microbiological parameters	Beef burger			Legislation*	
	HC	HS	HE	m	M
Total coliforms, g	Abs	Abs	Abs	-	-
Salmonella Enteritidis/25g	Abs	Abs	Abs	Abs	-
Salmonella Typhimurium/25g	Abs	Abs	Abs	Abs	-
Escherichia coli, g	Abs	Abs	Abs	$5x10^2$	$5x10^3$
BAM, g	$2.1 x10^3$	$4.5 x10^3$	$1.7 x 10^3$	10^5	10^6

HC: Control hamburger without added preservatives; HS: Hamburger with added synthetic preservative; HE: Hamburger with 0.5% added lemon essential oil; BAM: Mesophilic aerobic bacteria; *Legislation: BRASIL (2022a); Abs: Absence; m: minimum; M: maximum.

According to Normative Instruction No. 161/2022, which establishes microbiological standards for food, all hamburger samples analyzed in this study comply with the microbiological standards established by current legislation (BRASIL 2022a). Microbiological quality is an extremely important aspect in ensuring food safety for consumers. In this regard, it was found that the addition of lemon peel essential oil did not affect the microbiological quality of the hamburger produced.

The use of essential oils in hamburgers can prevent the growth of pathogenic bacteria due to the antibacterial action of the phenolic compounds present in these oils. However, their inhibitory effect may be reduced by interaction with compounds present in meat products, such as lipids (ALSAIQALI et al. 2016). The terpenes limonene and β-pinene, present in the essential oil of lemon peel, have antibacterial properties against Gram-positive and Gram-negative bacteria (BEN HSOUNA et al. 2017).

The antibacterial properties of lemon essential oil on *Escherichia coli* and *Salmonella Typhimurium*, at concentrations above 1000 mg/L, respectively, have already been confirmed by LOTFY et al. (2023). In addition, these researchers also demonstrated the effectiveness of this oil in controlling *E. coli* inoculated into ground beef during storage at 4 °C for 10 days.

BEN HSOUNA et al. (2017) found that concentrations of 0.06 and 0.312 mg/g of lemon essential oil promote the prevention of contamination and growth of pathogenic bacteria, such as *Listeria monocytogenes* in ground beef at 4 °C.

Citrus essential oils have several mechanisms of action that interfere with the growth of pathogenic bacteria and depend on their chemical composition, rich in terpenes, as well as the concentration of these compounds. Terpenes can interact with lipids present in the cell wall of bacteria, leading to cell membrane disintegration, denaturation of cellular proteins, leakage of cytoplasmic material, causing cell rupture and death (ANGANE et al. 2022).

CONCLUSION

Lemon peel essential oil is rich in terpenes, with d-limonene being the major compound, and its application in beef burgers has shown promise in replacing or reducing synthetic preservatives, such as curing salts and ascorbic acid, preserving pH, maintaining color stability, and the cooking characteristics of beef burgers. Furthermore, it did not affect the physical-chemical composition and microbiological quality of the product. Therefore, lemon peel essential oil may be a viable and sustainable alternative for use as an additive or coadjuvant in beef hamburger formulations.

NOTES

AUTHORS' CONTRIBUTIONS

Conceptualization, methodology, and formal analysis, Josilene Lima Serra Pereira and Adenilde Nascimento Mouchreck; formal analysis and research, Geisa Lohuama da Luz Pereira, Leidiana de Sousa Lima, and Leticia de Kássia Reis Frazão; resources and data curation, writing - preparation of the original draft, Josilene Lima Serra Pereira and Anderson Lopes Pereira; writing - revision and editing, Josilene Lima Serra Pereira and Geisa Lohuama da Luz Pereira; supervision, Geisa Lohuama da Luz Pereira; project management, Josilene Lima Serra Pereira and Adenilde Nascimento Mouchreck; fundraising, Josilene Lima Serra Pereira and Adenilde Nascimento Mouchreck. All authors have read and agreed to the published version of the manuscript.

FINANCING

This work was supported by the Maranhão Foundation for Research and Scientific and Technological Development (Fundação de Amparo à Pesquisa e ao Desenvolvimento Científico e Tecnológico do Maranhão – FAPEMA), Process UNIVERSAL-06644/22.

STATEMENT BY THE INSTITUTIONAL REVIEW BOARD

Not applicable to studies that do not involve humans or animals.

INFORMED CONSENT STATEMENT

Not applicable because this study did not involve humans.

DATA AVAILABILITY STATEMENT

Data can be made available upon request.

ACKNOWLEDGEMENTS

We would like to thank the Federal University of Maranhão and the Federal Institute of Maranhão-Maracanã Campus for providing the infrastructure.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest.

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