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Elaboration and evaluation of chicken burger patty added with oregano extract as a natural antioxidant

Elaboração e avaliação de hambúrguer de frango adicionado de extrato de orégano como antioxidante natural

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Highlights

Evaluation of the antioxidant activity of oregano extract.
Application of natural extract in chicken burger patties.
Burger patties with natural antioxidants were evaluated.

Abstract

This study aimed to evaluate chicken burger patties added with oregano extract as a natural antioxidant. A hydroalcoholic extract of dehydrated oregano was prepared. The lyophilized extract was evaluated for antioxidant activity by the Folin-Ciocalteu, DPPH, FRAP, and ABTS methods. Chicken burger patty formulations were prepared with the addition of lyophilized oregano extract at different concentrations: 0.00% (control formulation - C), 0.25% (NA1), 0.50% (NA2), 0.75% (NA3), and a formulation with the addition of 0.25% sodium erythorbate, a synthetic antioxidant (SA). The burger patties were evaluated for pH, water activity, lipid oxidation, yield, shrinkage, color, and texture. The oregano extract showed 182.38 g GAE g^{-1} of reducing capacity, 2531.13 mmol Trolox g^{-1} for antioxidant activity by FRAP, 2.16 mmol Trolox g^{-1} for ABTS, and an EC_{50} for DPPH of 33.88 g extract g^{-1} DPPH. The addition of oregano extract did not change the parameters of pH, water activity, shrinkage, and texture profile of the burger patties. The burger patties added with 0.50% (NA2) and 0.75% (NA3) of oregano extract were darker, less reddish, and more yellowish than C, NA1, and SA burger patties. Formulations NA1, NA2, NA3, and SA did not differ from each other regarding lipid oxidation at 60 days of storage, but with values significantly lower than formulation C (without antioxidants). Furthermore, an increase in TBARS values was observed during the storage period for formulations C and SA, which was not observed for formulations with the addition

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of natural antioxidants (NA1, NA2, and NA3). Oregano extract showed antioxidant properties evaluated by different methods, demonstrating the potential to be used as a substitute for synthetic antioxidants in foods. The addition of 0.25% of oregano extract in chicken burger patties led to lower lipid oxidation without compromising color, texture, and yield parameters, being considered the ideal concentration for application.
Key words: Antioxidant activity. Natural extract. Lipid oxidation.

Resumo

O objetivo deste estudo foi avaliar hambúrgueres de frango adicionados de extrato de orégano como antioxidante natural. Foi preparado extrato hidroalcoólico de orégano desidratado. O extrato liofilizado foi avaliado quanto a atividade antioxidante pelos métodos de Folin-Ciocalteu, DPPH, FRAP e ABTS. Formulações de hambúrgueres de frango foram preparadas com adição de extrato liofilizado de orégano em diferentes concentrações: 0,00% (formulação controle-C), 0,25% (NA1), 0,50% (NA2) e 0,75% (NA3) e uma formulação com adição de 0,25% de eritorbato de sódio, antioxidante sintético (SA). Os hambúrgueres foram avaliados, quanto ao pH, atividade de água, oxidação lipídica, rendimento, encolhimento, cor e textura. O extrato de orégano apresentou 182,38 g EAG.g^{-1} de capacidade redutora, 2531,13 mmol Trolox.g^{-1} para atividade antioxidante por FRAP, 2,16 mmol Trolox.g^{-1} para ABTS e um EC_{50} para DPPH de 33,88 g extrato. g^{-1} DPPH. A adição do extrato de orégano não alterou os parâmetros de pH, atividade de água, encolhimento e perfil de textura dos hambúrgueres. Os hambúrgueres adicionados de 0,50% (NA2) e 0,75% (NA3) de extrato de orégano apresentaram-se mais escuros, menos avermelhados e mais amarelados que os hambúrgueres C, NA1 e SA. Em relação à oxidação lipídica, no tempo de 60 dias de armazenamento, as formulações NA1, NA2, NA3 e SA não diferiram entre si, mas foram significativamente menores que a formulação C (sem antioxidantes). Ainda, no decorrer do período de armazenamento, houve aumento nos valores de TBARS para as formulações C e SA, o que não foi observado para as formulações com adição de antioxidante naturais (NA1, NA2 e NA3). O extrato de orégano apresentou propriedades antioxidantes avaliadas por diferentes métodos, demonstrando potencial para ser utilizado como substituinte de antioxidantes sintéticos em alimentos. A adição de 0,25% de extrato de orégano em hambúrgueres de frango levou a menor oxidação lipídica sem comprometer os parâmetros de cor, textura e rendimento, sendo considerada a concentração ideal para aplicação.
Palavras-chave: Atividade antioxidante. Extrato natural. Oxidação Lipídica.

Introduction

The search for processed and frozen products, ready-to-eat or easy and quick to prepare, has increased in recent decades and, among them, the burger patty stands out for its combination of flavor and practicality (Oliveira et al., 2013; Trevisan et al., 2016; Dal Bosco et al., 2019). However, these products are susceptible to undergoing lipid oxidation reactions because they present a high lipid content in their composition and undergo a milling process in their preparation (Leão et al., 2017; Awad et al., 2022).

Lipid oxidation is a process that affects the quality of meat and meat products, leading to changes in color, tenderness and flavor, and may also cause the formation of undesirable and potentially toxic compounds, reducing the shelf life of processed foods (Del Ré & Jorge, 2012; Rosa et al., 2013; Awad et al., 2022). Antioxidant substances, which can be synthetic or natural, depending on their source, are used in the industry to delay and/or prevent the oxidation of lipids and proteins in foods (Karre et al., 2013; Leão et al., 2017).

Concern about health and increased awareness of the safety of food additives has led consumers to look for natural products (Falowo et al., 2014), as synthetic preservatives can cause long-term health issues (Ghabraie et al., 2016; Ribeiro et al., 2019). Most natural antioxidants are found in phenolic-rich plants (Vallderdú-Queralt et al., 2014), such as oregano, which also has antimicrobial properties and is already used as a condiment in foods (Del Ré & Jorge, 2012; Mendes et al., 2015).

Oregano is a plant belonging to the family *Lamiaceae* and its antioxidant properties are related to the presence of compounds such as rosmarinic acid, caffeic acid, thymol, and carvacrol (Del Ré & Jorge, 2012; Milevskaya et al., 2019; Awad et al., 2022). Its use as an antioxidant potential has been investigated in different food products, such as in soybean oil (Aranha & Jorge, 2012), raw chicken fillets (Krishnan et al., 2014) and traditional Brazilian sausage (Savoldi et al., 2021) in the form of an extract, and as a spice in pork burger patties (Marins et al., 2021).

In this context, this study aimed to evaluate chicken burger patties added with oregano extract as a natural antioxidant.

Material and Methods

Preparation and obtaining of oregano extract

The dehydrated oregano (*Origanum vulgare* L.) used in this study was purchased at the local market (Londrina, PR, Brazil). The preparation of the 10% extract (m v^{-1}) was performed according to the methodology described by Pitaro et al. (2012), with modifications. For this purpose, 192.42 g of oregano were ground with 1.97 L of 70% ethanol solution (v v^{-1}) in a blender (Philco, 1200 W, Brazil) for 2 minutes and the mixture was maintained in contact for 24 hours at room temperature. After this period, it was vacuum filtered, and part of the solvent was removed on a rotary evaporator (Oven ASL 102, Solab, Brazil) at 50 °C and 72 rpm.

After preparation and pre-concentration, the extract was frozen at −18 °C and subjected to lyophilization drying (CHRIST Alpha 1-2 LD Plus Lyophilizer) for 48 hours to obtain the powdered extract. The antioxidant activity analysis consisted of resuspending the oregano extract after lyophilization in a 70% ethanol solution at the initial concentration of 1.0 g L^{-1}, in triplicate, and the dilutions were prepared according to the solvent used in each methodology.

Measurement of the reducing capacity of oregano extract

The reducing capacity of the oregano extract was determined by the Folin-Ciocalteu method, as described by Kumazawa et al. (2004), with modifications, using gallic acid as a standard. The results were expressed in grams of gallic acid equivalents (GAE) per gram of extract.

Evaluation of the antioxidant activity of oregano extract by the 2,2-diphenyl-1-picrylhydrazyl (DPPH) free-radical scavenging method

The method of Brand-Williams et al. (1995), as modified by Rufino et al. (2007a), was used to analyze the antioxidant activity of the oregano extract by DPPH. The results were expressed in EC_{50}, which corresponds to the amount of sample needed to reduce the initial concentration of the DPPH radical by 50%, in gram of extract per gram of DPPH radical.

Evaluation of the extract antioxidant activity by the ferric reducing power (FRAP) method

The antioxidant activity of the oregano extract was determined by the ferric reducing power (FRAP) method, as described by Benzie and Strain (1996) and Sánchez-González et al. (2005). The results were expressed in mmol of Trolox equivalent per gram of extract.

Evaluation of the antioxidant activity of oregano extract by the $ABTS^{\bullet+}$ (2, 2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) method

The ABTS method for evaluating the antioxidant activity of oregano extract was performed as described by Rufino et al. (2007b). A standard curve was used employing Trolox as a standard (100 µmol to 2000 µmol mL^{-1}). The results were expressed in mmol of Trolox equivalent per gram of extract.

Preparation of chicken burger patties

Five different formulations of chicken burger patties were prepared with the addition of oregano extract, being NA1 with the addition of 0.25%, NA2 with the addition of 0.50%, and NA3 with the addition of 0.75%, a control formulation (C) without the addition of the antioxidant, and a formulation (SA) with the addition of 0.25% sodium erythorbate (synthetic antioxidant) (Table 1). Extract concentrations were defined in preliminary tests. Formulations with 1.0 kg of mass, with a yield of 9 chicken burger patties in each one, were prepared.

Table 1
Formulations of chicken burger patties with the addition of oregano extract: NA1 with the addition of 0.25%, NA2 with the addition of 0.50%, and NA3 with the addition of 0.75%, C- control formulation without the addition of the antioxidant, and SA with the addition of 0.25% sodium erythorbate

Ingredients (%)	C	SA	NA1	NA2	NA3
Chicken breast	60.39	60.14	60.14	59.89	59.64
Mechanically separated meat	23.50	23.50	23.50	23.50	23.50
Isolated soy protein	4.00	4.00	4.00	4.00	4.00
Water	10.00	10.00	10.00	10.00	10.00
Salt	1.70	1.70	1.70	1.70	1.70
Onion poder	0.06	0.06	0.06	0.06	0.06
Garlic poder	0.20	0.20	0.20	0.20	0.20
White pepper	0.15	0.15	0.15	0.15	0.15
Sodium erythorbate	---	0.25	---	---	---
Oregano extract	---	---	0.25	0.50	0.75
Total	100	100	100	100	100

The chicken breast and mechanically separated meat (MSM) used in the preparation of burger patties were donated by a slaughterhouse in the region of Londrina, PR, Brazil. The ingredients were weighed according to each formulation to prepare the chicken burger patties. First, the chicken breast was ground in a food processor (Multi Pro All in One 2, Philco, Brazil) together with MSM. Subsequently, the other ingredients and additives were added to the meat mass, mixed until complete homogenization, and the mass remained at rest for 5 minutes. The chicken burger patties were molded using a burger patty mold, packed in plastic food bags, and stored in a freezer at −18 °C until analysis.

Determination of water activity and pH of chicken burger patties

The pH of the burger patties was determined using a pH meter (Testo 205, Testo, Germany) in the lateral region of the burger patties. The water activity analysis was determined by dew point in an Aqualab 4 TEV (4 TEV, AquaLab, USA). Analyzes were performed in triplicate at intervals of 1, 30, and 60 days of storage at −18 °C.

Evaluation of lipid oxidation of chicken burger patties

Lipid oxidation was evaluated at 1, 30, and 60 days of storage at −18 °C, using the thiobarbituric acid-reactive substances (TBARS) method described by Tarladgis et al. (1964), with modifications. A total of 10.0 g of sample were weighed and 15.0 mL of 7.5% trichloroacetic acid (m v^{-1}) were added. The mixture was homogenized in a Turrax (Turratec TE-102, Tecnal, Brazil) at 7000 rpm for 1 minute, centrifuged (Eppendorf, 5810 R, Germany) at 6000 rpm and 24 °C for 10 min, and filtered through filter paper. An aliquot of

5.0 mL of 0.02 mol L^{-1} 2-thiobarbituric acid was added to 5.0 mL of extract, heated in a boiling water bath for 35 minutes, cooled, and read in a spectrophotometer (Libra S22, Biochrom, England) at 532 nm. A standard curve was prepared with 1,1,3,3-tetraethoxypropane in 1% sulfuric acid at the concentration range of 400 to 3600 mmol L^{-1}. The results were expressed in mg of malonaldehyde kg^{-1} sample. Analyses were performed in triplicate.

Cooking yield, shrinkage, color, and texture analysis of chicken burger patties

Cooking yield, shrinkage, and texture profile analyses were performed at 60 days and color analysis was performed at 1, 30, and 60 days of storage at −18 °C. All analyses were performed in triplicate.

The samples of each formulation were cooked on a hotplate with a controlled temperature (150 °C) for 3 minutes on each side for yield and shrinkage analyses. The yield was calculated through the ratio between the mass of the cooked sample and the raw sample multiplied by 100, as described by Berry (1992):

$$\%\ cooking\ yield = \left(\frac{cooked\ sample\ mass}{raw\ sample\ mass}\right) x\ 100\% \quad \text{Eq. 1}$$

The percentage of shrinkage of burger patties was determined with a digital caliper, based on the difference in diameter of the burger patties before and after cooking, as described by Berry (1992):

$$\%\ shrinkage = \left(\frac{initial\ diameter - final\ diameter}{final\ diameter}\right) x\ 100\% \quad \text{Eq. 2}$$

Texture profile analysis (TPA) was performed using a TA.XTplus texture analyzer (Texture Analyzer TA.XTplus, Stable Micro Systems, UK) (Bourne, 1978), with the following parameters: pre-test speed of 5.0 cm min^{-1}, test speed of 20.0 cm min^{-1}, post-test speed of 10.0 cm min^{-1}, a force of 0.98 N, and compression distance of 0.50 cm. The samples were cut into 1 cm^3 cube, a P35 probe was used, and 2 compressions were performed. Each sample was submitted to six repetitions, in which six parameters were verified: hardness (N), resilience, springiness (mm), cohesiveness, adhesiveness (N s), and chewiness (N).

A Minolta CR-400 colorimeter (Konica Minolta, Japan), with a D65 illuminant and an observation angle of 10°, was used for the color analysis. Readings were taken at three points on each side of the sample. The results were expressed by the CIELab system: lightness (L*), red/green component (a*), and yellow/blue component (b*).

Statistical analysis

The results were subjected to analysis of variance (ANOVA), followed by Tukey's test of means at the 5% probability level, using the Statistica software version 7.0 (Statsoft, 2005).

Results and Discussion

Antioxidant activity of lyophilized oregano extract

The lyophilized extract showed a yield of 16.71% (Table 2), which is similar to that obtained by Aranha & Jorge (2012), who observed 25.3% using pure ethanol as an extracting solvent. The antioxidant activity of spices is mainly related to the phenolic-

rich composition of plants (Del Ré & Jorge, 2012; Aranha & Jorge, 2012), and this content can be estimated in the oregano extract by the results of the reduction capacity measurement (Folin-Ciocalteu), as the method interferences do not allow its direct determination (Sánchez-Rangel et al., 2013). The values obtained for this measure (182.38 g GAE g^{-1} extract) showed a high reducing capacity of the extracts, comparable to that of other antioxidant spices, such as basil (103.26 g GAE g^{-1} extract) (Savoldi et al., 2021), making the use of this extract interesting in foods susceptible to lipid oxidation.

Table 2
Yield and antioxidant activity results of oregano lyophilized extract

Analysis	Oregano lyophilized extract
Extract yield (%)	16.71
Reducing capacity (g GAE g^{-1} extract)	182.38 ± 12.78
FRAP (mmol Trolox g^{-1} extract)	2531.13 ± 200.93
ABTS (mmol Trolox g^{-1} extract)	2.16 ± 0.11
DPPH EC_{50} (g extract g^{-1} DPPH)	33.88 ± 11.28

The lyophilized oregano extract showed high antioxidant capacity (Table 2) for all evaluated methods, that is, DPPH EC_{50} (33.88 g extract g^{-1}), FRAP (2531.13 mmol Trolox g^{-1} extract), and ABTS (2.16 mmol Trolox g^{-1} extract). Savoldi et al. (2021) studied the antioxidant activity of oregano and basil extracts and obtained values for DPPH EC_{50} of 29.75 g oregano extract g^{-1} and 40.50 g basil extract g^{-1}, for FRAP of 2935.52 mmol Trolox g^{-1} oregano extract and 1358.39 mmol Trolox g^{-1} basil extract, and for ABTS of 2.58 mmol Trolox g^{-1} oregano extract and 0.71 mmol de Trolox g^{-1} basil extract. Fernandes et al (2016) found greater antioxidant activity for oregano extract with values for DPPH of 9.06 g extract g^{-1} and for FRAP of 472,32 mmol Trolox g^{-1} extract. Other authors have also reported good antioxidant activity for oregano extract by different methods (Aranha & Jorge, 2012; Pitaro et al., 2012; Gandra et al., 2013; Gonçalves et al., 2015).

Water activity and pH

Formulations did not differ from each other ($p>0.05$) regarding pH in the time of 1 day at −18 °C (Table 3). However, formulation NA2 presented lower pH values ($p<0.05$) than formulations SA and NA1 after 30 days of storage. Formulations NA1 and NA2 showed lower pH values ($p<0.05$) than the control formulation (C) in the evaluation after 60 days.

Table 3
Values of pH and water activity of chicken burgers patties with the addition of oregano extract: NA1 with the addition of 0.25%, NA2 with the addition of 0.50%, and NA3 with the addition of 0.75%, C-control formulation without the addition of the antioxidant, and SA with the addition of 0.25% sodium erythorbate

Days	Formulations	Parameters	
		pH	Water activity
01	C	$6.03^{aAB} \pm 0.06$	$0.96^{aB} \pm 0.01$
	SA	$5.95^{aA} \pm 0.10$	$0.96^{aA} \pm 0.00$
	NA1	$5.90^{aA} \pm 0.15$	$0.96^{aA} \pm 0.01$
	NA2	$5.88^{aB} \pm 0.08$	$0.96^{aB} \pm 0.00$
	NA3	$5.88^{aB} \pm 0.11$	$0.96^{aB} \pm 0.00$
30	C	$5.99^{abB} \pm 0.06$	$0.97^{aAB} \pm 0.00$
	SA	$6.04^{aA} \pm 0.06$	$0.97^{aA} \pm 0.00$
	NA1	$6.02^{aA} \pm 0.07$	$0.97^{aA} \pm 0.00$
	NA2	$5.85^{bB} \pm 0.06$	$0.97^{aA} \pm 0.00$
	NA3	$5.93^{abAB} \pm 0.04$	$0.97^{aAB} \pm 0.01$
60	C	$6.11^{aA} \pm 0.03$	$0.98^{aA} \pm 0.01$
	SA	$6.05^{abA} \pm 0.03$	$0.97^{aA} \pm 0.00$
	NA1	$6.01^{bA} \pm 0.01$	$0.98^{aA} \pm 0.00$
	NA2	$5.99^{bA} \pm 0.06$	$0.98^{aA} \pm 0.00$
	NA3	$6.02^{abA} \pm 0.02$	$0.98^{aA} \pm 0.00$

$^{a-b}$ Same lowercase letters in the column indicate that there is no difference between the formulations (Tukey, $p > 0.05$).
$^{A-B}$ Same capital letters in the column indicate that there is no difference between the days evaluated for the same formulation (Tukey, $p > 0.05$).

The pH variation over the storage period for the same formulation showed that the most stable formulations were SA and NA1, as the pH values showed no variation ($p>0.05$). On the contrary, the NA2 and NA3 formulations showed an increased pH after 60 days. Formulation C showed the least regular behavior and an increase of 2.0% in the pH value between the analyses carried out at 30 and 60 days of storage.

All formulations remained within the ideal pH value for meat products (pH 5.4 to 6.2) despite the pH variations ($p<0.05$) presented by some burger patty formulations during the storage period at −18 °C, demonstrating that the addition of oregano extract did not influence the pH value.

Burger patty formulations did not differ from each other ($p<0.05$) regarding water activity during the entire storage period at −18 °C. The water activity values ranged from 0.96 to 0.98 (Table 3), showing that the used concentrations of extract did not change the amount of free water present despite its hygroscopic properties.

Cooking yield, shrinkage, color, and texture profile (TPA)

Formulation NA3 presented the lowest cooking yield compared to the other formulations (Table 4). However, all formulations had yields above 80%, as observed by Huber (2012) for chicken burger patties with the addition of plant fibers as a fat substitute and Cócaro et al. (2019) for chicken burger patties with and without the addition of flaxseed meal, indicating that the yield values are within the expected range for this type of product. The formulations showed no difference ($p>0.05$) regarding shrinkage (Table 4). Similar values for cooking yield (81.39 and 84.82%) and shrinkage (10.43 and 8.22%) were found by Gonçalves and Magalhães (2018) for beef burger patties with a fat replacement for passion fruit peel flour. Moreover, lower yield values were found by Marins et al. (2021) (67.36 to 69.95%) and Rios-Mera et al. (2019) (33.11 to 41.16%) for pork burger patties added with rosemary and oregano and reduced-sodium beef burger patties, respectively.

Table 4
Cooking yield (%) and shrinkage (%) of chicken burger patties with the addition of oregano extract: NA1 with the addition of 0.25%, NA2 with the addition of 0.50%, and NA3 with the addition of 0.75%, C- control formulation without the addition of the antioxidant, and SA with the addition of 0.25% sodium erythorbate

Formulations	Cooking yield (%)	Shrinkage (%)
C	$89.10^{a} \pm 0.30$	$9.0^{a} \pm 0.4$
SA	$88.06^{a} \pm 1.33$	$8.3^{a} \pm 2.4$
NA1	$87.70^{a} \pm 2.17$	$9.0^{a} \pm 1.7$
NA2	$87.25^{a} \pm 0.87$	$9.2^{a} \pm 0.8$
NA3	$84.64^{b} \pm 1.46$	$11.0^{a} \pm 1.7$

$^{a-b}$ Same lowercase letters in the column indicate that there is no difference between the formulations (Tukey, $p > 0.05$).

The color of the chicken burger patties of the control formulation (C) was lighter ($p<0.05$) at the initial time (1 day), followed by formulations SA and NA1, which did not differ from each other ($p>0.05$), and NA2 and NA3 (Table 5), indicating that the increased concentration of oregano extract promoted darkening. Oregano extract also influenced the a* value, which decreased ($p<0.05$) with increasing concentration, indicating loss of red hue, with formulation C showing the highest value, followed by formulation SA. The b* value showed the highest values for formulations NA3 and NA2, thus showing a more yellowish color. The change in the color of burger patties with the addition of oregano extract is due to its natural color, which is slightly greenish and darker.

Rosa et al. (2013) also reported a trend in the reduction of red color and L* values during storage (150 days at −18 °C) of beef burger patties made with the addition of carob flour extracts, leading to their darkening. Marins et al. (2021) also found a lower L* value

(56.88) for the pork burger patty formulation with a higher concentration of rosemary and oregano. Krishnan et al. (2014) also found an increase ($p<0.05$) in b* values in raw chicken fillets with the addition of spice extracts".

Burger patty color at 30 and 60 days showed similar behavior to the first day of analysis. The inclusion of oregano extract at the highest concentration (NA3) caused color changes that may compromise the acceptance of burger patties by consumers. Therefore, the use of lower concentrations of oregano extract (formulations NA1 and NA2) is more suitable. Furthermore, formulation NA1 was the least influenced by color parameters (L*, a*, and b*).

Table 5
Color parameters, lightness (L*), red-green component (a*) and yellow-blue component (b*), of chicken burgers patties with the addition of oregano extract: NA1 with the addition of 0.25%, NA2 with the addition of 0.50%, and NA3 with the addition of 0.75%, C- control formulation without the addition of the antioxidant, and SA with the addition of 0.25% sodium erythorbate

Days	Formulations	L*	a*	b*
01	C	$60.36^{aA} \pm 0.53$	$16.75^{aA} \pm 0.24$	$15.15^{bA} \pm 0.82$
	SA	$57.56^{bA} \pm 0.52$	$15.51^{bA} \pm 0.44$	$14.45^{bcA} \pm 0.51$
	NA1	$57.33^{bA} \pm 0.66$	$12.29^{cA} \pm 0.32$	$15.41^{bA} \pm 1.84$
	NA2	$55.45^{cA} \pm 1.12$	$10.83^{dA} \pm 0.41$	$17.78^{abA} \pm 0.72$
	NA3	$54.96^{cA} \pm 0.41$	$9.09^{eA} \pm 0.47$	$18.12^{aA} \pm 0.46$
30	C	$60.41^{aA} \pm 0.85$	$14.02^{aB} \pm 0.68$	$13.18^{aB} \pm 0.89$
	SA	$58.97^{aA} \pm 0.92$	$13.57^{aB} \pm 0.06$	$14.16^{aAB} \pm 0.32$
	NA1	$56.97^{abA} \pm 1.75$	$9.63^{bC} \pm 0.20$	$12.26^{aB} \pm 0.86$
	NA2	$56.72^{abA} \pm 0.85$	$7.82^{cB} \pm 0.37$	$13.73^{aC} \pm 0.40$
	NA3	$54.48^{bA} \pm 0.67$	$7.15^{cB} \pm 0.69$	$15.87^{aA} \pm 2.82$
60	C	$60.48^{aA} \pm 0.44$	$14.10^{aB} \pm 0.67$	$13.46^{bAB} \pm 0.08$
	SA	$57.71^{bA} \pm 0.48$	$12.32^{bC} \pm 0.72$	$13.40^{bB} \pm 0.29$
	NA1	$56.44^{bcA} \pm 0.25$	$10.65^{cB} \pm 0.30$	$14.28^{bAB} \pm 0.42$
	NA2	$56.06^{cA} \pm 0.45$	$8.46^{dB} \pm 0.05$	$16.04^{aB} \pm 0.71$
	NA3	$55.13^{cA} \pm 0.58$	$6.68^{eB} \pm 0.51$	$16.70^{aA} \pm 0.39$

$^{a-e}$ Same lowercase letters in the column indicate that there is no difference between the formulations (Tukey, $p > 0.05$).
$^{A-C}$ Same capital letters in the column indicate that there is no difference between the days evaluated for the same formulation (Tukey, $p > 0.05$).

Texture showed no difference ($p<0.05$) between the five chicken burger patty formulations regarding the evaluated parameters (hardness, springiness, cohesiveness, chewiness, resilience, and adhesiveness) (Table 6). It indicates that the addition of oregano extract at the studied concentrations does not interfere with the texture profile of the product, which is positive, as the texture parameters are essential for product acceptability.

Table 6
Texture profile (TPA) of chicken burgers patties with the addition of oregano extract: NA1 with the addition of 0.25%, NA2 with the addition of 0.50%, and NA3 with the addition of 0.75%, C- control formulation without the addition of the antioxidant, and SA with the addition of 0.25% sodium erythorbate

Parameters	Formulations				
	C	SA	NA1	NA2	NA3
Hardness (N)	2413[a] ± 443	2463[a] ± 826	2429[a] ± 779	2482[a] ± 518	2857[a] ± 970
Springiness (mm)	1.03[a] ± 0.06	1.01[a] ± 0.05	0.97[a] ± 0.02	0.96[a] ± 0.02	0.96[a] ± 0.01
Cohesiveness	0.53[a] ± 0.02	0.50[a] ± 0.06	0.50[a] ± 0.06	0.52[a] ± 0.03	0.47[a] ± 0.05
Chewness (N mm)	1318[a] ± 260	1206[a] ± 221	1148[a] ± 210	1235[a] ± 193	1285[a] ± 321
Resilience	0.21[a] ± 0.01	0.18[a] ± 0.04	0.18[a] ± 0.04	0.19[a] ± 0.02	0.16[a] ± 0.03
Adhesiveness (N.s)	5.66[a] ± 1.72	5.48[a] ± 1.64	5.91[a] ± 1.71	5.94[a] ± 1.25	5.15[a] ± 0.91

[a] Same lowercase letters in the line indicate that there is no difference between the formulations (Tukey, $p > 0.05$).

Lipid oxidation

Burger patty formulations showed no difference ($p>0.05$) relative to lipid oxidation at 1 and 30 days of storage at −18 °C (Table 7). Formulation C showed higher TBARS values ($p<0.05$) than the other formulations after 60 days of storage, indicating higher oxidative instability. However, no formulation presented values above the human detection threshold (0.5 to 1.0 mg of malonaldehyde kg^{-1}) recommended by De Carli et al. (2013), characterized by the appearance of a rancid flavor. Pires et al. (2017) obtained higher values than this study for chicken burger patties with the addition of rosemary and green tea extracts (120 days at −18 °C).

Table 7
Values of TBARS (mg malonaldeyde kg^{-1} sample) of chicken burgers formulations patties with the addition of oregano extract: NA1 with the addition of 0.25%, NA2 with the addition of 0.50%, and NA3 with the addition of 0.75%, C- control formulation without the addition of the antioxidant, and SA with the addition of 0.25% sodium erythorbate

Parameters	TBARS (mg malonaldeyde kg^{-1} sample)		
	Days of storage at -18 ºC		
	1	30	60
C	0.08^{aB} ± 0.01	0.11^{aB} ± 0.02	0.26^{aA} ± 0.03
SA	0.08^{aB} ± 0.00	0.10^{aB} ± 0.01	0.16^{bA} ± 0.01
NA1	0.08^{aA} ± 0.01	0.10^{aA} ± 0.02	0.14^{bA} ± 0.06
NA2	0.08^{aA} ± 0.01	0.09^{aA} ± 0.01	0.11^{bA} ± 0.01
NA3	0.10^{aA} ± 0.01	0.12^{aA} ± 0.04	0.12^{bA} ± 0.01

$^{a-b}$ Same lowercase letters in the column indicate that there is no difference between the formulations (Tukey, $p > 0.05$).
$^{A-B}$ Same capital letters in the line indicate that there is no difference between the days evaluated for the same formulation (Tukey, $p > 0.05$).

Importantly, burger patties with the addition of oregano extract (NA1, NA2, and NA3) did not differ ($p<0.05$) from burger patties with the addition of sodium erythorbate (SA) at all storage times, demonstrating the possibility of using it to replace the synthetic antioxidant, as it had the same effects in protecting against lipid oxidation. Furthermore, formulation NA1 (addition of 0.25% oregano extract) did not differ from formulations NA2 and NA3 at 60 days, being equally efficient in controlling the product oxidation and indicating that the 0.25% oregano extract concentration may be sufficient for application in chicken burger patties.

Additionally, lipid oxidation values of the analyzed products were relatively low (0.08 to 0.26 mg of MDA kg^{-1} chicken burger patty). In this case, chicken burger patties are raw products stored at −18 °C, delaying oxidation, unlike what happens in cooked meat products, which are more susceptible to lipid oxidation due to the cooking process (Lima et al., 2013; Awad et al., 2022).

An increase in TBARS values ($p<0.05$) was observed for formulations C and SA during the storage period (60 days) (Table 7), which was not observed for formulations with the addition of natural antioxidants ($p>0.05$). Ferreira et al. (2011) also found protection against lipid oxidation (0.5 to 0.7 mg of MDA kg^{-1} burger patty) when adding 0.1% of yerba mate extract to beef burger patties under storage at −18 °C (90 days).

Importantly, all formulations with the addition of oregano extract (NA1, NA2, and NA3) showed low values of lipid oxidation. The choice of the ideal concentration for application in burger patties is necessary to consider the results of all burger patty quality parameters. Therefore, the 0.25% oregano extract concentration (NA1) seems to be the ideal one, as it inhibited the oxidative process and did not change the yield and color parameters.

Conclusions

Oregano extract showed antioxidant properties evaluated by different methods, demonstrating the potential to be used as a substitute for synthetic antioxidants in foods. The addition of 0.25% oregano extract in chicken burger patties led to lower lipid oxidation without compromising color, texture, and yield parameters, being considered the ideal concentration for application.

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