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Original Article

Comparative analysis of the use of natural and synthetic antioxidants in chicken meat: an update review

Análise comparativa do uso de antioxidantes naturais e sintéticos na carne de frango: uma revisão atualizada

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Abstract

The search for healthy foods has attracted the industry's attention to developing products that use natural ingredients, including natural antioxidants. Antioxidants act as free radicals or oxygen scavengers, inhibiting lipid oxidation and adversely affecting meat products' sensory and nutritional quality. Several synthetic antioxidants have been used in the meat industry; however, studies point to health risks related to their consumption. Such fact drives research into natural antioxidants extracted from grains, oilseeds, spices, fruits, and vegetables, which may have a health-promoting effect. This manuscript evaluates the effectiveness of several natural antioxidants in improving the quality and shelf life of chicken meat products during processing, storage, and distribution. The potential effects of natural antioxidants widely used in chicken products are also discussed. It can be concluded that these natural antioxidants are possible substitutes for synthetic ones. However, their use can affect the product's characteristics.

Keywords: chicken meat, healthy foods, natural additives, antioxidants.

Resumo

A busca por alimentos saudáveis tem atraído a atenção da indústria para o desenvolvimento de produtos que utilizam ingredientes naturais, incluindo antioxidantes naturais. Os antioxidantes atuam como radicais livres ou sequestradores de oxigênio, inibindo a oxidação lipídica e afetando adversamente a qualidade sensorial e nutricional dos produtos cárneos. Vários antioxidantes sintéticos têm sido usados na indústria da carne; no entanto, estudos apontam riscos à saúde relacionados ao seu consumo. Tal fato impulsiona a pesquisa de antioxidantes naturais extraídos de grãos, oleaginosas, especiarias, frutas e vegetais, que podem ter um efeito de promoção da saúde. Este manuscrito avalia a eficácia de vários antioxidantes naturais na melhoria da qualidade e prazo de validade de produtos de carne de frango durante o processamento, armazenamento e distribuição. Os efeitos potenciais de antioxidantes naturais amplamente utilizados em produtos de frango também são discutidos. Pode-se concluir que esses antioxidantes naturais são possíveis substitutos dos sintéticos. No entanto, seu uso pode afetar as características do produto.

Palavras-chave: carne de frango, comidas saudáveis, aditivos naturais, antioxidantes.

1. Introduction

During the processing and commercialization of industrialized foods, the products need preservation and conservation, thus maintaining their integrity and food security until final consumption. Salt was the first additive used as a food preservative. Other food additives are added to most industrialized foods to maintain their integrity and desirable characteristics (Aissa, 2010).

A food additive is any ingredient intentionally added to food with no nourishing purpose but to modify the physical, chemical, biological, or sensory characteristics during the manufacture, processing, preparation, treatment, packaging, storage, transport, or handling of food (ANVISA, 1997).

Among the food additives are antioxidants responsible for preventing lipid oxidation in food. Lipid oxidation can promote significant changes in food; many of the attributes of sensory quality are altered, such as unpleasant taste and odor, loss of pigment color, compromised texture, loss of vitamins, dehydration, and consequent decrease in product safety and quality, caused by the

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formation of potentially toxic compounds (Alves et al., 2020; Rigueto et al., 2017; Tsai et al., 2005). Although deteriorative, microbiological, and enzymatic reactions can be inhibited using low temperatures, lipid oxidation occurs even at freezing temperatures at reduced rates (Alves et al., 2020; Piedade, 2007).

In the food industry, antioxidants are classified into natural and synthetic. Synthetic antioxidants are currently the most used by the food industry and have a daily intake limit that is considered safe. However, the use of synthetic antioxidants in foods has been questioned, demonstrating the possibility that they have harmful effects, such as carcinogenic effects (Georgantelis et al., 2007), and therefore, the search for natural antioxidants has increased (Bauer et al., 2001; Souza & Villela, 2006).

In Brazil, the most used synthetic antioxidants are butyl hydroxytoluene (BHT), propyl gallate (PG), butyl hydroxy anisole (BHA), and tert-butyl hydroquinone (TBHQ) (Takemoto et al., 2009). Scientific research has been done with BHT (Butyl hydroxytoluene), BHA (Butyl hydroxyanisole), and TBHQ (tert-butyl hydroquinone) to prove its toxicity. BHA-induced gastrointestinal hyperplasia in rodents (Cruces-Blanco et al., 1999). The liver, blood, and lungs are the main targets of BHT, and the observed effects were more severe than the effects of BHA (Freitas et al., 2012; Ramalho and Jorge, 2006; Witschi, 1986). TBHQ was tested in long-term experiments and did not cause hemorrhagic changes similar to BHT (Navarro, 1996). However, it showed reduced hemoglobin levels and basal cell hyperplasia (Freitas et al., 2012; Ramalho and Jorge, 2006). Other research carried out in animals showed that prolonged and acute exposure to these compounds led to the development of tumors in the pancreas, liver, and glands (Jardini and Mancini Filho, 2007).

Based on scientific studies, the JECFA (FAO/WHO Joint Committee of Experts on Food Additives) has changed the acceptable daily intake of synthetic antioxidants, and, given the possible problems that synthetic antioxidants can cause, research has been done to replace them with natural antioxidants, or making associations between them, reducing the consumption of synthetic ones (Coneglian et al., 2011; Soares, 2002).

Most natural antioxidants are derived from phenolic compounds, defined as compounds with an aromatic ring with one or more hydroxyl substituents (Ribéreau-Gayon et al., 2012). Phenolic compounds can act as antioxidants in modifying the redox potential of the medium, fighting free radicals, working as a chelator of transition metals, and repairing damage to molecules attacked by free radicals (Min and Ebeler, 2008; Podsedek, 2007).

Due to these functions and the attention given to conserving the functional properties of foods for good quality food for consumers (Oliveira et al., 2012), studies on using natural antioxidants have progressively increased (Lee et al., 2005).

The consumer himself reinforces the use of natural antioxidants since there is an increasing search for healthy foods, and a large portion of the population is uncomfortable with consuming industrialized foods whose production involves the use of substantial amounts of synthetic antioxidants (Amarowicz et al., 2004; Keglevich, 2013).

Although synthetic antioxidants have been successfully used in food industry for their oxidative retardation effect, the recent described harm potential that these substances can cause to consumers health has led to an increase in the search for natural antioxidants. Based on this observation, this review aims to compare the literature describing the activity of natural and synthetic antioxidants in chicken meat.

2. Methodology: Natural and Synthetic Antioxidants in Chicken Meat

For the development of the discussion, articles were searched (Table 1) in the Scielo and Google Academics databases with the time interval between 2002 and 2022. The selected papers carried out the study on using natural antioxidants in chicken meat, comparing with the effectiveness of the synthetic antioxidant under the same conditions of storage, manipulation, and formulation.

Table 2(a) presents the results of the Lin and Liang (2002). In the study, chicken breast meat was homogenized with 20mL of 20mM phosphate buffer. Four antioxidants were used in the study: ascorbic acid, alpha-tocopherol, Trolox C and Catechin. The experiments were performed by analyzing the formation of TBARS, protein carbonyls, and fluorescence compounds. Table 2(a) presents the values of TBARS in mg/Kg of meat after storage for 24 h.

For the experimental conditions of the study, Trolox C exhibited antioxidant activity only in the system initiated by ascorbic acid 0.7% and iron chloride 0.3% (AA/EF); ascorbic acid, alpha-tocopherol, and catechin showed antioxidant activities in the AA/FE systems, copper 0.9% + hydrogen peroxide 0.1% (CU/Per.Hid) and Hemoglobin 1% (Hb). In the system initiated by 2,2'-azobis (2-amidinopropane) hydrochloride (AAPH), only catechin delayed oxidation (Lin and Liang, 2002).

Table 2(b) shows that hydrophilic antioxidants, such as catechin and Trolox C, effectively inhibited carbonyl formation in all initiation systems. At the same time, ascorbic acid and alpha-tocopherol were effective only in the Cu/Per.Hid system (Lin and Liang, 2002).

The carbonyl group is produced in the oxidation of side chains proteins. Carbonylation of proteins is considered one of the most irreversible modifications, being the carbonyl content, a biomarker of oxidative damage in proteins (Dalle-Donne et al., 2003; Fedorova et al., 2014).

According to this, the more oxidized the protein, the more fluorescent the reaction product will be. The study also presents the effects of catechin, Trolox C, and alpha-tocopherol in inhibiting fluorescence formation, i.e., delaying lipid oxidation. Ascorbic acid did not inhibit fluorescence formation in the Hb and AA/FE systems opposed to it; it presented a pro-oxidant effect (Lin and Liang, 2002).

The study by Lin and Liang (2002) demonstrated that alpha-tocopherol acted as an effective lipid oxidation inhibitor and that Trolox C inhibits the formation of protein carbonyl and fluorescence products. Trolox C has

Table 1. Using natural and synthetic antioxidants in chicken meat about antioxidant protection measured by Thiobarbituric Acid (TBARS) production.

Title	Reference	Cut	Storage	Natural Antioxidant	Synthetic control
Effect of Antioxidants on the Oxidative Stability of Chicken Breast Meat in a Dispersion System	Lin and Liang (2002)	Homogenized breast with 20mL phosphate 20mM	24h to 37ºC	Ascorbic acid Alpha-Tocopherol Catechin	Trolox C
Application of natural antioxidants in mechanically deboned poultry meat (CMS)	Pereira (2009)	Hip-bar, front and skinless neck chicken back	No vacuum at 4ºC	Yerba Mate Extract Marcela Extract Green tea extract Alcohol-free propolis extract	BHA
Wine industry residues extract as natural antioxidants in raw and cooked chicken meat during frozen storage	Selani et al. (2011)	Ground beef	Vacuum and frozen	Isabel and Niagara Grape Bark and Seed Extract	BHT Sodium erythrobate+ citric acid + sugar
Mango ethanolic extracts as antioxidants for broilers	Freitas et al. (2012)	Bare chest	In a vacuum, cooled at 4ºC	Peel extract and mango pit	BHT
Physical-chemical and sensory characteristics of fresh sausage from poultry prepared with different natural antioxidants	Borba et al. (2012)	Chest and thighs	Polyethylene bags at 4ºC	Clove Oregano Rosemary	None
Antioxidant activity of Cerrado plant extract in raw and cooked meat and chicken	Nascimento et al. (2019)	Ground thigh and drumstick meat	In refrigerated vacuum	Murici Extract, Mama-Bitch Extract, Monkey Pepper Extract, and Groundwood Extract	BHT
Incorporation of natural antioxidant in chicken burger: oxidative stability and descriptive and hedonic temporal sensory perception	Menegali et al. (2020)	Hamburger	Without vacuum and vacuum at 2ºC	Pink Pepper Extract	BHT
Impact of coffee husk extract (Coffea Arabica L.) on oxidative processes in chicken hamburger	Farias Marques et al. (2022)	Hamburger	No vacuum at -18°C	Coffee Hull Extract	BHT
Use of pink pepper extract (Schinus terebinthifolius Raddi) in the control of lipid oxidation of fresh chicken sausage	Araújo (2022)	Fresh chicken sausage	No vacuum at 4ºC	Pink Pepper Extract	Sodium Erythorbate
Antioxidant activity of cerrado plant extracts added to chicken meatballs and antimicrobial action “in vitro”	Carvalho (2020)	Meatballs	No vacuum at 4ºC and -12ºC	Murici extract, Pau-terra, Mama-cadela and Pepper-de-monkey	BHT
Effect of pink pepper extract and type of packaging on the quality and oxidative stability of chicken hamburger	Diniz (2022)	Hamburger - chicken leg and drumstick	PVC and vacuum cooled	Pink pepper extract	BHT
Effect of bioactive-rich mango peel extract on physicochemical, antioxidant, and functional characteristics of chicken sausage	Manzoor et al. (2022)	Chicken sausage	Hermetic bag at 4°C	Mango peel extract	None
Ethanolic extract of mango seed used in the feeding of broilers: Effects on phenolic compounds, antioxidant activity, and meat quality	Farias et al. (2020)	Chicken breast	Vacuum	Mango seed extract	BHT
Oxidative stability in chicken hamburger added with antioxidants extracted from pomegranate pulp and seed (Punica granatum, L.)	Menezes Santos et al. (2020)	Hamburger	Polyethylene bags at -18°C	Pomegranate pulp and seed extract	BHT
Plum (Prunus salicina) peel and pulp microparticles as natural antioxidant additives in breast chicken patties	Basanta et al. (2018)	Hamburger	Polyethylene film, 4°C, closed environment.	MCPs from Japanese plum peel and pulp	None

Trolox C: 6-Hidroxi-2,5,7,8-tetrametilchroman-2-ácido carboxílico; BHA: Butylated Hydroxyanisole; BHT: Butylated Hydroxy Toluene.

been shown to be more effective than alpha-tocopherol in preventing protein oxidation, which may be due to Trolox C being water and organic phases soluble and alpha-tocopherol being a hydrophobic antioxidant. Catechin presented satisfactory results as an antioxidant of lipids and proteins, consequently inhibiting fluorescence formation. Catechin has great potential as a free radical scavenger, exhibiting prominent antioxidant activity. The compound was the most effective inhibitor in the AA/E system and presented higher antioxidant efficiency when compared to alpha-tocopherol, based on protein carbonyl and fluorescence formation. Due to its more significant number of hydroxyl groups, catechin has a prolonged radical protective effect in the water. The authors concluded that catechin and Trolox C were more effective in preventing protein oxidation than alpha-tocopherol. Considering the necessity for lipids and protein protection in meat, catechin is the most effective antioxidant in the four initiation systems studied.

Table 3 presents the mean values of TBARS analysis performed by Pereira (2009). To dilute and enrich the sample, 25g of chicken meat was weighed and homogenized with 225mL of peptone and 1% buffered water. After dilution, the following antioxidants were added: mate extract, Marcela extract, green tea, alcohol-free propolis extract, and synthetic antioxidant BHA.

Analyzes of phenolic and flavonoid compounds were carried out in each antioxidant, of the average values of TBARS, color, through the Cielab system with readings under the surface of the meat and internally, odor by the

Table 2. Effect of antioxidants on the formation of TBARS (mg of malonaldehyde/kg of meat) and carbonyl protein in chicken breast meat catalyzed for 24 h.

(a)

Authors	Treatment	AA 0.7%/FE 0.3% (TBARS mg/kg)	Cu 0.9%/Per. Hid. 0.1% (TBARS mg/kg)	Hb 1% (TBARS mg/kg)	AAPH 1% (mg/kg)
Lin and Liang (2002)	Control	0.64	0.45	0.52	0.40
	Ascorbic acid	0.44	0.40	0.45	0.40
	Alpha-tocopherol	0.47	0.43	0.46	0.39
	Trolox C	0.32	0.64	0.57	0.48
	Catechin	0.23	0.41	0.48	0.37

(**b**)

Authors	Treatment	Carbonyl protein (mgmol/g protein)			
		AA 0.7%/FE 0.3%	Cu 0.9%/Per. Hid. 01%	Hb 1%	AAPH 1%
Lin and Liang (2002)	Control	0.91	0.54	0.54	0.48
	Ascorbic acid	0.92	0.38	0.52	0.47
	Alpha-tocopherol	0.91	0.39	0.55	0.44
	Trolox C	0.38	0.27	0.30	0.30
	Catechin	0.28	0.16	0.28	0.21

AA: Ascorbic acid.; FE: Iron chloride; CU: Copper +; Per. Hid.: Hydrogen peroxide; Hb: Hemoglobin; AAPH: 2,2'-azobis (2-amidinopropane) hydrochloride; TBARS: Thiobarbituric acid reactive substances.

Table 3. Mean values of TBARS (mg of malonaldehyde/kg of meat) in chicken meat kept under refrigeration. Analysis was performed daily for ten days.

Authors	Treatment	Amount of antioxidants added	Mean TBARS value (mg/kg)
Pereira (2009)	Control (peptone and buffered water 1%)	-	0.25
	Ext. Mate	0.50%	0.10
	Ext. Marcela	0.50%	0.03
	Ext. Mate + Ext. Marcela	0.25% + 0.25%	0.05
	Ext. Green	0.05%	0.17
	Ext. Alcohol-free propolis	0.10%	0.09
	BHA	0.02%	0.04

Ext. Mate: Yerba Mate Extract; Ext. Marcela: Marcela extract; Ext. Green: Green Tea Extract; Ext. Alcohol-free propolis: Alcohol-free Propolis extract; BHA: 2,3-terc-butil-4-hidroxianisol; TBARS: Thiobarbituric acid reactive substances.

sensorial analysis of trained tasters, pH, and of possible pathogenic microorganisms, such as Total coliforms, E. coli, C. perfringens, Salmonella spp, and Staphylococcus aureus.

The authors obtained some conclusions through the analyzes carried out, among them that the marcela extract had the best effect on the oxidative stability of chicken meat; extracts of Marcela, mate, green tea, própolis, and the mixture between marcela and mate inhibited oxidation, did not interfere with the pH or the peroxide index of the meat. However, extracts of marcela, mate, própolis, and the mixture between marcela and mate inhibited the color and odor of chicken meat.

The authors also concluded that natural antioxidants can inhibit the microbial population in fresh chicken meat. Still, further studies should be carried out to understand better the functioning of each extract's mechanisms of action on the lipid oxidation of CMS (mechanically processed meat) of chicken.

Selani et al. (2011) performed the treatments on raw ground chicken meat, shown in Table 4, using Isabel and Niagara grape extract as a natural antioxidant.

For the preparation of grape extracts, the mixture of pressed grape residues (seeds and skins) was dried and ground, after which extracts were obtained from ethanol solution, mechanical agitation, filtration, and solvent evaporation; the extracts were kept under refrigeration until the beginning of the preparation of the treatments.

The meatballs were prepared as follows, skinless thighs and drumsticks were ground and divided into five treatments:

- IGE: Isabel grape extract at a concentration of 60mg of total phenolics (PC)/kg of meat;
- NGE: Niagara extract at a concentration of 60mg PC/kg of meat;
- BHT: 0.01% dissolved in 5mL of soybean oil without antioxidant;
- SE: Sodium erythorbate, citric acid, and sugar at 0.37% dispersed in salt;
- Control: No added antioxidants.

1.5% sodium chloride was added in all treatments, and 25g meatballs were made after homogenization. Part of them was cooked on a hot plate, stored under a vacuum, and part was packed while still raw. All treatments were stored at a freezing temperature of -18°C for nine months.

To verify the effectiveness of the antioxidants and compare them, analyses of TBARS values, pH, instrumental color, and sensory analysis were carried out right after processing, at time 0, after 3, 6, and 9 months.

The lack of cooking, vacuum packaging, and frozen storage protects the product against lipid oxidation. Therefore, such samples showed much lower TBARS values than cooked products, with no substantial effect of antioxidants observed in raw samples. However, it is essential to emphasize that the quality of the grape pomace extract, maturity, variety, geographic origin, cultivation practices, and other factors can interfere with the values found since, contrary to the results of the analysis, Brannan (2008) found reductions significant differences in TBARS values in treatments compared to controls.

The TBARS analysis shows that the control showed significantly higher values than the other treatments. The malondialdehyde levels were higher than 3 mg MDA/kg, indicating that the control samples were unfit for consumption. When comparing synthetic antioxidants (BHT and SE) with treatments with natural extracts (IGE and NGE), the values did not show a significant difference for the cooked samples, even after nine months of freezing time.

The treatments, both raw and cooked, did not show significant differences in pH, indicating that adding extracts did not affect the pH of the chicken product right after processing. During the storage period, there were changes. However, the differences were marginal and insignificant on a practical level.

Regarding instrumental color, luminosity (L*), red (a*), and yellow (b*) were analyzed. The BHT treatment in the cooked samples presented lighter samples than the others, and IGE, NGE, and SE generated a reduction in the L* value; this may have happened, especially in the IGE and NGE treatments, due to the color of the extracts, a fact which also decreased the b* value in the cooked samples. In the raw samples, a difference was observed only about the value of a*, which reduced after the 6th month of freezing; among all treatments, BHT showed the most significant reduction in a* value over the nine months of storage.

The treatments with natural antioxidants did not alter the color of the raw samples nor interfered with the pH value of the raw and cooked samples. However, the NGE interfered with the flavor and odor of the chicken meat, which was noticed in the sensory analysis by some tasters who detected a wine flavor in the samples. Of the two natural antioxidants, IGE was the one that had the best results in the sensory analysis, especially about odor, since it did not present a significant difference compared to BHT and SE.

Table 4. Ground raw chicken meat with TBARS (mg malonaldehyde/kg of meat) as a reagent, stored for nine months.

Authors	Treatment	Amount of antioxidant added	TBARS values (mg/kg) after nine months
Selani et al. (2011)	Control	-	1.29
	BHT	0.01%	0.13
	IGE	60mg PC/kg	0.81
	NGE	60mg PC/kg	0.81
	Sodium erythorbate, citric acid, and sugar	0.37%	0.70

BHT: Butylated Hydroxy Toluene; IGE: Extract of bark and grape seed Isabel; NGE: Niagara grape seed and peel extract.

They concluded that using Isabel and Niagara grape extracts, vacuum packaging, and storage under freezing temperatures can effectively delay lipid oxidation in raw chicken meat. Isabel has greater sensory acceptance.

The study by Freitas et al. (2012), shown in Table 5, consisted of supplementing the diet of 360 male Ross chicks with antioxidants BHT, mango seed extract, mango peel extract, and the control (ration without antioxidants).

The chicks were separated into groups, taking into account the treatment performed in each feed. After 42 days of life, four adult birds from each group were selected. The substances that are reactive to TBARS were analyzed in the breast meat of the bird on day 0, immediately after slaughter, discuss. Separation of breasts, and after 15 days, new analyses were performed. The meats were stored at 4ºC during the 15 days interval.

Freitas et al. (2012) observed that the values of TBARS were lower on day zero for broilers who received the feed supplemented with BHT and mango pit extract (ECAR) at the concentration of 400ppm and that after 15 days of storage, only the meat of broilers fed with extract of mango pit, in concentrations of 200 and 400 ppm, differed significantly from the control experiment. The statistical data analyses were performed by the GLM method (General Linear Model), and the means were compared by the SNK test (Student-Newman-Keuls) at a 5% probability.

In the storage period of 15 days, the ECAR extract at 200ppm and 400ppm presented lower TBARS values even when compared with the synthetic antioxidant BHT, and the difference was statically different. Therefore, the authors concluded that ethanol extracts of mango pit were the most efficient among the evaluated components that can delay the oxidative reaction in chicken meat.

Table 6 presents the experiments Borba et al. (2012) carried out. The breast and leg meat of 45 birds of the Isa Brown lineage were used in the experiments. The breasts and legs were separated and dosed manually; later, they were ground twice for the inlay preparation. The ingredients used were salt (3%), garlic (0.4%), sugar (0.3%), allspice (0.1%), black pepper (0.2%), nutmeg (0.1%), onion (2%), pork bacon (15%) and ground chicken meat (78.75%). For each treatment, in addition to the ingredients mentioned above, natural antioxidants, rosemary, clove, and oregano were added, including 0.15%. After inlay in previously sanitized swine casings, the gums were packed in polyethylene packages and stored in a refrigerator at 4ºC.

A completely randomized design was used in the study, categorizing the analysis into treatment types and four storage periods (days 0, 3, 6, and 9). Moisture, pH, and color were evaluated using the Cielab scale, where L* (luminosity), a* (red intensity), and b* (yellow intensity), substances reactive to thiobarbituric acid (mg malonaldehyde/kg sample) and sensory analysis of roasted buds.

For each characteristic studied, the results were evaluated by analysis of variance according to the SAS operating system and the comparations made by the Tukey method at 5%.

The authors observed that the samples containing oregano and rosemary presented no significant difference in oxidation characteristics when stored during different periods; these treatments also gave value for red intensity

Table 5. Adult chicken meat produced chicks feed supplementation with TBARS (mg malonaldehyde/kg of meat) as a reagent. They were analyzed in 0 and 15 days.

Authors	Treatment	Amount of antioxidant added	TBARS values on day 0 (mg/kg)	TBARS values on day 15 (mg/kg)
Freitas et al. (2012)	Control (perchloric acid 3.86%)	-	0.19	0.57
	BHT	200ppm	0.16	0.52
	Mango peel extract	200ppm	0.18	0.56
	Mango peel extract	400ppm	0.19	0.52
	Mango pit extract	200ppm	0.19	0.46
	Mango pit extract	400ppm	0.14	0.43

BHT: 2,6-diterc-butyl-p-creso; ppm: parts per million.; TBARS: Thiobarbituric acid reactive substances.

Table 6. TBARS value of the chicken meat sausage (mg malonaldehyde/kg of meat) after nine days of storage.

Authors	Treatment	Amount of antioxidant added (%/kg of meat)	TBARS values (mg/kg of meat) day 0	TBARS values (mg/kg of meat) day 9
Borba et al. (2012)	Control	-	0.27	0.40
	Clove	0.15%	0.21	0.52
	Oregano	0.15%	0.27	0.28
	Rosemary	0.15%	0.34	0.39

TBARS: Thiobarbituric acid reactive substances.

(a*) equal to control and, about the texture and acceptance parameter, the treatment with oregano received the highest scores, differing significantly from the other ones.

From the analyses performed, the authors concluded that using oregano as an antioxidant in the formulation of chicken meat sausage delayed lipid oxidation and produced better preference in sensory analysis.

Table 7 presents the results of the study conducted. In the study, 26.3g of sodium chloride was mixed in 5,256kg of thigh and drumstick ground chicken meat. Next, the ground meat was divided, and 4.38g of extract, water, and BHT were mixed to perform the experiments.

Meatballs were prepared for each treatment used and then vacuum-packed. Subsequently, a portion of the meatballs was cooked in a water bath, and then analyses were performed on the raw and cooked meatballs. One can notice that in cooked meats, murici and monkey pepper extracts presented high oxidative delay, with more expressive results than the synthetic antioxidant BHT. Rufino et al. (2010) already analyzed the antioxidant capacity of dry extract of non-traditional native plants by the bleaching method ABTS, FRAP, DDPH, and β-carotene. Murici extract presented higher antioxidant activity, a healthy substitute for the synthetic antioxidant BHT.

Meatballs were prepared for each treatment used and then vacuum-packed. Subsequently, a portion of the meatballs was cooked in a water bath, and then analyses were performed on the raw and cooked meatballs. One can notice that in cooked meats, murici and monkey pepper extracts presented high oxidative delay, with more expressive results than the synthetic antioxidant BHT. Rufino et al. (2010) already analyzed the antioxidant capacity of dry extract of non-traditional native plants by the bleaching method ABTS, FRAP, DDPH, and β-carotene. Murici extract presented higher antioxidant activity, a healthy substitute for the synthetic antioxidant BHT.

Araújo (2022) evaluated the effectiveness of pink pepper extract as a natural antioxidant in fresh chicken sausage. The pink pepper extract was obtained by agitation, and after receiving it, it was frozen until the sausages were manufactured. For the preparation of sausages, ground chicken meat and skin, water, salt, and curing salt were used. For the formulation of treatments, pink pepper extract and the synthetic antioxidant sodium erythorbate were added. The treatments were separated as follows:

- LC: Control sausage;
- LE: Sausage with sodium erythorbate;
- LEP 0.5%: Sausage with 0.5% pink pepper extract;
- LEP 1.0%: Sausage with 1% pink pepper extract;
- LEP 2.0%: Sausage with 2% pink pepper extract.

The sausages were stored in polystyrene trays, wrapped in cling film, refrigerated at 4°C, and evaluated at 0, 7, and 14 days for lipid oxidation and physical-chemical composition.

There was a small decrease in the protein and lipid content when antioxidants were added, both synthetic and natural; however, after the analyses, Araújo (2022) confirmed that all formulations presented compositions within limits established by legislation.

The pH varied within a range of 6 and 6.6, with a decrease in these values only in LE and L0.5 on the last day of storage, probably due to the fermentation of cereals or the sugars in the sausage (Haouet et al., 2019). However, an increase in pH was observed in the LC treatment, indicating the possible development of microorganisms.

Regarding the analysis of the TBARS content, the values differed. In the treatments LC, L0.5, and L1.0, there was a significant increase in the storage time, with the control sample being the highest. Contrary to the Lc, L0.5, and L1.0 samples, the LE and L2.0 samples showed lower values.

Araújo (2022) concluded that pink pepper extract in fresh chicken sausage has a similar behavior to the synthetic antioxidant, effectively delaying lipid oxidation. However, it emphasizes the need to expand the study, including sensory and microbiological analyses.

Menegali et al. (2020) also conducted experiments to evaluate the antioxidant activity of the Pink Pepper extract in chicken meat hamburgers, comparing it with the synthetic antioxidant BHT and the control (without antioxidant). Araújo (2022) and Menegali et al. (2020) expanded the study, performing microbiological analyzes and sensory analyses.

To experiment, meat from boneless and skinless thighs and drumsticks were ground and separated into three parts for the realization of three different formulations, namely, PP (addition of the volume of pink pepper extract

Table 7. Mean values of TBARS (mg of malonaldehyde/kg of meat) obtained through analysis of variance of raw and cooked chicken meat.

Authors	Treatment	Amount of antioxidant added	Average values of Raw Meat TBARS (mg/kg)	Average values of TBARS cooked meat (mg/kg)
Nascimento et al. (2019)	CON (water)	-	0.11	0.78
	MUR	4.38g	0.12	0.10
	MC	4.38g	0.13	1.04
	PM	4.38g	0.11	0.11
	EN	4.38g	0.18	0.53
	BHT	4.38g	0.10	0.29

CON: Control; MUR: Murici extract; MC: Breast-bitch extract; PM: Monkey pepper extract; EN: Earthwood extract; BHT: Butylated Hydroxy Toluene; TBARS: Thiobarbituric acid reactive substances.

equivalent to 90mg of EFA/kg of meat), BHT (addition of 90 mg of BHT/kg of meat), C (control, without antioxidants).

In each sample, sodium chloride (1%), monosodium glutamate (0.2%), powdered onion (2%), and powdered garlic (0.2%) were added and homogenized, and then manually modeled portions of 100g. The hamburgers and vacuum bags were packaged in aerobic packaging (polystyrene tray wrapped with polyvinyl chloride (PVC) film).

Considering the three formulations and the two types of packaging, the experiment was carried out based on six treatments, named as follows:

- PP_PVC: Hamburger with pink pepper extract under aerobic conditions;
- PP_V: Hamburger with pink pepper extract in vacuo;
- BHT_PVC: Hamburger with BHT under aerobic conditions;
- BHT_V: Hamburger with BHT in a vacuum;
- C_PVC: Hamburger under aerobic conditions;
- C_V: Vacuum hamburger.

The samples were stored at 2ºC for seven consecutive days, with the incidence of white light, and the analyzes were carried out on days 1, 3, 5, and 7 of storage.

To evaluate the effectiveness of the antioxidant activity of the pink pepper extract, tests were carried out on the levels of TBARS, the color using the CR-400 Minolta colorimeter, with lightness (L*), redness (a*) and yellowness (b*), the pH using a potentiometer with automatic temperature compensation and determination of pathogenic microorganisms, including Salmonella, according to the methodologies present in the Compendium of Methods for the Microbiological Examination of Foods (Salfinger and Tortorello, 2015) and, a sensory analysis was carried out with 87 regular consumers of chicken burger.

At the end of the storage period, it can be observed that the PP and BHT treatment had significantly lower TBARS values throughout the storage period when compared to the control; it was also observed that the type of packaging did not significantly influence the effectiveness of the treatments. PP and BHT are essential information because even with the presence of oxygen in the aerobic package, both were able to delay lipid oxidation; however, according to Lucarini and Pedulli (2007), the antioxidants suppress lipid oxidation while they are present in the food and when all are consumed oxidation occurs as quickly as if no oxidants were present, so it is possible that storage time needs to be longer to see a significant effect on vacuum packaging.

PP samples had the lowest pH value, which is probably related to the slightly acidic character of the pink pepper extract. Although a difference in pH was found between the samples, the variation was minimal, which is not considered significant at a practical level, even after seven days of storage.

Among the color parameters, the PP-treated hamburgers were darker than the others, probably due to the presence of pink pepper extract, which affected the natural color of the formulations. The vacuum-packed hamburgers were slightly darker than the aerobic packs, and 4this may be related to lipid oxidation, as it negatively influences the odor and flavor and causes discoloration of the meat. Yellowing was little influenced throughout the storage period and, contrary to what Insausti et al. (2001) showed that "the increase in red color and the decrease in yellow during storage have been related to the form of metmyoglobin and meat discoloration," the study by Menegali et al. (2020) showed the opposite behavior, that is, there was an increase in a* values and maintenance of b* values, meaning that probably oxymyoglobin was present at the beginning and remained stable throughout the period.

Considering the red color, the PP hamburgers were redder than the other treatments; again, this color may be related to the color of the extract. Vacuum packed samples also resulted in redder samples.

Microbiological analysis indicated the absence of thermotolerant coliforms, Salmonella, and sulfite-reducing clostridia, approving the samples for human consumption.

In the sensory analysis, it is essential to emphasize that the rancid attribute was not associated with any sample, confirming that the TBARS values mentioned above were below the quality loss limit, 2 mg of malondialdehyde/kg of meat (da Trindade et al., 2009; Heck et al., 2019). All the hamburgers were generally well accepted; however, the aerobically packed samples obtained the lowest scores, which reinforces the results obtained through the physical-chemical analyses, that the vacuum-packed hamburgers showed less lipid oxidation.

Menegali et al. (2020) concluded that pink pepper extract proved to be as effective as BHT in delaying lipid oxidation and preserving the sensory and nutritional characteristics of chicken hamburgers, being a substitute for synthetic antioxidants.

In his research, de Farias Marques et al. (2022) fused the coffee husk extract of Coffea arabica L. to verify its effectiveness in delaying oxidative processes as a substitute for the synthetic antioxidant BHT. Fazenda Yaguara Ecológica provided the coffee husks for obtaining the extract in Pernambuco, and the extraction process was carried out according to the methodology proposed by (Cordon et al., 2020; Silva et al., 2020); shortly after extraction, the total phenolic content, volatile profile, antioxidant capacity, Trolox equivalent antioxidant capacity (TEAC) and iron-reducing antioxidant power (FRAP) were determined.

To prepare the hamburgers, boneless chicken thighs, and drumsticks were used. Meat and skin were ground separately, and the burger formulation consisted of 70% chicken meat, 10% chicken skin, and 2% sodium chloride. For the control sample, 18% of cold water was added to the initial formulation; for the sample with BHT, 0.1% of the synthetic antioxidant was added, subtracting the percentage of water added in the control sample, and 3.8% and 7.0% were added. 6% of coffee extract, subtracting the percentage of water added, content equivalent to 100 and 200ppm chlorogenic acid equivalent (CAE)/kg. After mixing, the hamburgers (80g) were molded, wrapped in plastic and aluminum foil, and stored at -18ºC.

Four treatments were produced:

- HC: negative control - without antioxidant;
- HS: Positive control - with synthetic antioxidant;
- HE100: hamburger with extract at 100ppm;
- HE200: hamburger with extract at 200ppm.

The analysis of lipid oxidation was performed in four storage times, 0, 15, 30, and 45 days under freezing, both in raw and grilled samples. The four formulations were evaluated for physical and chemical parameters, such as color, oxidative stress, and volatile compounds.

Regarding the luminosity parameter (L*), the HE samples did not differ. Still, they differed from the HC and HS treatments, indicating that the extract affected the luminosity, making the HS and HC treatments darker. Adding the extract also changed the intensity of the red color (a*) and the yellow color (b*), leaving the HE100 and HE200 treatments with a* and b* more intense.

Analyzes related to oxidative stress showed that TBARS values for both grilled and raw hamburgers were influenced by the type of treatment and storage period. Both HE100, HE200, and HS samples were effective at all analyzed times, reducing oxidation reactions compared to the control sample.

It is essential to point out that on the 45th day of storage, the HE200 treatment (0.22mg MDA/kg) promoted more excellent antioxidant activity than the HS sample, supplemented with the synthetic antioxidant BHT. When evaluating the malondialdehyde content/kg of the grilled hamburgers, except for the control sample, the values obtained were lower than 2 mg/kg of meat, demonstrating that rancid odors were absent. It is also noteworthy that the bioactive compounds of the coffee husk extract are resistant to high temperatures due to the pre-preparation process. Therefore, the HE200 treatment showed oxidative stability even after the thermal treatment.

De Farias Marques et al. (2022) recall the importance of monitoring the development of undesirable odors since foods are subjected to various procedures that promote lipid oxidation and, when these values exceed the desired level, there may be consumer rejection; however, with this study, it was evidenced that coffee husk extract as an antioxidant protected the samples.

Reinforcing the oxidative protection of the coffee husk extract, adding the extract promoted less impact on the development of volatile compounds from lipid oxidation. At the end of the storage period, the HE200 treatment proved more effective than the HE100.

Through this research, de Farias Marques et al. (2022) concluded that coffee husk extract at 200ppm is effective against lipid oxidation in chicken burgers. Its results are similar to the synthetic antioxidant BHT, being considered a potential natural additive. However, it suggests that analyses be carried out regarding the antimicrobial action and sensorial analysis to evaluate the consumers' perception regarding adding coffee husk extract.

Carvalho (2020) researched to verify cerrado plant extracts' antioxidant and antimicrobial activity in chicken breast meat. For the choice of plants, Carvalho (2020) was based on previous studies and, among the plants, Murici extract (Cyrsonima sp.), Pau-terra (qualia frandiflora), Mama-cadela (Brosimum gaudichaudii) and Pepper were used. monkeywort (Xylopia aromatic). Extraction was obtained by alcoholic extraction, agitation, filtration, and evaporation.

The chicken breast meat was boned, stored under a vacuum, and frozen until the start of the test. The meat was ground to prepare the meatballs, and 0.5% sodium chloride was added. It was divided into portions for the application of the treatments, and, as the extracts were applied in liquid form, the negative control received the same weight in water, and the treatments were as follows:

- CONT: negative control, without antioxidants;
- BHT: positive control, with the addition of 0.015% BHT;
- MUR: addition of 0.5% Murici extract;
- PT: addition of 0.5% of pau-terra extract;
- MC: addition of 0.5% of mama-cadela extract;
- PM: addition of 0.5% of monkey pepper extract.

After homogenizing the treatments, 25g meatballs were made for the refrigerated test and 20g for the frozen test, vacuum-packed and pre-cooked in a bain-marie. Then, the meatballs were packed two by two in oxygen-permeable bags and stored under refrigeration at 4ºC for eight days, and, for the frozen test, they were packed in the same way but stored at -12ºC for 120 days.

For the analysis of TBARS values, the cold storage tests were carried out on days 0, 2, 4, 6, and 8, and, for the frozen one, they were carried out at times 0, 1, 2, 3, and 4 months, they have also evaluated TBARS values in raw meatballs before the storage test; the degree of protein oxidation was determined by the method described by Jongberg et al. (2011) on day 0 and 8 and months 0 and 4.

Regarding raw meat, the control values did not differ from the other treatments since the meat was analyzed right after the incorporation of the extracts; however, after cooking, there was a significant difference between the control and the treatments. The results showed that all the antioxidants tested were effective against oxidation caused by pre-cooking.

Some treatments showed significant variation in TBARS values during frozen storage since the time was prolonged. The control was the treatment that presented the highest values, showing that, regardless of the added antioxidant, when compared to the control, all were effective in delaying lipid oxidation.

During the storage period, up to the 4th month, all extracts showed a significant difference, reducing the TBARS values about the control and BHT, verifying the antioxidant protection potential of these extracts, emphasizing that the treatments MU, PT, MC, and PM showed greater efficacy than the synthetic antioxidant BHT in the frozen test.

Unlike TBARS, where lower values are desired, high values of thiols (um/mg) indicate less protein oxidation and, according to the results obtained, pau-terra and murici extracts showed more excellent protein protection about BHT, when analyzed under refrigeration on days 0 and 8, however, in the frozen storage test, no significant difference was detected between treatments.

All extracts studied in this research showed antioxidant activity and potential protein protection. However, Carvalho (2020) concluded that murici and pau-terra extracts were superior to other treatments, including the synthetic antioxidant BHT, under the studied storage conditions.

Diniz (2022) evaluated the antioxidant capacity of pink pepper extract, compared to the synthetic antioxidant BHT, in chicken hamburgers. For the research, pink pepper extract was extracted, and then the chicken burgers were prepared.

Chicken thighs and drumsticks were boned and ground without excess fat and skin. After grinding, the meat was divided into three parts to receive the formulations then, namely:

CT: Control without antioxidants;

BHT: Addition of BHT at a concentration of 90mg/kg of meat dissolved in 5ml of soybean oil without antioxidants;

PR: Addition of aqueous pink pepper extract at a concentration of 90mg AGE/kg of meat.

1% Sodium Chloride, 0.2% Monosodium Glutamate, 2% Onion Powder, and 0.2% Garlic Powder were added to all formulations. After the additions, each formulation was homogenized, and 100g portions were molded manually.

The hamburgers resulting from the formulations were packed, half in a polystyrene tray wrapped in polyvinyl chloride (PVC) film, that is, in an aerobic environment, and the other half vacuum packed. Considering the 3 treatments and the 2 types of packaging, 6 treatments were analyzed, and the samples were stored at 4ºC and evaluated on days 1, 3, 5, and 7 of storage.

In the lipid oxidation test for aerobic packaging, Diniz (2022) observed that after 1 day of storage, the PR treatment showed significantly lower values of TBARS than the other treatments, indicating that, even after a short period, the natural antioxidant already conferred protection against lipid oxidation.

Only the CT sample showed significant values about storage time, showing high values at the end of the 7 days. During storage time, both the PR and BHT treatments showed similar values of TBARS, significantly lower than the CT treatment, demonstrating the protection against lipid oxidation of both antioxidants.

There was a significant effect of treatment and time on samples packed in vacuum packaging. The analysis of the TBARS values in this type of packaging showed that the BHT and CT samples presented similar values throughout the storage period. The PR sample presented TBARS values significantly lower than the others from the third day of storage. It was also shown that until the 5th day of storage, there was no significant oxidation of the samples, and only on the last day of storage was a slight increase in TBARS values.

Another important fact, in addition to the antioxidant activity of the added additives, was also observed as a significant difference between the two packages, being that because the aerobic package is permeable to oxygen, the samples packaged in it showed greater lipid oxidation.

Diniz (2022) concluded, about TBARS values, that pink pepper extract was more effective than BHT in delaying lipid oxidation, both in samples conditioned in aerobic packaging and vacuum packaging, but observed that, due to the Due to the short period during which the analysis of lipid oxidation was carried out in the samples packed in vacuum packaging, consequently the low oxidation rate obtained, it was not possible to evaluate the effectiveness of the natural extract of pink pepper, requiring a longer storage time.

Regarding the pH values, the samples packed under a vacuum and in the PVC film showed similar values during storage. After the 5th day of storage, the pH values decreased in both packages, especially in the PR treatment, presenting a variation from 5.81 to 6.31. This result may be because the pink pepper extract is slightly acidic. However, other factors may also be involved in pH variations, such as bacteria, storage conditions, and type of chicken cut. and chicken drumstick, the variation obtained was within the expected range.

For the color analysis, the value of L* (brightness), a* (red color intensity), and b* (yellow color intensity) were verified.

The PR treatment had a lower L* value than the other treatments, which is related to the presence of pink pepper extract, which affected the natural color of the hamburger. Selani et al. (2011) reported that treatments with the natural extract of seed and grape skin also caused changes in the L* value of chicken meat due to the dark color of the extracts used. This lower L* value for the PR treatment was observed in both forms of packaging; however, in vacuum packaging, the samples showed a lighter color from the 3rd day of storage, a color that remained until the end of the treatment.

The PR treatments also showed higher a* values than the other treatments in both forms of conditioning, and this again occurs due to the color of the pink pepper extract, emphasizing that (Diniz, 2022) observed that both in aerobic and vacuum activity, there was a significant effect of treatment and storage time on red color intensity.

Regarding the* value in the BHT treatment, it was verified that, especially in the vacuum package, the* values were lower about the control, thus indicating that the BHT, despite being efficient in delaying lipid oxidation, is unstable concerning maintaining the intensity of the red coloration.

The b* values showed a significant difference only in the storage time for both packages and treatments. The results obtained in the three treatments showed b* values with no significant difference between them. The author concluded that pink pepper extract is an efficient method to delay lipid oxidation. However, more studies must be conducted to improve its application and minimize undesirable results, such as changes in luminosity and color intensity values in red.

Manzoor et al. (2022) aimed to evaluate the antioxidant and physicochemical capacity of mango peel extract in chicken sausages and other quality attributes. To carry out the study, the mango peel extract was prepared with mangoes purchased from Aligarh, India. After converting the extract into powder and determining the total phenolic content and antioxidant activity, the extract was added to chicken sausages at 2%, 4%, and 6%.

Chicken sausages were prepared from boneless breast meat. The chicken was mixed with fat, ice water, soy protein isolate, pepper, and salt, and the mixture was blended in a chopper. The mixture was divided into four portions; in each piece, a concentration of mango peel extract (MPE) was added, these being 2%, 4%, and 6%, and a control sample without adding peel extract. After the ready formulation, the sausages were filled in a cellulose casing with the help of a unique filler.

The sausages were cooked in a conventional oven. After cooking, they were immersed in cold water, packed in airtight bags, and stored at 4°C for later analysis for 1, 5, and 10 days.

The results obtained concerning the moisture, protein, fat, and ash content in the chicken sausage did not differ, showing that the incorporation of MPE and the storage time did not affect the proximate composition of the sausages. It was observed that in the treatment with the highest concentration of MPE (6%), the pH showed lower values, and in all treatments, this pH decreased according to the storage time. This pH reduction is a desirable and positive feature, as it hinders microbial growth.

Color analysis was performed referring to luminosity (L*) and the intensity of red (a*) and yellow (b*). The value of L*, on all days of storage and in all samples formulated with MPE, showed lower values than the control, and the treatment with MPE (6%) presented the lowest values among all treatments. The red color also showed significantly lower values, about the control treatment, in the sausages formulated with MPE, significantly as the concentrations were increased in the treatments. The yellow color (b*) presented a behavior similar to a*, except in the MPE treatment (4%), where the value was almost constant.

The cooking loss was analyzed in all treatments, and the addition of mango peel extract proved to be beneficial since the control sample was the one that presented the most excellent shrinkage during the storage period and after cooking.

Treatments with concentrations of 4% and 6% were the ones that showed the highest antioxidant activity due to the elimination of DPPH (2,2-diphenyl-1-picrylhydrazyl), which may be because the mango peel has phytochemical agents such as polyphenols, anthocyanins, and carotenoids, that is, potent antioxidant agents. Following the lipid oxidation analysis, TBARS values increased in all samples throughout the storage period; however, compared with the control sample, all treatments with MPE showed significantly lower values throughout the period, showing that the mango peel extract has the potential to prevent lipid oxidation.

The addition of mango peel extract also had a positive effect on the carbonyl content of the sausages. On the first day of storage, no significant difference was observed; however, after the 10th day of storage, the value of the control sample increased and differed considerably from the other treatments, especially the MPE (4%) that presented the lowest values of carbonyl content; the thiol content values showed the same behavior as the carbonyl content for all treatments.

Manzoor et al. (2022) concluded that adding mango peel extract at a concentration of 2%, 4%, and 6% prevented lipid oxidation of chicken sausages. However, the color parameters were significantly affected. Among all treatments, 4% MPE caused minor changes in color parameters and the most significant antioxidant effect. It was highlighted that the centesimal composition, pH, and cooking parameters were not altered by adding the extract.

Farias et al. (2020) also used mango as a source of antioxidants; the extract was removed from the mango seed and was used in broiler chicken feed as well as Freitas et al. (2012) to evaluate the effects of mango seed extract at different concentrations in the diet of broiler chickens, about the levels of phenolic compounds and antioxidant activity.

To experiment, 756 male chicks of the Ross 308 lineage, one day old, were distributed in an experimental design. The treatments consisted of (i) feed without the addition of antioxidants (control), (ii) feed with the addition of 200 ppm of the antioxidant BHT and (iii) feed with the addition of 200, 400, 800, or 1000 ppm of ethanolic extract of mango (EEMS). The seed extract was carried out by the cold extraction method, and the analysis of phenolic compounds was carried out using the Folin-Ciocalteu method and the BHT as standard.

The rations were formulated following the recommended requirements according to the growth phases, and the inert ingredient of the allocation was replaced by antioxidants according to the treatments, 200, 400, 800, and 1000ppm.

After the arrival of the chicks to the aviary, they were weighed and distributed in the different treatments by weight so that the plots were obtained by average weight. Daily care such as heating, lighting, and environment were carried out as required. The chicks used in the research were already vaccinated against Marek and Gumboro disease, and throughout the experiment, feed and water were provided ad libitum.

At the end of the experiment, when the chicks were 42 days old, two birds from each treatment were selected, according to the average weight similar to that of the plot, and these were slaughtered. The breast of each slaughtered bird was deboned, divided in Half, and each half was vacuum packed, totaling 4 portions per treatment.

The two right halves of the breast from each treatment were used to determine the meat's antioxidant activity and peroxidation. The two left halves were used to determine the quality, i.e., loss of cooking water, shear force, color and color, and pH.

Regarding the antioxidant capacity, the linear regression analysis showed a linear increase in the antioxidant capacity of the meat with the rise of the ethanolic extract of the mango seed in the diet. It was observed that the meat of the breasts of chickens fed with the diet containing EEMS with a concentration from 600ppm presented greater antioxidant capacity when compared to the control. There was no significant difference in ABTS+ (ability to sequester the 2,2'-azinobis-3-ethylbenxothiazoline-6-sulfonic acid radical) between using BHT and EEMS at different levels of antioxidant capacity. Therefore, including 600ppm of EEMS in the feed may be enough to delay lipid oxidation.

Farias et al. (2020) observed that the TBARS values obtained in the control treatment were not significantly different from those obtained using the antioxidant BHT or EEMS at different concentrations. Malondialdehyde levels were also maintained at all concentration levels of EEMS and the synthetic antioxidant BHT.

The color parameters analyzed were brightness (L*), red intensity (a*), and yellow intensity (b*). The values obtained for L*, a*, and b* did not differ when comparing the different treatments with different levels of EEMS concentration. This difference probably did not occur due to the significant absence of TBARS values between treatments.

Regarding the shear characteristics, water retention capacity, and tenderness, the mango extract in the chicken diet provided meat with favorable aspects since there were no changes in the physical quality characteristics, including the pH values that did not have significant differences between the treatments.

Farias et al. (Farias et al., 2020) concluded that adding mango seed ethanol extract did not change the quality characteristics of chicken meat and that when added from a concentration of 600ppm, there was an increase in the antioxidant capacity of the meat.

In the study by Menezes Santos et al. (2020), the objective was to evaluate the oxidative stability of chicken hamburgers by adding pomegranate pulp and seed extracts. The materials necessary for the production of the hamburgers and the pomegranate for the production of the extracts were purchased at a local market in Sergipe.

The extracts from pomegranate pulp (EPR) and pomegranate seed (ESR) were placed in an amber glass bottle and stored at -18°C.

The cut was chicken thigh and drumstick, textured soy protein, salt, ground white pepper, garlic, and onion powder to prepare the chicken hamburgers. The meat was boned and subjected to freezing for 24 hours. After this period, it was kept cold, ground in a blender, and added the above ingredients. This mixture was divided into four portions to receive the addition of the antioxidant according to each treatment, namely:

T1 – Hamburger without added antioxidant (control);
T2 – Hamburger with the addition of the synthetic antioxidant BHT;
T3 – Hamburger with the addition of ESR (0.02%);
T4 – Hamburger with the addition of EPR (0.02%).

For each treatment, 10 hamburgers were prepared; each hamburger was shaped with Petri dishes, obtaining portions with a net weight of 80 g. They were packed in polyethylene bags and stored at -18°C. Analysis of instrumental color, pH, and lipid oxidation by TBARS value was performed after cooking at 0, 7, 14, 21, and 28 days. Statistical analysis was performed using Analysis of Variance (ANOVA) and Tukey test of means ($p \leq 0.05$).

Regarding total phenolic compounds and ABTS+ content, the pomegranate pulp extract showed a higher value than the seed extract.

The pH values obtained in treatments T2, T3, and T4 did not differ significantly from each other during the entire storage period, differing only from the control treatment, which presented lower pH values.

The parameters of brightness (L*), red intensity (a*), yellow intensity (b*), saturation (C*), and hue angle (h) were analyzed in all treatments. The values obtained showed that the treatments did not present a significant difference between them at the 5% significance level.

TBARS values were expressed in mg of malondialdehyde/kg of the sample, and it was observed that only the control treatment, without antioxidants, showed a significant difference. Treatments T2, T3, and T4 did not differ significantly during the entire storage period and showed lower values than the control (T1).

Menezes Santos et al. (2020) concluded that pomegranate pulp and seed extracts are possible substitutes for the synthetic antioxidant BHT since they did not cause color changes, contributed to the maintenance of the pH value, and both were effective in oxidative control; however, highlighted the need for further study regarding the ideal dosage of extract to be used in the meat product.

Basanta et al. (2018) sought to evaluate the antioxidant capacity of fiber microparticles (MPCs) from Japanese plums in oxidative retardation and maintenance of chicken burger quality.

MPCs were extracted separately from the exocarp (peel) and mesocarp (pulp) tissues of plums with ethanol. They were lyophilized and frozen for later use in hamburger formulations.

Forty-two-day-old chicken breast meat raised in confinement in Argentina was used to produce hamburgers. The skin and breast meat were ground separately, and the base formulation consisted of ground chicken breast meat, ground chicken skin, water, sodium tripolyphosphate, and salt. For the preparation of the treatments, the base formulation was divided into three and added MPCs from the peel and MPCs from the Pulp. In the third treatment, no antioxidant was added, being the control system.

Then, 140g portions of meat were separated and molded into hamburgers in a manual press, which was placed in plastic trays and stored at -20°C for 24 hours. Two more miniature hamburgers were obtained from each hamburger, placed in expanded polystyrene trays covered with polyethylene film, and stored at 4°C in a closed environment.

Analyzes were carried out on raw and cooked hamburgers, and the raw ones were evaluated on days 0, 1, 3, 6, and 10, and the cooked ones were removed from storage on days 0, 3, and 10 and roasted on a grill until reaching the temperature of 75°C in the center.

Regarding antioxidant preservation, raw hamburgers containing MPCs in the peel and pulp showed significantly lower TBARS values than the control treatment. Both had TBARS values on day 10, approximately 50% lower than the control.

The tocopherol content was determined in the raw and cooked samples, and the values obtained in the treatments containing MPCs were higher than in the control treatment. The antioxidant capacity observed in hamburgers containing MPCs, especially the peel, may be related to the high content of tocopherols, lutein, anthocyanins, and flavonoids found in fiber MPCs.

The treatments with MPCs presented a red color superior to the control during the storage period. After cooking, the treatments with pulp MPCs retained more redness than that observed in the treatment with peel MPCs. This behavior was probably due to the lower pectin content and the higher lignin content of the peel MPCs.

The quality analysis of the texture and water retention property showed that the MPCs of the pulp could contribute to the hydration and formation of the gel network, contributing to the water retention, not modifying the texture. On the other hand, the MPCs of the bark did not contribute to water retention. They changed the texture parameters because the polysaccharide composition differed from the first one.

Basanta et al. (2018) concluded that the use of MPCs from the peel and pulp obtained from Japanese plums is useful for the preservation of chicken hamburgers, and the MPCs from the pulp performed better in terms of desirable characteristics of the meat in terms of color, texture, and water holding capacity.

3. Conclusion

The consumption of synthetic antioxidants is becoming worrisome for consumers and scientists; At the same time, the search for healthier foods with few synthetic additives has increased. Based on this conjecture, research has been performed to verify the replacement of synthetic antioxidants with natural ones or the association between them.

Comparing the results obtained by different antioxidants tested in the literature contained in this study, one can notice the success of some natural antioxidants in replacing synthetic ones.

Catechin presented efficiency against lipid oxidation, carbonyl, and fluorescence formations, due to the presence of hydroxyl groups capable of eliminating radicals during extended periods in the aqueous phase.

Marcela, mate, green tea, própolis, and the combination of Marcela and mate inhibited oxidation, did not alter pH, and did not interfere with the peroxide index of chicken meat. However, only green tea extract did not change the color and odor.

Isabel and Niagara grape extract also acted effectively as antioxidants. However, its performance was successful, combined with vacuum packaging and storage under freezing temperatures.

When comparing the use of mango pit extract at the concentration of 200ppm and 400ppm with the results obtained from the synthetic antioxidant BHT, ethanol extracts of mango pit were more effective than BHT.

Oregano also presented good results regarding lipid oxidation. However, its use altered the flavor of chicken meat.

The efficacy of Murici extract and monkey pepper as a natural antioxidant was demonstrated to be at the same level as na oxidation retarder, as in cooked chicken meat with synthetic antioxidant BHT. The extracts showed high oxidative retardation, sometimes even superior to the synthetic antioxidants used in the analyzed studies.

The natural antioxidants reported in this study might be substitutes for synthetic antioxidants and, above, effectively delay lipid oxidation, whether in raw chicken meat or after heat treatment. Natural antioxidants, in addition to showing oxidative retardation, were analyzed for antimicrobial protection and acceptability in the sensory analysis and showed promising results about these requirements.

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