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Chemistry

Effects of the application of natural antioxidants on the inhibition of lipid oxidation and the influence on sensory aspects of chicken meat and its derivatives

Efeitos da aplicação de antioxidantes naturais na inibição da oxidação lipídica e influência nos aspectos sensoriais da carne de frango e seus derivados

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ABSTRACT

Lipid oxidation in meat and its derivatives causes gradual degradation of sensory and nutritional qualities, impacting consumer acceptance of the product. To delay and/or reduce this deterioration and extend shelf life, antioxidant substances are often used, predominantly synthetic ones. However, synthetic antioxidants can have carcinogenic properties, leading consumers to prefer natural products. Consequently, numerous studies have been conducted to replace synthetic antioxidants with natural alternatives. The purpose of this study is to assess the most widely used sources of natural antioxidants in meat and its derivatives, identify the main chemical groups associated with them, and examine the types of extraction methods used. Research in the Scopus and Web of Science databases yielded 35 relevant articles. It was observed that 29% of the published studies applied natural antioxidants to chicken meat, while 71% applied them to derivatives. The chemical groups most commonly associated with natural antioxidants were phenolic and flavonoid compounds. These antioxidants were used in various forms, such as extracts, powders, essential oils, and encapsulated oils. Additionally, it became evident that the concentration of natural antioxidants applied to chicken meat and its derivatives must be limited to avoid altering sensory attributes. Natural antioxidants have been shown to positively affect lipid oxidation inhibition, making them a viable alternative to synthetic antioxidants.

Keywords: Chicken meat; Lipid oxidation; Natural antioxidants; Sensory aspects

RESUMO

A oxidação lipídica em carnes e derivados causa efeitos graduais nas qualidades sensoriais e nutricionais dos alimentos, interferindo na aceitação do produto pelo consumidor. Na tentativa de retardar e/ou reduzir a deterioração dos produtos e aumentar sua vida útil, são utilizadas substâncias antioxidantes, principalmente sintéticas. No entanto, os antioxidantes sintéticos apresentam características cancerígenas e em atenção a isso, a população está preferindo optar por produtos naturais. Portanto, existem muitos estudos para substituir antioxidantes sintéticos por antioxidantes naturais. O objetivo deste estudo é avaliar as fontes de antioxidantes naturais mais utilizadas em carnes e derivados, principais grupos químicos associados e tipo de extração utilizada. Foi realizada uma pesquisa nas bases de dados Scopus e Web of Science, resultando em 35 artigos relevantes. Observou-se que 29% dos estudos publicados realizaram aplicação de antioxidantes naturais em carne de frango e 71% aplicaram em derivados. Os grupos químicos associados aos antioxidantes naturais mais utilizados foram compostos fenólicos e flavonoides. Esta aplicação está associada ao modo de utilização dos alimentos como extrato, pó, pasta, óleo essencial e óleo encapsulado. Além disso, ficou evidente que a concentração de antioxidantes naturais aplicados à carne de frango e seus derivados deve ser limitada para evitar alterações nos atributos sensoriais. Foi demonstrado que os antioxidantes naturais afetam positivamente a inibição da oxidação lipídica, tornando-os uma alternativa viável aos antioxidantes sintéticos.

Palavras-chave: Carne de frango; Oxidação lipídica; Antioxidantes naturais; Aspectos sensoriais

1 INTRODUCTION

The global production of white meat, particularly chicken, has increased mainly due to its sensory attributes, such as color, odor, taste, and texture. Additionally, there is a consumer perception that white meat is healthier than red meat (Ezz El-Din Ibrahim; Alqurashi; Alfaraj, 2022).

It is expected that within the next few years, white meat will become the most globally consumed type of meat because it tends to be less costly, making it more accessible to the population. Another notable aspect is that there are no significant cultural or religious limitations to its consumption, unlike pork and red meat. Additionally, white meat is easy to process and is commonly found in industrialized products such as hamburgers, sausages, meatballs, and nuggets (Özünlü; Ergezer; Gökçe, 2018).

Chicken meat is known for being low in fat, but its muscle lipids are highly susceptible to lipid oxidation due to their high degree of unsaturation. Because of this characteristic, chicken meat tends to be more affected by lipid oxidation than other types of meat (Özünlü; Ergezer; Gökçe, 2018). Various meat processing methods such as grinding, mixing, heating, and exposing the muscle surface to air accelerate these reactions. This deterioration can alter the texture, lead to a loss of nutrients, and ultimately reduce the shelf life of the product.

Lipid oxidation can produce free radicals and compounds that may contribute to diseases and negatively impact consumer health. Byproducts of lipid oxidation are known to have carcinogenic potential (Huang; Ahn, 2019). Consequently, antioxidants substances that slow down or prevent oxidative reactions are commonly used in the food industry (Mäkinen et al., 2020; Shah; Bosco; Mir, 2014). These antioxidants act as reducing agents, scavenging free radicals and radical species, or as pro-oxidant inactivators (Abeyrathne; Nam; Ahn, 2021).

The use of synthetic antioxidants such as butyl hydroxyanisole (BHA), butylated hydroxytoluene (BHT), tertiary butylhydroquinone (TBHQ), propyl gallate (PG), and synthetic tocopherol is widespread in the food industry (Manessis et al., 2020). However, studies suggest that these antioxidants may have toxicological and carcinogenic effects (Kumar et al., 2015; Wang; Kannan, 2019). For instance, Yang et al. (2018a) demonstrated that even at low concentrations (1 μM), BHA can promote endocrine disorders by increasing the secretion of 17β-estradiol (E2) in H295R cells (in vitro) and zebrafish (in vivo). Furthermore, studies by Sun et al. (2019) using in vitro tests discovered that 3-BHA, at a concentration of 50 μM induced obesity and other related diseases.

BHA can also adversely affect developmental and reproductive systems (Yang et al., 2018b). Additionally, propyl gallate (PG) is linked to testicular toxicity, contributing to male infertility. This effect is attributed to its ability to induce mitochondrial dysfunction and disrupt calcium homeostasis (Ham et al., 2019).

With increasing consumer interest in health, the use of natural antioxidants has become a trend. Sources such as herbs, spices, seeds, fruits, and teas are considered natural alternatives to synthetic additives (Ribeiro et al., 2019). In this context, the use of natural antioxidants in chicken meat and its derivatives emerges as a promising strategy to reduce reliance on synthetic additives. Incorporating natural antioxidants in these products enhances health safety, ensures food quality, and meets consumer expectations for healthier ingredients.

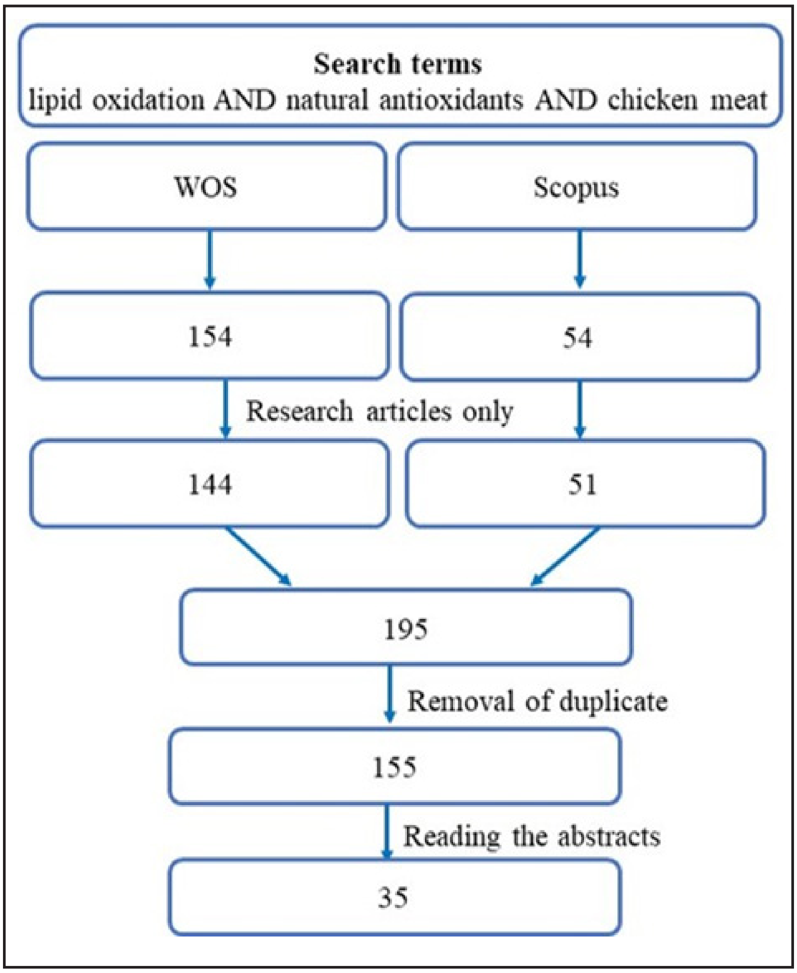
This study aimed to review research that utilized natural antioxidants in chicken meat and its derivatives, with a focus on the behavior of these antioxidants, their applications, concentrations, and the bioactive compounds responsible for the antioxidant reactions. Additionally, the study aims to evaluate the impact of natural antioxidants on sensory properties during storage or cooking, including possible limitations and challenges to the use of these compounds in the industry.

2 RESEARCH METHODOLOGY

The Scopus and Web of Science (WOS) database was used to obtain the bibliographic information for this study. The keywords used in the search were: “lipid oxidation” AND “natural oxidants” AND “chicken meat”, the filters used were “titles, summary and keywords”, and “scientific article” and the research period was restricted to the last five years.

In the initial screening only research articles were selected, to obtain a better view of the state of the art with the use of natural antioxidants used on chicken meat and derivatives. Posteriorly the duplicated articles were excluded, in the following the summaries were read, and then, the articles that were not aligned with the purpose of the research were excluded. The selected articles were the ones that used natural antioxidants for the inhibition of lipid oxidation on chicken meat and/or products based on chicken meat, while articles that used natural antioxidants as broiler chicken food supplementation were not included. Articles that applied natural antioxidants on biodegradable biofilms for application on food were also excluded. To deepen explanations and conceptualizations about mechanisms of the act of natural antioxidants on chicken meat and its derivatives were used articles and book chapters that were part of the executed selection. Figure 1 presents the method used in the selection of articles used in this research.

Figure 1 – Scientific research mapping

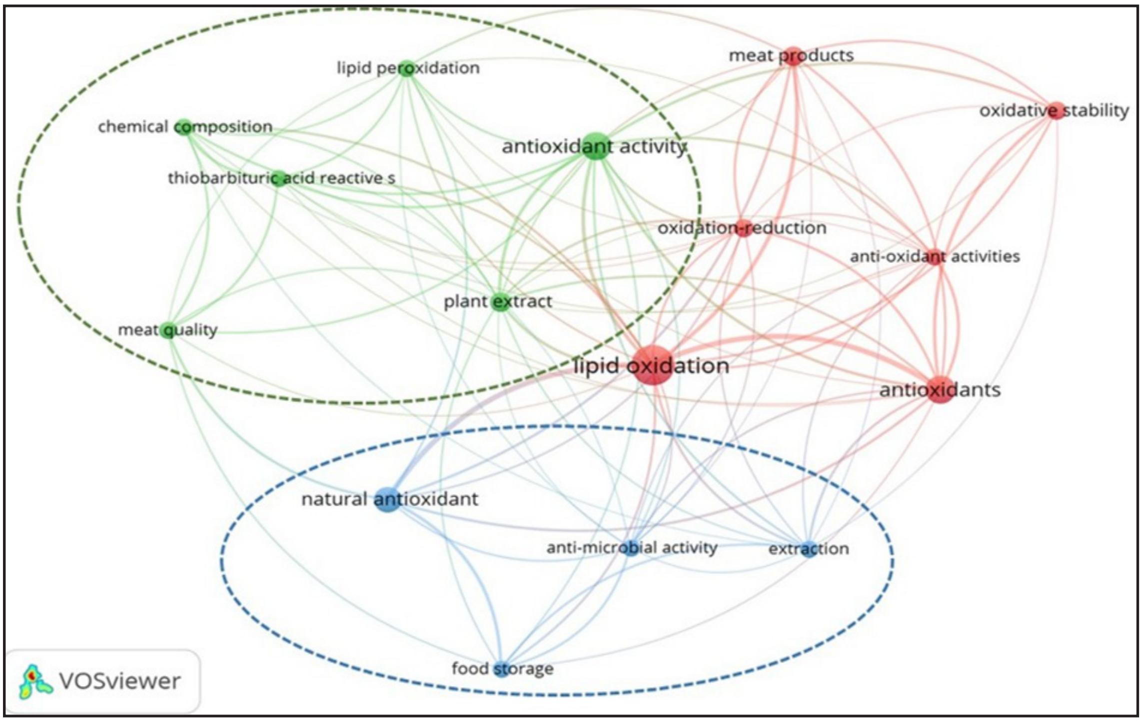


Source: Authors (2023)

The VOSviewer version 1.6.18 was used for the article's bibliometric analysis. The Scopus database was used to obtain the bibliometric map. The Scopus keywords were extracted from the title and summary using a minimum of 5 occurrences of a correlation binary time. This way, the word cluster (Fig. 2) was generated.

The results were focused on the use of natural antioxidants in chicken meat and derivatives. The blue cluster presents a relation between the use of natural antioxidants and lipid oxidation, with indications of shelf-life studies. The term "antimicrobial action" appears due to its food spoilage relevance. The natural antioxidants overall are extracted from vegetables and can present, besides the antioxidant activity, an antimicrobial activity according to the type of chemical structure used. The green cluster highlights the importance of the extraction of plant's bioactive compounds on antioxidant activity. The extraction of these compounds is an essential step to obtain the total performance and application of the product. The chemical composition is an important factor in the development of lipid oxidation and the action of antioxidant compounds. In this cluster, there's a recommendation for studies that aim at chicken meat quality verification after the use of natural antioxidants. The words that are in the red cluster are general terms of the research.

Figure 2 – Cluster obtained by bibliometric mapping using Scopus database



Source: Authors (2023)

3 LIPID OXIDATION IN CHICKEN MEAT AND IN ITS DERIVATIVES

Lipid oxidation causes food spoilage and is a limiting factor for the quality and acceptability of meat products, due to negative influence on sensorial attributes like taste, color and texture, also affecting the nutritional value (Ezz El-Din Ibrahim; Alqurashi; Alfaraj, 2022; Ribeiro et al., 2019). Lipid oxidation is a complex process that can occur by different mechanisms depending on the factors involved, being called auto-oxidation, photo-oxidation or enzyme-catalyzed oxidation (Abeyrathne; Nam; Ahn, 2021; Campbell-Platt, 2015; Ezz El-Din Ibrahim; Alqurashi; Alfaraj, 2022; Ribeiro et al., 2019).

The lipid oxidation mechanism occurs in three steps: initiation, propagation, and termination. In the initiation step, the free radicals production happens by unsaturated fatty acids. The generation of free radicals can start with heat action and/or catalytic enzymes. In the propagation step, it happens the formation of hydroperoxide that is very reactive, this way, it turns responsible for the rapid occurrence of the reaction, besides, in this step it also initiates the appearance of sensory alterations. The termination step consists of reactions among free radicals forming more stable new substances like ketones and aldehydes (Carocho; Morales; Ferreira, 2017; Ribeiro et al., 2019).

Compounds like hydroperoxide and aldehydes are formed during the reaction and are considered the main contributors to the release of flavors and aromas associated with rancid (Campbell-Platt, 2015; Ezz El-Din Ibrahim; Alqurashi; Alfaraj, 2022; Huang; Ahn, 2019). Furthermore, during lipid oxidation, compounds harmful to health are generated like malondialdehyde, acrolein, 4-hydroxynonenal, 4-hydroxyhexanal, and similar compounds to crotonaldehyde. These were associated with diseases like inflammation, cancer, atherosclerosis and premature aging in humans (Abeyrathne; Nam; Ahn, 2021; Huang; Ahn, 2019).

Some factors can influence the extension of lipid oxidation in meat. Intern factors, like iron concentration and antioxidant enzymes, can act as catalysts of lipid oxidation reaction (Huang; Ahn, 2019; Mäkinen et al., 2020; Özünlü; Ergezer; Gökçe, 2018).

Lee et al. (2020) highlight that the oxidative processes that occur in meat affect not only the lipids but also the proteins, which can contribute to product deterioration and changes in sensory attributes, directly impacting consumer acceptability of the meat product. In this context, in trying to avoid or slow down food lipid oxidation, the use of antioxidants is essential due to their capacity to mitigate radical-free effects (Campbell-Platt, 2015).

4 SYNTHETIC ANTIOXIDANTS APPLIED IN CHICKEN MEAT AND DERIVATIVES

According to Huang and Ahn (2019) and Makris and Boskou (2014) an ideal antioxidant applied in meat and food in general must be economically viable, easy to obtain and efficient in low concentrations, must not contain toxic substances, and not be absorbed by the human organism, it must have stability under food processing conditions and in no time alter the food sensory characteristics, like color, taste or odor.

The synthetic antioxidants are used a lot by the industry because of their accessibility, availability, and stability (Parcheta et al., 2021; et al., 2019). The synthetic antioxidants usually used are the butylhydroxyanisole (BHA), the butylated hydroxytoluene (BHT), the propyl gallate (PG), and the tertiary butylhydroquinone (TBHQ), given that the first two are types more used to reduce the lipid oxidation.

The Codex Alimentarius Commission is the international standard-setting organization responsible for regulating and establishing rules governing the use of antioxidant compounds, their functions, and food categories. However, regulatory food systems and legislative structures regarding the use of natural antioxidants as food additives can vary among different countries (Manessis et al., 2020).

In Brazil, the antioxidants used in food are regulated by the Health Regulatory Agency (ANVISA), through the RDC n. 272 of March 14, 2019. Are authorized by ANVISA (2019) for the use in natura meat products: the ascorbic acid, the sodium ascorbate, the calcium ascorbate, the sodium erythorbate, the sodium isoascorbate, the butylhydroxyanisole (BHA), the propyl gallate (PG), the D-alpha-tocopherol and the concentrated tocopherol mix; To industrialized cooked meat products, besides these substances, the citric acid and the butylated hydroxytoluene (BHT) are also included.

The antioxidants approved for use as food additives by the European Union (EU) include ascorbates, tocopherols, gallates, erythorbate, butyrates, lactates, citrates, tartrates, phosphates, malates, adipates, EDTA, and rosemary extracts (Carocho; Morales; Ferreira, 2017).

The use of this form of antioxidant is limited and regulated due to its toxic and carcinogenic effects (Dolatabadi; Kashanian, 2010; Ezz El-Din Ibrahim; Alqurashi; Alfaraj, 2022; Son Yue et al., 2019). This fact has been transmitting worry about the safety of these additives and has motivated researchers of the food industry to search for alternatives derived from natural fonts (De Oliveira et al., 2018).

5 NATURAL ANTIOXIDANTS APPLIED IN CHICKEN MEAT AND DERIVATIVES

Natural compounds with antioxidant properties are capable of slowing down or preventing food lipid oxidation (De Oliveira et al., 2018; Xu et al., 2017). Natural antioxidants derived from plants originate from fruits, teas and herbs, seeds, spices, vegetables, cereals, and trees (Xu et al., 2017). Many parts of plants, such as leaves, flowers, fruits, stalks, or roots, accumulate antioxidant substances in high concentrations, which vary according to the plant species and the antioxidant compound itself. Studies show that these plant parts can be applied directly in food for example, as fruit puree or juice or after the extraction and purification of antioxidant substances, such as rosemary extract (Karre; Lopez; Getty, 2013; Shah; Bosco; Mir, 2014).

Studies by Gutiérrez-del-Río et al. (2021) demonstrated that the most important plant-based natural antioxidants are polyphenols, carotenoids, and vitamins. Carocho et al. (2017) highlight compounds included in these functional groups, such as bixin, norbixin, and lutein. Furthermore, among all vitamins, vitamin E, specifically α-tocopherol, is the most effective against lipid oxidation. These bioactive compounds present in plant extracts have antioxidant capacities similar to synthetic ones (De Oliveira et al., 2018).

Polyphenols are derived from the secondary metabolism of most plants and can be divided into different classes depending on their chemical structure: phenolic acids (such as hydroxybenzoic acids and hydroxycinnamic acids), coumarins, lignans, chalcones, flavonoids, lignins, and stilbenes. Natural polyphenols can be used to control the oxidation process in various food matrices, with the most commonly used being extracts from rosemary leaves (Salvia rosmarinus L.), sage (Salvia officinalis L.), and oregano leaves (Origanum vulgare L.) (Carocho, Morales, & Ferreira, 2017).

The antioxidant potential of phenolic compounds depends on the number and arrangement of hydroxyl groups (OH). Phenols have a predisposition to donate hydrogen atoms to lipid radicals, thereby stabilizing lipid molecules and reducing their susceptibility to auto-oxidation. Flavonoids possess hydroxyl groups that can chelate metallic ions such as iron, which is present in meat structure. Additionally, their chemical structure includes an o-diphenolic group, a conjugated 2-3 double bond with a 4-oxo function, and OH groups at positions 3 and 5 (Shahidi & Ambigaipalan, 2015).

Studies made by Canan et al. (2021) shows that the phytic acid extracted from rice antioxidant activity is performed by the act of an iron chelate. The big capacity of eliminating free radicals demonstrated, for example, by the rosmarinic acid contained in oregano, is due the hydroxyl groups that are present in the ring in ortho position (Hać-Szymańczuk et al., 2019).

According to Gao et al. (2021), the inhibition mechanism of natural antioxidants can vary depending on the type of compounds extracted from plants, vegetables, teas, and fruits. For example, antioxidants from rosemary extract interrupt the chain reaction during the lipid oxidation process.

The European Union (EU), under regulation EC 1333/2008, established a list of authorized food additives, such as rosemary extracts (E 392), carotenes (E 160a), extracts rich in tocopherol (E 306), α-tocopherol (E 307), β-tocopherol (E 308), γ-tocopherol (E 309), and annatto, bixin, and norbixin (E 160b). These natural antioxidants have maximum limits for use in meat products and are permitted additives in processed meat products (Manessis et al., 2020).

Table 1 presents the natural antioxidants used in chicken meat and its derivatives, their compounds, active factors, form of application and types of extraction according to the studies used in this research. These substances have been applied to a variety of products, including hamburgers, sausages, hamburgers, nuggets, marinades, meatballs, pâtés, mortadella, chicken breasts and thighs.

Table 1 – Natural antioxidants applied in chicken meat and derivatives

Origin	Concentration	Active compound	Extraction	Tested Products	Form of application	References
Black cumin seed extract	2 % (w/w)	Phenolic compounds	Water Ethanol 70 %	Chicken meatballs	Liquid extract	(Zwolan et al., 2020)
Purified rice bran	0.33 e 0.66 % (w/w)	Phytic acid	Cloridric acid	Mechanically deboned chicken meat	Liquid extract	(Canan et al., 2021)
Dehydrated oregano	2 % (w/w)	Phenolic compounds	NA	Mechanically separated chicken meat	Powder, liquid extract and essential oil	(Hać-Szymańczuk et al., 2019)
Oregano extract	2 % (v/v)		Water			
Oregano extract	2 % (v/v)		Ethanol 40 %			
Oregano extract	2 % (v/v)		Ethanol 70 %			
Oregano essential oil	0.1 % (w/v)		NA			
Holm oak acorn	0.1 % (w/v)	Phenols	Ethanol/ Water 80 %	Boneless and skinless chicken thigh	Liquid extract	(Özünlü; Ergezer; Gökçe, 2018)
White oak acorn	0.1 % (w/v)					
Mount Tabor oak acorn	0.1 % (w/v)					

Table 1 – Natural antioxidants applied in chicken meat and derivatives

(Continuation...)

Origin	Concentration	Active compound	Extraction	Tested Products	Form of application	References
Cardamom, cumin, black cumin, cloves, bay leaves and nutmeg lyophilized extract	0.5% (w/w)	Phenolic compounds	Ethanol 50%	Ground chicken thigh	Liquid extract	(Muzolf-Panek et al., 2020)
Oregano essential oil + tanin acid from oak galls	0.01 and 0.02% (w/v) 0.0005 and 0.001% (w/v)	Phenolic compounds	NA	Ground chicken thighs and chest	Essential oil	(Al-Hijazeen et al., 2018a)
Oregano essential oil L-ascorbic acid	0.01 and 0.015% (w/v) 0.03% (w/v)	NA	NA	Ground and cooked chicken thighs and chest	Essential oil	(Al-Hijazeen, 2018b)
Pequi waste extract Palm-juçara waste extract	0.1% (w/w) 0.1% (w/w)	Phenolic acids, flavonoids, antocyanins e carotenoids	Ethanol 94%	Ground and boneless chicken thighs and upper legs	Liquid extract	(Frasao et al., 2018)
Cork oak leaf	2% (v/w)	Phenolic compounds, flavonoids, condensed tannins e tocopherols	Ethanol/ Water (1:1) Ethanol/ Water (7:3)	Cooked chicken	Liquid extract	(Lavado; Ladero; Cava, 2021)
Moringa oleifera powder	1 and 2% (w/w)	Phenols e flavonoids	Methanol 80%	Chicken hamburguer	Powder and liquid extract	(Ezz El-Din Ibrahim; Alqurashi; Alfaraj, 2022)
Moringa oleífera extract	0.02% (v/w)					
Olive powder	1 and 2% (w/w)					
Olive extract	0.02% (v/w)					
Pink pepper extract	0.009% (w/w)	Phenolic compounds	Ethanol/ Water 80%	Chicken hamburguer	Liquid extract	(Menegali et al., 2020)
Coffee silver skin powder	1.5% and 3% (w/w)	NA	NA	Chicken fillet hamburger	Powder	(Martuscelli; Esposito; Mastrocola, 2021)

Table 1 – Natural antioxidants applied in chicken meat and derivatives

(Continuation...)

Origin	Concentration	Active compound	Extraction	Tested Products	Form of application	References
Pectin	10% (w/w)	Lycopene e Phenolic compounds	Bleached in hot water	Chicken chest sausage	Paste	(Jouki; Rabbani; Shakouri, 2020)
Tomato paste	1.2 % and 10% (w/w)					
Blueberry leaf	4% (w/w)	Poliphenols	Water Ethanol 50% Subcritic water	Chicken thigh marinades	Liquid extract	(Mäkinen et al., 2020)
Sea buckthorn leaf	4% (w/w)					
Blueberry leaf extract	0.4 and 2% (w/w)					
Sea buckthorn leaf extract	0.4 and 2% (w/w)					
Moringa olifera seed flour	1. 3 and 5% (w/w)	Phenolic compounds	NA	Chicken mortadella	Powder	(Auriema et l., 2019)
Moringa oleifera leaf extract	0.25, 0.5 and 1% (w/v)	Phenols	Ethanol/ Water (80:20)	Chicken mortadella	Liquid extract	(Francelin et al., 2022)
Moringa oleifera flower extract	1 e 2% (w/v)	Phenolic compounds	Ethanol/ Water (60:40)	Baked chicken nuggets	Liquid extract	(Madane et al., 2019)
Sorrel free extract Sorrel nano extract encapsulated with carboxymethylcellulose	0.1% (w/v)	Phenolic compounds and anthocyanins	Ethanol 80%	Chicken nuggets	Liquid extract and nanoextract encapsulated	(Feridoni; Shurmasti, 2020)
Fish oil	0.4 and 0.8% (w/w)	NA	NA	Chicken nuggets	Essential oil and encapsulated fish essential oil	(Raeisi et al., 2020)
Fish oil + encapsulated garlic essential oil	4 and 8% (w/w)					
Rosemary, marjoram, cloves and sage essential oil	0.06 (w/v)	Phenolic compounds	NA	Chicken nuggets	Essential oil	(Ghasemi et al., 2022)
Encapsulated quercetin, sunflower oil and free quercetin	2% (w/w) 2% (w/w)	Flavonoids	NA	Chicken pâté	Encapsulated oil	(De Carli; Moraes-Lovison; Pinho, 2018)
Grape pomace extract and micro encapsulated grape pomace	0.03% (w/w)	Phenolic compounds	Ethanol 80%	Chicken pâté	Lyophilized and microencapsulated extracts	(Carpes et al., 2020)

Table 1 – Natural antioxidants applied in chicken meat and derivatives

(Conclusion...)

Origin	Concentration	Active compound	Extraction	Tested Products	Form of application	References
Rosemary Green tea	0.02, 0.04 and 0.06% (w/w) and 0.02, 0.06 and 0.08% (w/w)	Phenolic compounds	NA	Chicken chest	Powder	(BAK; RICHARDS, 2021)
Chinese raspberry powder	0.5 and 1% (w/w)	Phenolic compounds e flavonoids	NA	Marinated chicken chest	Powder	(Kim; Chin, 2021)
Licorice extract	0.25, 0.5, 1 and 1.25% (w/v)	Phenolic compounds	Water	Chicken rissoles	Liquid extract	(Aslam, 2020)
Mamao luang	0.05 and 0.1% (w/w)	Phenolic compounds e flavonoids	Acetone 70% Ethanol 70% Methanol 70% Ethyl acetate 100%	Chicken rissoles	Paste	(Chinprahast; Boonying; Popuang, 2020)
Cashew bagasse extract (fruit peel, seed and residual pulp)	0.02% (w/w)	Phenols e flavonoids	Ethanol 55 %	Chicken rissoles	Liquid extract	(Neto et al., 2021)
Rosemary extract	1% (w/w)	Poliphenols	NA	Chicken's chest rissoles	Liquid extract	(Gao et al., 2019)
Rosemary, pine rusk and pomegranate extract	1% (w/v)	Poliphenols	NA	Chicken's chest rissoles	Liquid extract	(Gao et al., 2021)
Cinnamon essential oil	0.02 and 0.04% (w/w)	Phenolic compounds e flavonoids	Hydrodistillation	Chicken sausage	Essential oil and liquid extract	(Aminzare et al., 2018)
Grape seeds extract	0.08% and 0.16% (w/w)		Water			
Lemon-grass extract	0.5 and 1% (w/v)	Phenolic compounds e flavonoids	Hydroalcoholic extracts	Chicken sausage	Liquid extract	(Boeira et al., 2020)
Barberry extract	0.75, 1.5 and 3.0% (w/v)	Phenolic compounds	Ethanol 80% Citric acid 2%	Chicken sausage	Liquid extract	(Jaberi; Kaban; Kaya, 2020)
Propolis, sage and lavender extract	5 and 10% (w/v)	Phenolic compounds	Ethanol	Chicken sausage	Liquid extract	(Yerlikaya; Şen Arslan, 2021)

NA: Not Available

The studies focused on plant-based antioxidant substances, such as phenolic and flavonoid compounds. Most of the studies involved simple applications, such as direct addition or mixing of antioxidant materials (powders, paste, extracts, essential oils) in chicken meat or derivatives. Generally, antioxidant materials used in higher concentrations did not undergo an extraction step, while lower concentrations were used with extracts, essential oils, and encapsulated substances. The antioxidant activity depends on the method and type of extraction used to obtain the compounds of interest. Factors such as solvent polarity, pH, temperature, and extraction time can affect the performance and antioxidant power (Lee et al., 2020; Turkmen, Sari, & Velioglu, 2006; Xu et al., 2017) due to their high susceptibility to degradation (Carocho, Morales, & Ferreira, 2017).

The most commonly used solvents were ethanol and water, as corroborated by Turkmen, Sari, and Velioglu (2006). Lee et al. (2020) state that these solvents are preferred because they can be safely consumed. In the studies reviewed, all the antioxidant materials used exhibited antioxidant activity in chicken meat and its derivatives during storage or after cooking.

6 SENSORY ASPECTS OF CHICKEN MEAT AND DERIVATIVES WITH ADDED NATURAL ANTIOXIDANTS

The meat industry faces challenges in developing products that use natural antioxidants due to potential alterations in the product's sensory characteristics. Most of the studies report about the negative effects of unwanted flavor and color (Lee et al., 2020; Mäkinen et al., 2020). However, several studies have demonstrated that certain plants can be promising due to their interesting sensory properties (Mäkinen et al., 2020).

Sensory analysis is widely used in the development of new products and can also be used to measure the degree of lipid oxidation based on sensory aspects such as color, flavor, and odor (Bak & Richards, 2021).

Jouki (2020) tested the antioxidant potential of tomato paste at concentrations of 1%, 2%, and 10% (w/w) in chicken breast sausage. The results of the sensory tests suggested that the incorporation of tomato paste at up to 2% does not adversely affect color, texture, or overall acceptability. However, the 10% (w/w) concentration of tomato paste showed a greater effect against lipid oxidation compared to the other concentrations tested. Nevertheless, at higher addition levels, the samples exhibited significant changes in appearance compared to the control product. Therefore, the 2% (w/w) concentration was deemed sufficient to inhibit lipid oxidation without causing unwanted changes in the overall appearance of the product.

Ezz El-Din Ibrahim et al. (2022) investigated the antioxidant effects of oleifera Moringa powder and olive powder (Olea europaea L. var. koroneiki) in concentrations of 1 % and 2 % (w/w). The authors also evaluated the Oleifera Moringa extract and the olive extract (Olea europaea L. var. koroneiki), in the adding level of 0.02 % (w/v) in chicken hamburgers. The sensory results demonstrated that the treatment with the moringa and Oliveira didn't negatively affect the color, but the flavor was altered when the olive powder 2 % (w/w) was tested compared to the other samples. Regarding odor and texture, none of the treatments had a negative effect. With the general acceptability, the chicken hamburgers treated with olive powder 2 % (w/w) were the least accepted among the samples, but it didn't have significant differences. The chicken hamburgers submitted to the other treatments didn't present significant general acceptability changes. The extracts and the moringa powder presented more pronounced color, flavor, odor and texture effects in relation to the olive extracts.

According to Madane et al. (2019), the moringa flower is a source of dietary fiber and has significant antioxidant potential, acting as a ferric reducing antioxidant and free radical scavenger. Incorporation of moringa flower extract at concentrations of 1% and 2% (w/v) significantly altered the color value of treated chicken nuggets compared to the control, with a notable increase in luminosity levels. Additionally, a decrease in the weight of treated chicken nuggets was observed after 10 days of storage, which may be attributed to the dilution of meat pigments due to the presence of non-meat ingredients. The sensory attributes of the treated nuggets were acceptable until the 15th day of storage, with a noticeable appearance effect observed after this period compared to the control. The addition of moringa flower in chicken nuggets increased lipid stability, odor, and shelf life.

Studies made by Francelin et al. (2022) and Auriema et al. (2019) in chicken mortadella used the adding of 3 % (w/v) of Moringa seed flour and Moringa extract, resulting in the increase of the lipids stability without causing any perceptible organoleptic changes, and obtaining products that got general acceptability.

According to the mentioned studies, it is evident that for the use of natural antioxidants in the form of extracts and powders, the concentration must be limited to avoid altering the product's sensory attributes. The sensory tests showed similar results at the beginning of storage for both the control samples and the treatments using natural antioxidants. However, over the storage period, the samples that received the addition of natural antioxidants showed higher values compared to the control.

De Carli, Moraes-Lovison, and Pinho (2018) evaluated the encapsulation of sunflower oil with quercetin and free quercetin in chicken pâtés at a concentration of 2% (w/w). The sensory tests indicated significant changes in color and flavor attributes when free quercetin was used.

Raeisi et al. (2020) studied the application of free fish essential oil in concentrations of 0.4 and 0.8 % (w/w), encapsulated fish essential oil, and garlic essential oil in levels of 4 and 8 % (w/w) in chicken nuggets. The sensory analysis showed that for the color, flavor, odor and general acceptability the treatments in free form had a worse score than the control and the encapsulated samples. The encapsulated samples at a higher level (8 %) presented better sensory quality than the ones at a lower level (4 %). Feridoni and Shurmasti (2020) also found more promising results in the sensory properties of chicken nuggets with green tea encapsulations at 0.1% (w/v) compared to the free extract at the same concentration.

Al-Hijazeen et al. (2018a) tested oregano essential oil combined with tannic acid in various combinations: 0.0005% (w/v) tannic acid and 0.01% (w/v) oregano oil, 0.001% (w/v) tannic acid and 0.01% (w/v) oregano oil, 0.0005% (w/v) tannic acid and 0.02% (w/v) oregano oil, and 0.001% (w/v) tannic acid and 0.02% (w/v) oregano oil in chicken breast and thighs. The treatment with 0.001% (w/v) tannic acid and 0.02% (w/v) essential oil had the highest acceptability. Additionally, this proportion showed a positive effect on inhibiting lipid oxidation. In this study, higher concentrations (0.02% and 0.001%) of oregano oil and tannic acid presented more acceptability compared to the formulas with lower concentrations (0.01% and 0.0005%).

Ghasemi et al. (2022) explored the use of clove, rosemary, marjoram, and sage essential oils at a level of 0.6% (w/v) applied to chicken nuggets. Clove oil, followed by rosemary, marjoram, and sage, presented higher scores for color and odor attributes. For color and flavor, none of the essential oils presented significant changes. Additionally, samples treated with clove and rosemary essential oils received acceptable scores from the evaluators, whereas samples treated with marjoram and sage essential oils did not please the testers.

Aminzare et al. (2018) demonstrated that the use of cinnamon essential oil at a concentration of 0.04% (w/w) (the highest level tested) resulted in the best sensory characteristics for flavor and texture attributes, thus enhancing the general acceptability of chicken sausage. Al-Hijazeen (2018b) studied the application of oregano essential oil at concentrations of 0.01%, 0.015%, and 0.03% (w/v) in chicken breast and thighs, and demonstrated that the most effective result for lipid oxidation inhibition, color stability, and general acceptability was at 0.015% (w/w).

7 CONCLUSIONS

The studies covered in this review applied natural antioxidants in the form of extracts, powders, essential oils, and encapsulated oils. The most studied plants were Moringa Oleifera, rosemary, cloves, and oregano. The predominant method to obtain the natural antioxidants was by extraction using solvents such as ethanol and water. The studies focused on plant-based antioxidant materials, particularly phenolic and flavonoid compounds. Only 29% of the addressed studies were conducted using chicken meat; the rest used derivatives such as hamburgers, nuggets, sausages, meatballs, rissoles, pâté, mortadella, and marinades.

The plants extract and powders concentrations applied directly in chicken meat and in derivatives must be limited, because they interfere in sensory attributes, like color, flavor, odor and texture, When the active compounds are encapsulated, the concentrations can be higher, overcoming the concentrations applications limitations, and still, keeping the product's sensory characteristics. The studies show that natural antioxidants have positive effects on the inhibition of lipid oxidation, being an alternative to substitute synthetic ones. Besides, when used in lower concentrations, they don't alter the sensory properties.

However, it is necessary to observe the need for security tests that show the natural antioxidant potential and eliminate any health risks or unwanted effects, so it is possible to legally adopt the use of this type of antioxidant in the chicken meat industry.

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