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Properties of films and coatings added of tocopherol for food packaging: tool-based review for systematic reviews and bibliometric analysis

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Abstract

Purpose – The aim was not to perform a systematic review but firstly to search in PubMed, Science Direct, Scopus and Web of Science databases on the papers published in the last five years using tools for reviewing the statement of preferred information item for systematic reviews without focusing on a randomized analysis and secondly to perform a bibliometric analysis on the properties of films and coatings added of tocopherol for food packaging.

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Design/methodology/approach – On January 24, 2022, information was sought on the properties of films and coatings added of tocopherol for use as food packaging published in PubMed, Science Direct, Scopus and Web of Science databases. Further analysis was performed using bibliometric indicators with the VOSviewer tool.

Findings – The searches returned 33 studies concerning the properties of films and coatings added of tocopherol for food packaging, which were analyzed together for a better understanding of the results. Data analysis using the VOSviewer tool allowed a better visualization and exploration of these words and the development of maps that showed the main links between the publications.

Originality/value – In the area of food science and technology, the development of polymers capable of promoting the extension of the shelf life of food products is sought, so the knowledge of the properties is vital for this research area since combining a biodegradable polymeric material with a natural antioxidant active is of great interest for modern society since they associate environmental preservation with food preservation.

Keywords Antioxidant, Functionality, Review, Packaging, VOSviewer, Bibliometric research

Paper type General review

1. Introduction

Coatings and packaging are essentially adopted to minimize the deterioration of foodstuffs, reduce the risk of contamination and keep the product safe to be marketed. This practice reduces sensory damage by providing semi-permeable blockage around the product (Nair *et al.*, 2020). Edible coatings extend the shelf life of foods because they inhibit oxidation and protect against pathogenic microorganisms and moisture (Al-Tayyar *et al.*, 2020; Iqbal *et al.*, 2021; Tahir *et al.*, 2019a). Allied with these characteristics, the application of edible coating films can also promote food preservation through the incorporation of antimicrobial, antioxidant and antifungal agents into the polymer matrix (El-Sayed *et al.*, 2020; Tahir *et al.*, 2019b).

Knowing the properties of films and coatings for food is essential from the point of view of developing a package that will have direct contact with the food product, as it may or may not produce desirable effects on the food. Therefore, several works seek not only to develop polymers but also to evaluate the peculiar properties of films or coatings (Costa *et al.*, 2022; Emragi *et al.*, 2022; Nurhayati *et al.*, 2022; Radi *et al.*, 2022). It also happens in films and coatings in which tocopherol is added to generate antioxidant properties. There is a wide range of studies on tocopherol-added polymers, such as the works of Agudelo-Cuartas *et al.* (2020) who developed whey protein-based films; Hamid *et al.* (2018) who developed carrageenan semi-refined films from *Eucheuma cottonii* and Tongdeesoontorn *et al.* (2021) who developed cassava starch/gelatin films.

Bibliometric analysis of journals can be used by editorial boards to make decisions about developing future publications (Mokhtari *et al.*, 2020). In addition, it can contribute new ideas to researchers who study the development and use of food packaging (Öğretmenoğlu *et al.*, 2021). In the works of Azevedo *et al.* (2022), Fasogbon and Adebo (2022), Rigueto *et al.* (2023), Vila-Lopez and Küster-Boluda (2021) and Wang *et al.* (2021), one observes the application of the bibliometric analysis is observed in the search for information on active flexible food films; a global and African view of 3D food printing; gelatin-based polymeric films for food packaging applications; research on sustainable food packaging; sustainable Chinese packagings, respectively.

However, a search and a bibliometric analysis that addressed information on assembly polymers/tocopherol properties for use in the food sector were not found. Thus, the aim of this research was not to perform a systematic review but firstly to search in PubMed, Science Direct, Scopus and Web of Science databases on the articles published in the last five years using tools for reviewing the statement of preferred information item for systematic reviews without focusing on a randomized analysis and secondly to perform a bibliometric analysis on the properties of tocopherol-added films and coatings for food packaging.

2. Films and coatings

Films and edible coatings are thin membranes applied to the surface of the food product to preserve shelf-life and quality (Díaz-Montes and Castro-Muñoz, 2021). The difference between films and coatings is in the forming ingredient and the manner of application because edible coatings are usually applied directly on the product by dipping or spraying followed by a drying process, while films can be made by first spreading the polymer solution on support (casting), followed by drying and then applying it to the food (Galus and Kadzińska, 2015; Mohamed *et al.*, 2020).

The employment of biodegradable polymers as edible coatings is getting significant attention due to the environmental problems associated with non-degradable plastic materials (Abdel Aziz and Salama, 2021; Salama *et al.*, 2021). Taking advantage of biocompatibility, biodegradability and edibility, biopolymers are considered ideal candidates for the production of edible coatings (Abdel Aziz *et al.*, 2015; Salama and Abdel Aziz, 2020). The most commonly natural biopolymers used are starch, cellulose, chitosan, alginate, whey protein and collagen (Rosseto *et al.*, 2020).

Polysaccharide-based are the most studied biopolymers, among them starch, cellulose, chitosan and agar. The technological innovation in biopolymer technology has contributed to the development of synthetic biopolymers like polylactic acid, polycaprolactone, polyglycolic acid, polyglycolic acid, polybutylene succinate and polyvinyl alcohol. These synthetic biopolymers have several advantages over natural biopolymers, including better mechanical and other barrier properties (Shankar and Rhim, 2018).

The main advantages associated with biopolymers are their environment-friendly nature, renewability, biocompatibility, non-toxic, low cost, availability and biodegradability (Wankhade, 2020). The high-quality, eco-friendly, biodegradable and natural base materials have gained demand in packaging applications, along with active ingredients that can extend the shelf life of food materials (Varghese *et al.*, 2020; Mahmud *et al.*, 2021).

Each food has different packaging requirements and several quality factors, such as color, oxidation, microbiology, structure, flavor, enzymatic degradation, photooxidation and chemical changes such as hydrolysis, protein denaturation and cross-linking. That is, films and coatings for food use are highly complex to develop, as a strategy must be drawn up to develop the ideal packaging, respecting the peculiar aspects of the food (Lindström and Österberg, 2020).

The design for the development of eco-friendly package materials has received significant attention (Dehghani *et al.*, 2018) like materials based on protein or polysaccharide biopolymers used as an alternative to synthetic petroleum derivatives (Dammak *et al.*, 2017). According to European Bioplastics (2023), the global capacity of bioplastics was 1,792 million tons in 2021, 2,217 million tons in 2022 and is forecast to reach 6,291 million tons in 2027, of which 58.50%, 51.51% and 56.23%, respectively, are biodegradable.

Complementarily, additives added to biopolymers can improve optical properties, mechanical strength, barrier properties and other functionalities. Such active agents can, in many cases, be diffused for a long time into the food and extend the applied effect. However, because some assets are volatile, insoluble in water and chemically unstable, the incorporation directly into the polymer matrix of these assets is a challenge, as it can negatively impact the properties of the film (Ranjbaryan *et al.*, 2019). Figure 1 shows advances in films and coatings – active packaging.

3. Active films and coatings

The first citation referring to the terms active packaging and intelligent packaging was made in Regulation 2004/1935/EC of the European Parliament and the Council, which states that:

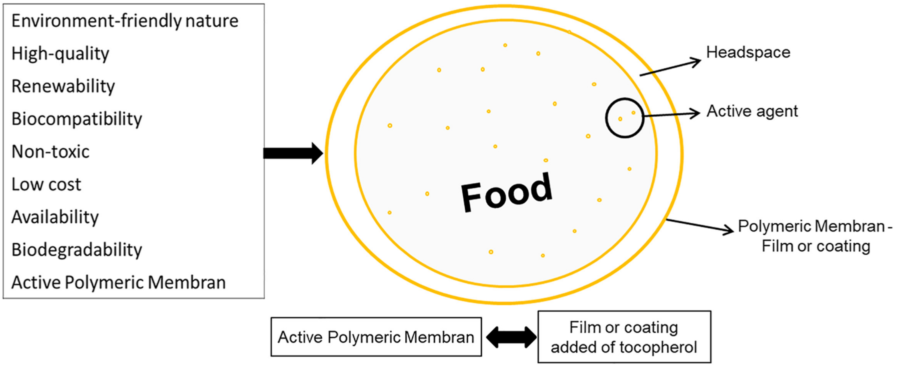

Figure 1. Advances in films and coatings – active packaging

Source(s): Author

“all substances incorporated into foodstuffs coming from packaging must meet the criteria set out in Directive 89/107/EC on food additives” (European Parliament, 2004).

The primary mechanism consists of immobilizing the active compound in the polymer matrix by covalence to act immediately when the food is in contact with the film. In a second mechanism, the active compound is incorporated into the matrix in the dry state so that when the film is placed in contact with moist food, the compound is released, acting directly on the food (Chen *et al.*, 1996; Buonocore *et al.*, 2005).

Active packaging is a promising future in the packaging market, with the ability to slowly release functional additives on the surface of food, with an antioxidant and antimicrobial role, extending the shelf life of products, storage of oils, the use of biodegradable packaging in the treatment of food spoilage is also of great importance (Espitia *et al.*, 2014). Consequently, the effectiveness of edible films or coatings depends on three criteria: (1) the selected materials for their preparation, (2) the technical and operational parameters of their application on the food product and (3) the specific requirements of the food product (Bizymis and Tzia, 2021).

Active packaging acts as a barrier to external detrimental factors and has an active role in food preservation, maintaining or prolonging its shelf-life. There is a diversity of active packaging systems that are comprised of additives that release properties, absorption, removal and control of microbial and quality. Besides this, several studies are interested in the properties of essential oils and their actives, such as antioxidants, polyphenols and tocopherols (Atarés and Chiralt, 2016; Alfonzo *et al.*, 2017; Ribeiro-Santos *et al.*, 2017; Kumar *et al.*, 2020).

Active food packaging is one of the new innovative packaging technologies that combine the food and packaging environment and their interactions to ensure the preservation of quality and increase the shelf life of food biological materials in natural polymers to protect the consumer and the environment by preserving food (Yildirim *et al.*, 2017).

3.1 Antioxidant activity in the polymeric films or coatings and active films and coatings with tocopherol

When a polymeric matrix is developed by adding antioxidant compounds, some advantages are observed, such as protection against free radicals and minimization of oxidation. Together with other benefits to food systems, they could present anti-inflammatory and antimicrobial action (Brito *et al.*, 2021). Films and coating containing active antioxidant agents prolong the food shelf life, and these agents are incorporated into films and coating (Kumar *et al.*, 2021; Tanwar *et al.*, 2021).

Antioxidants are stable molecules, and they can donate electrons to unstable molecules. These antioxidants react with unstable molecules known as free radicals and reactive oxygen species and terminate the chain reaction that can spoil the food products (Lobo *et al.*, 2010). They inhibit or delay food oxidation by limiting the initiation or propagation of oxidative chain reactions (Singh *et al.*, 2022).

Antioxidants have been incorporated as active ingredients into plastic films for polymer stabilization, protection from oxidative degradation and prevention of discoloration, rancidity and food degradation (Dutta and Sit, 2022). Among the most common is tocopherol (Avramescu *et al.*, 2020). Natural agents such as polyphenols, tocopherols, plant extracts and essential oils are becoming increasingly popular in the application of active packaging materials (Iversen *et al.*, 2022).

Tocopherols are widely known for preventing lipid oxidation in food products. In addition, tocopherols come in four different forms (β, α, γ and δ) (Moure *et al.*, 2001; Barouh *et al.*, 2022). The addition of tocopherol in films and coatings has been studied in several studies over time due to its antioxidant action, such as in the works of Zhu *et al.* (2012), Dias *et al.* (2018), Ferreira *et al.* (2021) and Keshari *et al.* (2022) which developed low-density polyethylene (LDPE)/polypropylene (PP) blend films; studied chitosan films on salmon fillet; applied coatings of thermoplastic starch and chitosan with α-tocopherol/bentonite in special green coffee beans; and applied sodium alginate coating on minimally processed carrots, respectively.

4. Methodology

This review was performed by stating preferred reporting items for systematic reviews and meta-analyses (PRISMA) (Moher *et al.*, 2009) but without focusing on a randomized analysis. On January 24, 2022, information on the properties of tocopherol-added films and coatings for use as food packaging published in PubMed, Science Direct, Scopus and Web of Science databases was sought. Research articles from the year 2017 to 2022 were searched. No language restrictions were applied. The descriptor terms “tocopherol coatings” and “tocopherol films” were applied in ALL FIELDS, and the Boolean operators “AND” and “OR” were used to search the PubMed, Science Direct, Scopus and Web of Science databases.

When performing a search in the databases, with descriptors and Boolean operators listed, they were inserted in the “Topic” search field, which searches for words in titles, abstracts, author keywords and WoS keywords – also called Keywords Plus. These strategies were necessary for the selection of the final dataset. The records were exported, according to the necessary formatting of the document about each database, to be then analyzed through an analysis of co-occurrences of keywords, which allows the visualization of spatial proximity and shows the relationships between the data and the information found (Inomata *et al.*, 2015).

Keyword co-occurrence analysis was performed using VOSviewer version 1.6.17, a software tool to create maps based on network data and to visualize and explore these maps (Van Eck and Waltman, 2021). The graphics were constructed with at least five occurrences of the keywords among the works published in the “Web of Science” databases; “Science Direct,” “PubMed” and at least 20 occurrences for those from “Scopus,” as this database presented a more significant number of files to be analyzed when compared to the others, so to improve the visualization of information in the graphs it was essential to increase the minimum number of keywords. Two evaluators analyzed the dataset obtained; a third evaluator analyzed the material in case of doubt. Duplicate articles were excluded and after reading the title and abstract, articles that did not meet the inclusion criteria were excluded.

Figure 2 shows the evaluation flowchart of the articles resulting from the bibliographic survey.

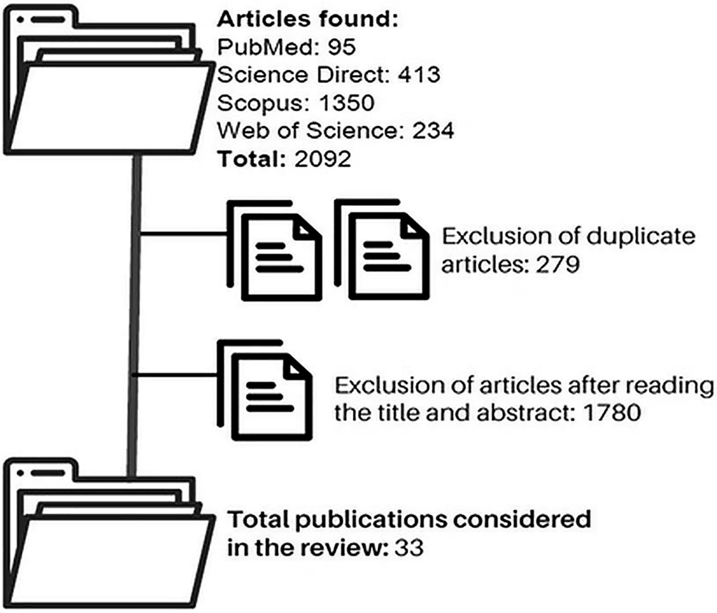

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Figure 2. Evaluation flowchart of articles resulting from the search in PubMed, Science direct, Scopus and Web of Science databases

Figure 3 shows the step-by-step of the entire bibliographic search in the databases until the bibliometric analysis to obtain the graphs in the VOS viewer software.

5. Results and discussion

5.1 Films and coatings added of tocopherol for food packing

The survey returned 33 studies referring to the properties of films and coatings added with tocopherol for food packaging (Table 1).

5.1.1 Properties of films and coatings added of tocopherol for food packing. The properties of tocopherol-added films and coatings have been extensively studied in food packaging, as demonstrated by the works of Dias *et al.* (2018), Hamid *et al.* (2019a, b), Jiang *et al.* (2021), Rosenbloom and Zhao (2020) and Yan *et al.* (2019), Zhang *et al.* (2020a) which will be further commented in the item 5.3 Possible foods for application of tocopherol films and coatings. A highlight is the application of film or coating with food preservation by the action of the antioxidant in the polymer matrix. We also observed that this action was enhanced when tocopherol was added to various polymers, such as LDPE, where the addition of the antioxidant promoted a synergistic controlled release in the active films (Li *et al.*, 2019), chitosan and pectin in which the films exhibited high antioxidant activity up to 90.60% and high initial release profile followed by an extended release for 10 days (Hapsari *et al.*, 2020), and poly (lactic) acid-poly(3-hydroxybutyrate-co-4-hydroxybutyrate) (PLA-PHB) films added of α-tocopherol showed less oxidative deterioration in packaged peaches (Jiang *et al.*, 2021).

In the last five years, in addition to the well-established antioxidant property of tocopherol, other properties have been studied for films and coatings added with tocopherol for use in food packaging, such as thickness, optical properties, microstructure, barrier properties to water and gases, mechanical properties, thermal properties (thermogravimetric analysis

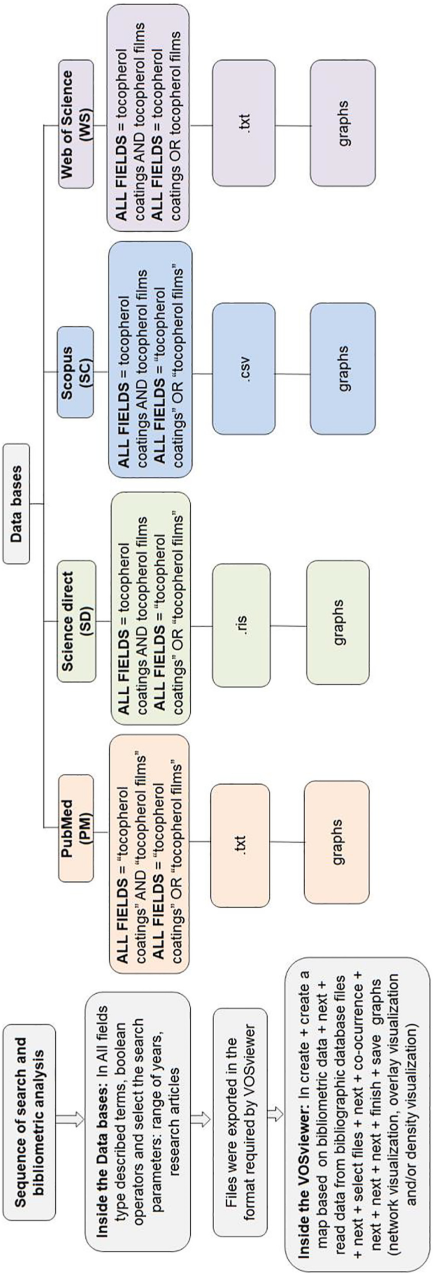

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Figure 3.
Step-by-step of the entire bibliographic search in the databases until the bibliometric analysis to obtain the graphs in the VOSviewer software

Table 1. Systematization of the 33 works referring to the properties of films and coatings added with tocopherol for food packaging resulting from searches in PubMed, Science Direct, Scopus and Web of Science databases

No	Article title	USE	Purpose of the article	Composition material	Properties evaluated in films/coatings or food products	Principal results of the article	REF.
01	Development of chitosan-based extended-release antioxidant films by control of fabrication variables	Films	Evaluate the influence of the concentration of tween 80, as an emulsifying agent, the stirring speed of homogenization and the presence of ethanol, as the solvent of α -tocopherol, on the physicochemical properties of the α-tocopherol incorporated chitosan film and the release of α-tocopherol into ethanol 95%, as the fatty food simulant	- Chitosan - Glycerol - Tween 80 - α-tocopherol	- Thickness - Water content - Opacity - Solubility in water - TS, EB - WVP - Release of α-tocopherol - FTIR - DSC	Incorporation of the α-tocopherol, changes the textural and optical properties of chitosan films. Preparing conditions including concentration of emulsifier and speed of homogenization as well as incorporation of ethanol as a co-surfactant could affect the release rate of antioxidants. The higher concentration of emulsifier and higher speed of homogenization reduced the release rate of antioxidants. The addition of ethanol strongly decreased the rate of tocopherol release in the early stages of measurement. Promoting a slower, proper start and proper later releases. Therefore, increasing the stirring speed of homogenization and ethanol addition produced an adequate release of α-tocopherol from chitosan-based films, promoting adequate long-term conditions to minimize lipid oxidation of foods	Darbasi *et al.* (2017)
02	Edible carboxymethyl cellulose films containing natural antioxidants and surfactants: α-tocopherol stability, in vitro release and film properties	Edible film	Develop edible films containing Carboxymethylcellulose (CMC), α-tocopherol (α-TC) as an antioxidant and surfactants for food applications	- CMC - Tween 80 - Lecithin - α-tocopherol	- Thickness - SEM - WVP - TS, EB, modulus of elasticity - *In vitro* release and quantification - DPPH and ABTS	Tocopherol incorporated into CMC films showed satisfactory stability over 8 weeks. It was possible to control the tocopherol release profile from the CMC matrix by altering the ratio of lipophilic/hydrophilic surfactant used to stabilize the tocopherol droplets in the polymer. The addition of lecithin to the CMC films helped to maintain the stability of tocopherol after its release due to chemical interactions, which contributed to the higher antioxidant activity	Martelli *et al.* (2017)

(*continued*)

Table 1.

No	Article title	USE	Purpose of the article	Composition material	Properties evaluated in films/coatings or food products	Principal results of the article	REF.
03	Physical and antioxidant properties of films based on gelatin, gelatin-chitosan or gelatin-sodium caseinate blends loaded with nanoemulsified active compounds	Films	Develop and characterize active gelatin-based films, gelatin-chitosan or gelatin-sodium caseinate mixtures, apply active compounds (α-tocopherol, garlic essential oil and cinnamaldehyde) nanoemulsified in water	- Gelatin - Chitosan - Sodium caseinate - Glycerol - α-tocopherol	- Thickness - Water content - Solubility in water and swelling - WVP - FTIR - SEM - Contact angle - ABTS	All films added with tocopherol nanocapsules showed antioxidant activity, but the film with the highest activity was the films obtained from the Gelatin-Sodium Caseinate mixture. The nanoencapsulated active compounds were well distributed throughout the biopolymer matrix. Films developed based on gelatin and gelatin-chitosan or gelatin-sodium caseinate blends loaded with NACs showed adequate physical properties and strong antioxidant activity	Pérez Córdoba and Sobral (2017)
04	Efficacy of whey protein coating incorporated with lactoperoxidase and α-tocopherol in shelf life extension of Pike-Perch fillets during refrigeration	Coating	Design an active coating package based on whey protein incorporated with Lactoperoxidase system (LPOS) and α-tocopherol for the control of two main factors involved in the deterioration of food quality in to prolong the shelf life of pike perch fillets (*Sander lucioperca*, Linnaeus 1758) stored under refrigeration (4 °C)	- Whey protein - Ethanol - LPOS - D-α -tocopherol	In fillet of the fish - Psychrotrophic bacteria determination - pH - Thiobarbituric Acid - Total volatile basic nitrogen - Sensory evaluation	The results indicated that whey protein coating incorporated with LPOS and α-tocopherol could maintain the microbial, chemical and sensory qualities of Pike-Perch fillets during 16 days of refrigeration storage (4 °C). Although interaction between LPOS and α-tocopherol in some cases led to the mutual antagonistic effect in both cases, the obtained results indicated that the combination of LPOS and α-tocopherol can donate antibacterial and antioxidant properties to WPS coating	Shokri and Ehsani (2017)

(*continued*)

Table 1.

No	Article title	USE	Purpose of the article	Composition material	Properties evaluated in films/coatings or food products	Principal results of the article	REF.
05	Influence of α-tocopherol/MCM-41 assembly on physical and antioxidant release properties of LDPE antioxidant active films	Films	Investigate the influence of addition amount of α-tocopherol/mesoporous silica (Mobil Composition of Matter No. 41- MCM-41) assembly on the properties of LDPE films including physical properties and release profile of the antioxidant in the films	- LDPE - MCM-41 - α-tocopherol	- SEM - FTIR - XRD - DSC - WVP - Transmittance - TS, EB - Migration Test	The addition of the α-tocopherol/MCM-41 set has little effect on the melting temperature of the LDPE films, however, the films showed a decrease in crystallinity with the increase in the amount of the set, the same trend occurred in the evaluation of TS and film stretching. The antioxidant release rate can be affected by the addition of the set, it was found that a large addition of the set can contribute to the slow release of the antioxidant in the polymer	Sun *et al.* (2017a)
06	Development of LDPE antioxidant active films containing α-tocopherol loaded with MCM-41 (Mobil Composition of Matter No. 41) mesoporous silica	Films	To develop a new type of antioxidant active packaging of LDPE containing α-tocopherol adsorbed on MCM-41 mesoporous silica	- LDPE - MCM-41 - α-tocopherol	- Thickness - XRD - FTIR - TGA - WVP - GP - TS, EB - Quantification of α-tocopherol in fatty food simulant - Migration Test - DPPH	In the migration tests, the developed films showed that the adsorption of α-tocopherol in MCM-41 has a significant influence on the antioxidant release profile, the diffusivity for adsorbed a-tocopherol decreased approximately 53% compared to that of free a-tocopherol and water vapor permeability increased. α-Tocopherol maintained its antioxidant activity in the newly developed film	Sun *et al.* (2017b)

(*continued*)

Table 1.

No	Article title	USE	Purpose of the article	Composition material	Properties evaluated in films/coatings or food products	Principal results of the article	REF.
07	Effect of active films incorporated with montmorillonite clay and α-tocopherol: Potential of nanoparticle migration and reduction of lipid oxidation in salmon	Films	To evaluate the montmorillonite (MMT15 A) and α-tocopherol migration potential and antioxidant effect of chitosan/ MMT15 A/α-tocopherol active films on reduction of lipid oxidation in fresh salmon	- Chitosan - MMT15 A - α- tocopherol	- Thickness - Energy-dispersive X-ray spectroscopy - WVP In salmon fish - Thiobarbituric Acid - Water content - Ether extract - Ashes - Quantification of tocopherol - Color analysis - Minerais (Mg e Si)	The use of chitosan films with 15% α-tocopherol + 1% MMT15 A is recommended in order to obtain high barrier of vapor permeability and a controlled release of α-tocopherol at storage time, and it can be used as a packaging antioxidant and enrich nutritionally the food	Dias *et al.* (2018)

(*continued*)

No	Article title	USE	Purpose of the article	Composition material	Properties evaluated in films/coatings or food products	Principal results of the article	REF.
08	Physico-chemical, antimicrobial and antioxidant properties of gelatin-chitosan-based films loaded with nanoemulsions encapsulating active compounds	Films	To develop and characterize gelatin-chitosan-based films that incorporate nanoemulsions loaded with a range of active compounds (α-tocopherol, cinnamaldehyde, garlic oil)	- Gelatin - Chitosan - canola oil - Cinnamaldehyde - Garlic oil - Glycerol - Tween 20 - α-tocopherol	- Thickness - Water content - Solubility in water and swelling - TS, EB and modulus of elasticity - Light transmission and transparency - XRD - DSC - Atomic force microscopy analyses - SEM - Antimicrobial activity - DPPH, ABTS, FRAP	The films demonstrated a homogeneous structure with good distribution of nanoencapsulated active compounds (NAC) throughout the biopolymer matrix and without unfavorable effects on the original film thickness, water content, glass transition and melting temperature. The nanoemulsion filler increased the film's resistance to water, reducing its solubility and increasing the film's EB and light barrier properties, in addition to directly affecting its transparency, reducing its TS and stiffness and increasing its stiffness. surface. Nanoemulsions encapsulating active compounds are suitable for producing G-Ch-based films	Pérez-Córdoba *et al.* (2018)

(*continued*)

Table 1.

Table 1.

No	Article title	USE	Purpose of the article	Composition material	Properties evaluated in films/coatings or food products	Principal results of the article	REF.
09	PVA antioxidant nanocomposite films functionalized with α-tocopherol loaded solid lipid nanoparticles	Films	To develop active packaging films of PVA incorporated with different amounts of α-tocopherol-loaded SLN and to evaluate the influence of these nanoparticles on by fluorescence analysis, antioxidant activity, α-tocopherol release in fat food simulant, as well as morphology, X-ray, thermal properties and contact angle	- Polyvinyl alcohol - Soy lecithin - α-tocopherol	- SEM - Wettability and surface free energy - FTIR - XRD - TGA and DSC - Fluorescence analysis - DPPH and ABTS - Release of α-TC from PVA films incorporated with α-TC-NLS	Poly (vinyl alcohol) (PV) films embedded with solid lipid nanoparticles (NL) containing α-tocopherol (TC) at different concentrations showed good stability for 12 weeks. The PV/TC-NL films showed a rapid initial release followed by an equilibrium state between the α-TC transferred through the film to the simulator and the natural migration of α-TC from the simulator to the film. The rate of α-TC release increased with increasing percentage of α-TC-NL added to PV/TC-NL films, explaining the higher antioxidant activity with increasing addition of α-TC-NL to PV/TC-NL films. Morphologically showed that the incorporation of α-TCNL was homogeneous and resulted in a matrix with a rough surface and less cohesive cross-section with greater volume than pure PVA. The films added with NL tocopherol showed greater thermal stability and lower degree of crystallinity than the pure PVA films	De Carvalho *et al.* (2019)

(*continued*)

No	Article title	USE	Purpose of the article	Composition material	Properties evaluated in films/coatings or food products	Principal results of the article	REF.
10	Supercritical CO_2 impregnation of α-tocopherol into PET/PP films for active packaging applications	Films	Obtain active packaging, using SC–CO_2 that incorporates TOC into multilayer PET/PP films. To optimize the asset packaging, a comparison between a film in which TOC is impregnated on the surface of untreated PET (ut-PET) and a film in which TOC is adsorbed on the surface of PET subjected to corona discharge treatment (ct-PET)	- PET - Polypropylene - α-tocopherol	- Field emission scanning electron microscopy (FESEM) - FTIR - DSC - Migration Test - DPPH	Obtaining loaded tocopherol in PP films was the best option to produce a controlled release package with high TOC loading values. The results obtained for monolayers, to create multilayer active films, impregnation of TOC with SC–CO_2 were studied considering the PP surface of the PET/PP film. Migration tests demonstrated that impregnation of TOC in polymeric films using $SCCO_2$ induced a prolonged release of the vitamin, confirming that the controlled release in the package production process was effective	Franco *et al.* (2019)
11	Semi-refined carrageenan (SRC) film incorporated with α-tocopherol Application in food model	Films	To develop and characterize active packaging film from SRC plasticized with glycerol (G) and incorporated with different concentrations of α-tocopherol (0.1%, 0.2%, 0.3% and 0.4% [v/v])	- Semi-refined carrageenan - Glycerol - α-tocopherol	- Thickness - FTIR - TGA - SEM In meat patties - Thiobarbituric Acid - Metmyoglobin assay - pH	Thermally of the SRC-based film improved when α-tocopherol and G were incorporated into the film matrix. The antioxidant effect of α-tocopherol in the SRC-based films was tested using beef burgers and the greatest antioxidant effect was demonstrated by incorporating the highest concentration of α-tocopherol into the SRC-based film. The antioxidant film delayed the development of lipid oxidation and the formation of brown coloration in the hamburgers during storage	Hamid *et al.* (2019a)

(*continued*)

Table 1.

Table 1.

No	Article title	USE	Purpose of the article	Composition material	Properties evaluated in films/coatings or food products	Principal results of the article	REF.
12	SRC film Incorporated with α-Tocopherol and *Persicaria minor* for Meat Patties Application	Films	To analyze the antioxidant effect of new semi-refined carrageenan (SRC) active packaging films that incorporated α-tocopherol (0.4% [v/v]) and *Persicaria minor* (PM) (0.4% [v/v]) in beef burgers, in addition, changes in pH and brown color development in ground beef burgers stored for 14 days at 4 °C were evaluated	- Semi-refined carrageenan - *Persicaria minor* - Glycerol - α -tocopherol	- FTIR - Total phenolic content (TPC) - DPPH, ABTS and FRAP In meat patties - Thiobarbituric Acid - Metmyoglobin assay - pH	α-Tocopherol and *Persicaria minor* (PM) extract exhibited different levels of phenolic content and antioxidant activity. The addition of α-tocopherol and PM extract into the SRC-based films delayed the lipid oxidation and metmyoglobin formation in the meat patties throughout the 14-day refrigerated storage	Hamid *et al.* (2019b)
13	Preparation of LDPE with quercetin and α-tocopherol loaded with mesoporous silica for synergetic-release antioxidant active packaging	Films	To develop an antioxidant active LDPE film containing α-tocopherol controlled by Mesoporous Molecular Sieves MCM-41 and Quercetin	- Low-density polyethylene - MCM-41 - Quercetin - α-tocopherol	- TS, EB - WVP - GP - Migration Test - DPPH	The adsorption capacity of α-tocopherol is approximately 40% by weight. The migration test proves that being loaded with MCM-41 decreases α-tocopherol diffusivity by approximately 48.2%, while increasing quercetin diffusivity by approximately 39.5% (MCM-41+α-tocopherol + quercetin) and 50.5% (α-tocopherol + quercetin) after the introduction of α-tocopherol than Q. The DPPH radical scavenging increased after the addition of α-tocopherol	Li *et al.* (2019)

(*continued*)

No	Article title	USE	Purpose of the article	Composition material	Properties evaluated in films/coatings or food products	Principal results of the article	REF.
14	Optimization, antioxidant attributes, stability and release behavior of carboxymethyl cellulose films incorporated with nanoencapsulated vitamin E	Films	To optimize vitamin E (α-tocopherol) loaded polycaprolactone (PCL) nanocapsules into the carboxymethyl cellulose (CMC) film	- CMC - PLC - Glycerol - α-tocopherol	- DPPH - Quantification of initial α-tocopherol in film samples - Release test of α-tocopherol nanocapsules from film samples - Release kinetics of encapsulated ingredient	The preparation of α-tocopherol nanocapsules using polycaprolactone by the nanoprecipitation method was successfully performed, considering the high encapsulation efficiency and favorable suspension stability obtained in this research, which means that the encapsulation of this ingredient in industrial films used in packaging and factories of food is also applicable. The antioxidant properties of the core material and the controlled release of α-tocopherol (from these films) in fatty foods are among the most important effects of these nanoparticles observed in this research	Mirzaei-Mohkam *et al.* (2019)
15	Poly (-Dodecyl-Glutamate) (PAAG-12) and polylactic acid films charged with α-Tocopherol and Their Antioxidant Capacity in Food Models	Films	PAAG-12 films were prepared and enriched with 5% α-tocopherol, with the aim of using them as novel antioxidant active packaging for food applications	- PAAG-12 - Polylactic Acid (PLA) - α-tocopherol	- SEM - TGA and DSC - Food simulation	The increase in the initial temperature of the PAAG-12 film by the addition of the natural antioxidant α-tocopherol validates the improvement in the thermal stability of the branched polymer, which implies better processability for industrial applications in food packaging. When the concentration of ethanol was higher in the simulators, the migration of α-tocopherol from the films was higher. PLA allowed greater migration of antioxidants to the food simulation medium than PAAG-12 in short contact times, which demonstrates that this new polymer is a promising matrix for applications in active packaging. The peroxide test of the oil/water emulsions showed high levels of protection of the active films, capable of increasing the shelf life of up to 29 days	Villasante *et al.* (2019)

(*continued*)

Table 1.

Table 1.

No	Article title	USE	Purpose of the article	Composition material	Properties evaluated in films/coatings or food products	Principal results of the article	REF.
16	Preparation of α-tocopherol-chitosan nanoparticles/chitosan/montmorillonite film and the antioxidant efficiency on sliced dry-cured ham	Films	To prepare a novel antioxidant film by incorporating α-tocopherol-chitosan nanoparticles (TOC-CSNPs) with chitosan/montmorillonite film (namely, TOC-CSNPs/CS/MMT) and investigate the antioxidant activity of TOC-CSNPs/CS/MMT film on sliced dry-cured ham in a period of 120 days at 4 °C	- Chitosan (CS) - Montmorillonite (MMT) - Acetic acid - α-tocopherol (TOC)	- Solubility in water - Swelling ratio - WVP - FTIR - SEM - Cumulative release of TOC - DPPH In Sliced dry-cured ham - Peroxide value - Thiobarbituric Acid	TOC-CSNPs/CS/MMT film with added TOC-CSNP demonstrated long-term, stable and enhanced antioxidant activity during 120 days of storage of sliced cured ham. The film can be applied as edible packaging wrap for food products, maintaining quality and prolonging shelf life without chemical preservatives	Yan *et al.* (2019)
17	Characterization and release kinetic of crosslinked chitosan film incorporated with α-tocopherol	Films	To produce the *in situ* crosslinking emulsification chitosan film by the casting solution method and to study the effect of sodium tripolyphosphate (TPP), sodium citrate (CT) and glutaraldehyde (GLU) for the physical properties, barrier properties, mechanical properties and release kinetics of chitosan film incorporated with α-tocopherol	- Chitosan - Acetic acid glacial - Glycerol - Tween 80 - α-tocopherol	- Color and light transmission - SEM - WVP - EB, TS, Young's Modulus - FTIR - Contact angle - Release of α-tocopherol and estimation of the diffusion coefficient	The cross-linking emulsification process *in situ* was successful and demonstrated the influence of the cross-linking agent on the properties and release kinetics of chitosan incorporated with α-tocopherol, in addition, the cross-linking agent decreased the film luminosity, barrier properties to light and increased the green and yellow of the film, in addition to reducing the EB and TS values. But, the hydrophobicity and roughness of the film increased and there was no significant difference in the water vapor barrier	Yeamsuksawat, Liang (2019)

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Table 1.

No	Article title	USE	Purpose of the article	Composition material	Properties evaluated in films/coatings or food products	Principal results of the article	REF.
18	Characterization of whey protein-based films incorporated with natamycin and nanoemulsion of α-tocopherol	Films	Evaluate the effect of adding natamycin, α-tocopherol nanoemulsion and a mixture of them, on chemical, physical, mechanical, antioxidant and antimicrobial properties of whey protein-based films	- Natamycin - Whey protein concentrate - Glycerol - α-tocopherol	- Thickness - Water content - Solubility in water - TS, EB and modulus of elasticity - Color, opacity and UV–Vis light barrier - WVP - SEM - FTIR - DPPH, ABTS and FRAP - Antimicrobial activity	The addition of natamycin, nanoemulsified α-tocopherol or both did not change the water content of the whey protein-based films. They led to a significant reduction in TS and modulus of elasticity, while showing growth in EB, film opacity, total color difference, UV–Vis light barrier and water vapor, with the addition of the compounds there was an increase in permeability values. The film showed uniform porosity. The activity of the α-tocopherol nanoemulsion remained during its addition to the films	Agudelo-Cuartas *et al.* (2020)
19	Release of α-tocopherol from chitosan/pectin polyelectrolyte complex film into fatty food simulant for the design of antioxidant active food package	Films	Use as packaging material and α-tocopherol (α-TOH) as antioxidant and polyelectrolyte complex (PEC) of chitosan (CS) and pectin (PE) to develop an antioxidant-active packaging with the addition of Tween-80 to facilitate incorporation of hydrophobic α -TOH into hydrophilic PEC CS/PE solution	- Chitosan - Pectina - Tween 80 - Acetic acid - α-TOH	- FTIR - TS - Solubility in water - Release Study - DPPH	PEC CS/PE composition, Tween–80 concentration and α-tocopherol concentration affected the α-TOH release profile. The hydrophilicity of the film increased with increasing pectin content in PEC and Tween-80 concentration, leading to an increase in the accumulated release of α-TOH. The increase in the concentration of incorporated α-TOH also promoted an increase in the release of α-TOH due to its plasticizing effect. The complex films exhibited high antioxidant activity of up to 90.60%. The release profile of all films exhibited an initial burst effect followed by sustained release over 10 d	Hapsari *et al.* (2020)

(*continued*)

Table 1.

No	Article title	USE	Purpose of the article	Composition material	Properties evaluated in films/coatings or food products	Principal results of the article	REF.
20	Eco-friendly materials produced by blown-film extrusion as potential active food packaging	Films	To use the blown-extrusion technique to obtain fully biodegradable and low-cost starch/PBAT blends incorporated with α-tocopherol as an antioxidant	- poly (butylene adipate-co-terephthalate) (PBAT) - Native cassava starch - Glycerol - α-tocopherol	- Thickness - TS, EB, Young's modulus - WVP - Color and opacity - Weight loss in water (WLW) - SEM - TGA - Wide angle X-ray diffraction (WAXD) - Release profile of α-tocopherol from pellets and films - Degradation efficiency of the films by composting	The processability of the films was adequate, even with the inclusion of α-tocopherol. The hydrophobic character of α-TOC starch probably destabilized the matrix/PBAT, which was demonstrated by SEM images. This increases water vapor permeability and reduces performance, regardless of antioxidant concentration. X-ray patterns offer the diffusion complexity crystallization of amyl. The formulation containing the lowest concentration of α-TOC was almost complete, favoring its application as food packaging. The assets offered biodegradability. Demonstrating that active films based on starch/PBAT with low α-tocopherol added (0.25 g.100 g^{-1}) are an alternative to non-degradable food packaging materials	Lopes *et al.* (2020)

(*continued*)

Table 1.

No	Article title	USE	Purpose of the article	Composition material	Properties evaluated in films/coatings or food products	Principal results of the article	REF.
21	Biodegradable Poly(ε-Caprolactone) Active Films Loaded with MSU-X Mesoporous Silica for the Release of α -Tocopherol	Films	Develop and characterize new films active PCL-based containing α-tocopherol and MSU-X mesoporous silica	- PCL - MSU-X - α-tocopherol	- TGA and DSC - WVP - Oxygen transmission rate (OTR) - Optical Properties - Release Tests - DPPH and ABTS - Antimicrobial Activity	Both PCL-AD (direct addition of TOC and MSU-X) and PCL-IMP (MSU-X impregnated with TOC silica) films demonstrated good thermal stability and showed no significant changes in oxygen and water vapor barrier properties. The increase in the values of the oxidation onset parameters (oxidative onset temperature-OOT and oxidative induction time-OIT) obtained for these formulations indicated the effectiveness of the addition of mesoporous silica and antioxidant TOC to protect the final material from oxidation and thermal degradation, favoring its processing at high temperatures and later use. PCL-IMP showed a slower antioxidant release in 50% ethanol (v/v) than the other films (PCL-TOC) and (PCL-AD). The antioxidant diffusivity of PCL-IMP films decreased 10-fold compared to films containing free α-tocopherol. PCL-IMP and PCL-AD films exhibited greater antibacterial activity against Gram-positive strains (*S. aureus*) and PCL-TOC film against Gram-negative bacteria (*E. coli*)	Mellinas *et al.* (2020)

(*continued*)

Table 1.

No	Article title	USE	Purpose of the article	Composition material	Properties evaluated in films/coatings or food products	Principal results of the article	REF.
22	Physical, mechanical, thermal and structural characteristics of nanoencapsulated vitamin E-loaded carboxymethyl cellulose (CMC) films	Films	To study the effect of nanoencapsulation of α-tocopherol (TOCNPS) in CMC films on film properties to understand whether this useful change can improve film characteristics as it is very important to deliver food products in packages which can meet customers' expectations, e.g. to be resistant against environmental changes (mechanical, thermal, humidity, etc.) and fluctuations	- CMC - Glycerol - Lechitin - α -tocopherol	- Thickness - Transmittance - Color properties - Contact angle - WVP - TS, EB, Young's modulus - DSC - FTIR - SEM	The properties of carboxymethyl cellulose films form improved with the addition of α-tocopherol nanocapsules, the nanoparticles may be the cause of porosity and changes in the structure of the film matrix, which according to the research results, these films can influence mainly, with regard to water vapor permeation	Mirzaei-Mohkam *et al.* (2020)
23	Hydroxypropyl methylcellulose or soy protein isolate-based edible, water-soluble and antioxidant films for safflower oil packaging	Films	To develop edible, antioxidant, heat-sealable, oil-resistant and water-soluble packaging	- 1hydroxypropyl methylcellulose (HPMC) - oleic acid (OA) - Soy protein isolate (SPI) - Cellulose nanocrystals (CNC) - Glycerol - DL-α-tocopherol acetate (VE)	- Color - Transparency - Opacity - SEM - WVP - Water solubility - Film disintegration - Oil permeability - Contact angle - TS, EB, Young's modulus In safflower oil - Peroxide value	Packages were developed based on hydroxypropylmethyl cellulose (HPMC) and soy protein isolate (SPI), with combinations of DL-α-tocopherol acetate, oleic acid and CNCs. The HPMC-derived films showed good strength and were highly water soluble at 20–40 °C. Low concentration of CNCs improved the film barrier and mechanical properties. SPI films showed highly elastic characteristics, disintegrated in water over a wide temperature range (20–90 °C) and maintained superior antioxidant protection of safflower oil compared to HPMC films and a polypropylene control, with an estimated lifetime of more than one year based on lipid oxidation	Rosenbloom, Zhao (2020)

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Table 1.

No	Article title	USE	Purpose of the article	Composition material	Properties evaluated in films/coatings or food products	Principal results of the article	REF.
24	Characterization of α-tocopherol-loaded MCM-41 mesoporous silica with different pore sizes and antioxidant active packaging films	Films	To investigate the influence of pore size and morphology of MCM-41 on physical properties of controlled release LDPE films and the effect of these factors on the release profiles of α-tocopherol from controlled release films to fatty food simulant	- LDPE - MCM-41 - α-tocopherol	- DSC - TS, EB, Young's modulus - SEM - Migration test	Was investigated the influence of mesoporous silica MCM-41 loaded with α-tocopherol, with different pore sizes and antioxidant active packaging films, the main result found was that the pore size and particle size of the antioxidant used in the controlled release packaging films should be comparable for a good controlled release effect	Sun *et al.* (2020)
25	Effect of α-tocopherol antioxidant on rheological and physicochemical properties of chitosan/zein edible films	Edible films	To fabricate edible film containing α-tocopherol as an antioxidant packaging for food applications	- Chitosan - Zein - α-tocopherol	- Rheological analysis - Particle size and zeta potential - Thickness - TS, EB - WVP - Opacity - XRD - SEM - DPPH	Was produced of a chitosan/zein-based edible film incorporating α-tocopherol as antioxidant packaging for food applications, the results showed that all solutions forming the composite film showed excellent stability, with good barrier properties, opacity. Evidencing the compatibility of α-tocopherol and chitosan/zein in edible films	Zhang *et al.* (2020a)

(*continued*)

Table 1.

No	Article title	USE	Purpose of the article	Composition material	Properties evaluated in films/coatings or food products	Principal results of the article	REF.
26	Combined antioxidant and sensory effects of active chitosan/zein film containing α-tocopherol on *Agaricus bisporus*	Films	To prepare active packaging films which were incorporated with α-tocopherol and evaluate its effect on the postharvest quality, antioxidant enzymatic system and bioactive compounds contents of *Agaricus bisporus*	- Chitosan (C) - Zein (Z) - Glycerol - α-tocopherol	- Package atmosphere composition In Mushroom - Weight loss - Firmness - Membrane permeability - Respiration rate - Browning degree - Polyphenol oxidase (PPO) and peroxidase (POD) activity - Malondialdehyde (MDA) content - Total phenolic content - Catalase (CAT) activity - Superoxide dismutase (SOD) activity - DPPH	The active packaging film composed of chitosan/zein containing α-tocopherol proved to be efficient in reducing the postharvest quality of mushrooms at 4 °C. Where in all treatments the mushroom treated with the film showed the highest firmness, catalase, superoxide dismutase activities, total phenolic content and DPPH radical scavenging activity, showing that the film could improve antioxidant properties and maintain mushroom quality	Zhang *et al.* (2020b)

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No	Article title	USE	Purpose of the article	Composition material	Properties evaluated in films/coatings or food products	Principal results of the article	REF.
27	Chitosan-nanocomposites as a food active packaging: Effect of addition of tocopherol and modified montmorillonite	Films	To evaluate the effect of tocopherol concentration (0%, 5%, 10% and 20%) and modified montmorillonite clay (MMT15 A) nanoparticles (0 and 1%) on the properties of chitosan (CS) films	- Chitosan (CS) - Montmorillonite (MMT) - DL-α-tocopherol acetate	- Transmission electron microscopy - SEM - Colorimetric parameters - Transparency - TS, elastic modulus - DPPH - Contact angle - Moisture sorption - WVP - TGA and DSC	The application of tocopherol provided antioxidant activity, increased the thermal stability of the film. This resulted in the development of antioxidant bionanocomposites with improved properties both for packaging and for foods that had their nutritional properties enriched by the addition of tocopherol	Dias *et al.* (2021)
28	Optimization of PCL Polymeric Films as Potential Matrices for the Loading of α-Tocopherol by a Combination of Innovative Green Processes	Films	To compare two different polymeric structures: nanofibrous films obtained by electrospinning and continuous films obtained by solvent casting, to identify the best solution and process conditions for subjecting the samples to the supercritical fluids impregnation process (SFI)	- Polycaprolactone (PCL) - Polyethylene glycol (PEG) - α-tocopherol	- FESEM. - Migration tests	The polymeric support was produced both by electrospinning, by pouring solvent, and then it was loaded with alpha-tocopherol by impregnation with $SCCO_2$. The authors noted that the optimal operating conditions must be properly selected to obtain an active package	Drago *et al.* (2021)

(*continued*)

Table 1.

Table 1.

No	Article title	USE	Purpose of the article	Composition material	Properties evaluated in films/coatings or food products	Principal results of the article	REF.
29	Antioxidant edible film based on a carrot pectin-enriched fraction as an active packaging of a vegan cashew ripened cheese	Edible films	To determine the filmogenic performance of CPEF, the capability of the film network to stabilize at 25 °C the orange color and hence the carotenoids responsible for it and finally evaluate the antioxidant capacity of the edible film for the preservation of a vegan cashew ripened cheese during storage	- Commercial pectin (*CP*) - Pectin-enriched fraction from carrots (CPEF) - Glycerol - α-carotene - β-carotene - Lutein - α-tocopherol	- Moisture content, water activity and pH - DSC - Color - Thickness - Water solubility - Contact angle - WVP - TS, EB - FTIR - Determination of carotenoids - In vegan ripened cheese made of cashew nuts - TBARS - MDA	Evaluated antioxidant edible film based on carrot pectin enriched fraction for the preservation of a vegan matured cashew cheese during storage. As main results, it was evidenced that 100% CPEF films stabilized orange color even under light storage at 25 °C and 57.7% RH, and carotenoids were lost according to a first-order kinetics. In addition, films containing CPEF showed high resistance to dissolution in water. These properties made the 100% CPEF film an effective material to preserve, during 60 days of storage at 7 °C, foods with high aW (0.952) and vulnerable to oxidation such as vegan cured cashew cheese	Encalada *et al.* (2021)
30	Active coatings of thermoplastic starch and chitosan with α-tocopherol/bentonite for special green coffee beans	Coatings and films	To incorporate α-tocopherol, a powerful antioxidant, in thermoplastic starch (TPS) and chitosan (TPC) and determined the best cavitation energy (960–3840 J mL^{-1}) using an ultrasonic probe	- TPS - TPC - Soy lecithin - Bentonite (BNT) - α-tocopherol	- DPPH - Contact angle and surface energy - XRD - FTIR - WVP - Puncture strength (PS) - TGA and DSC - Compressive load supported by coated green coffee beans	Was developed active coatings of thermoplastic starch and chitosan with α-tocopherol/bentonite for specialty green coffee beans, was observed that the combination chitosan/α-tocopherol/bentonite, dispersed with energy of 960 J-mL^{-1}, is effective in developing biopolymeric coatings for green coffee beans. These coatings provided antioxidant activity, lowered water vapor permeability and increased compressive loading of the beans, thereby protecting them from oxidation, moisture and compression during storage conditions	Ferreira *et al.* (2021)

(*continued*)

Table 1.

No	Article title	USE	Purpose of the article	Composition material	Properties evaluated in films/coatings or food products	Principal results of the article	REF.
31	Enhanced mechanical and antioxidant properties of biodegradable poly (lactic) acid-poly(3-hydroxybutyrate-co-4-hydroxybutyrate) film utilizing α-tocopherol for peach storage	Films	To develop biodegradable and active films that could match petroleum-based films both in antioxidant and mechanical properties	- Poly (lactic) acid (PLA) - Poly(3-hydroxybutyrate-co-4-hydroxybutyrate) (PHB) - α-tocopherol	- Thickness - TS, EB - GP - WVP - Contact angle - TGA and DSC - SEM - FTIR - DPPH In peach - Determination of firmness and Total soluble sugar (TSS) - MDA - Measurement of weight loss - relaxation time and magnetic resonance imaging (MRI) detection	The incorporation of α-tocopherol in PLA-based films increased the mechanical properties, WVP and gas permeability compared to the pure PLA film. Some intermolecular gaps were found in the PLA-PHB-α-tocopherol film, with higher gas permeability. The firmness of the peach sample packaged with PLA-PHB-α-tocopherol film effectively delayed the aging of the fruit, the active substances increased the gas permeability and WVP of the film, improved the external gas and moisture exchange and further maintained the quality of peaches. The PLA-PHB-α-tocopherol film showed the highest DPPH value, inhibited the increase in MDA content and protected the fruit cell wall structure	Jiang *et al.* (2021)

(*continued*)

Table 1.

No	Article title	USE	Purpose of the article	Composition material	Properties evaluated in films/coatings or food products	Principal results of the article	REF.
32	Development of active low-density polyethylene (LDPE) antioxidant packaging films: Controlled release effect of modified mesoporous silicas	Films	To develop active LDPE antioxidant packaging films with modified MCM-41and study the controlled release effects and mechanisms of modified MCM-41 on α-tocopherol in active LDPE packaging films	- LDPE - MCM-41 - α-tocopherol	- Migration tests - FTIR - isotherms of N2 adsorption/ desorption of mesoporous materials - TGA - XRD	The main results obtained were that active low-density polyethylene films with enhanced slow-release effect were developed by incorporating modified mesoporous silicas loaded with α-tocopherol, which has potential application in the protection of fatty foods. Furthermore, modification with different organic groups can attribute to different textural properties and active loading capabilities of mesoporous silica compounds. And strong interaction energies between adsorbates and adsorbents caused by organic groups lead to slow release effects of mesoporous silicas	Sun *et al.* (2021)
33	Effect of *α*-dl tocopherol acetate (antioxidant) enriched edible coating on the physicochemical, functional properties and shelf life of minimally processed carrots (*Daucus carota* subsp. sativus)	Edible coatings	Evaluate the effect of antioxidant-enriched edible coating on shelf life and shelf life and nutritional quality retention of minimally processed carrots	- Sodium Alginate - Glycerol - Calcium chloride - Tocopherol Acetate	In minimally processed carrots - Weight loss - Total soluble solids (TSS), pH, reducing sugar, total sugar and Ascorbic acid estimation - Color - DPPH and ABTS - Total phenolic content - Carotenoid content and provitamin A activity - Firmness - Microbiological quality	The alginate-based coating supplemented with tocopheryl acetate showed potential application in extending the shelf life of minimally processed carrots during refrigerated storage, maintaining quality, acceptability and nutritional value of the tested product	Keshari *et al.* (2022)

Note(s): WVP, water vapor permeability; GP, gas permeability; FTIR, Fourier transform infrared spectroscopy; XRD, X-ray diffraction; DSC, differential scanning calorimetry; SEM, scanning electron microscope; TGA, thermogravimetric analysis; –FESEM, field emission scanning electron microscopy
Source(s): Author

[TGA]/differential scanning calorimetry [DSC]), X-ray diffraction (XRD), hydrophobicity, α-tocopherol migration, more details of these properties will be described below.

From this point on, for a better understanding of the subject, it was decided to separate the discussion topic from the articles that dealt with the properties of films and the properties of coatings added of tocopherol for use in food packaging. However, when analyzing Table 1, it can be seen that of the articles that developed coatings, only the work by Ferreira *et al.* (2021) evaluated the properties of the material developed, while the articles by Shokri and Ehsani (2017) and Keshari *et al.* (2022) evaluated the properties of the food systems to which the coatings were applied, only Ferreira's work will be discussed together with the articles that determined the properties of the tocopherol films, precisely because in this work a film was also developed to carry out the evaluations, while the articles by Shokri and Ehsani (2017) and Keshari *et al.* (2022) will be discussed in Section 5.1.3.

5.1.2 Properties of films added of tocopherol for food packing. 5.1.2.1 Thickness. Thickness can influence other film properties such as mechanical, barrier properties (Mirzaei-Mohkam *et al.*, 2020) and optics. The increase in film thickness attributed to the application of α-tocopherol was reported, mainly in film formulations with increasing concentrations of α-tocopherol (Hamid *et al.*, 2019a; Lopes *et al.*, 2020; Mirzaei-Mohkam *et al.*, 2020; Encalada *et al.*, 2021). Film thickness can be influenced by high concentrations of solids (Piñeros-Hernandez *et al.*, 2017). Therefore, changes in the concentration of the polymer and even the antioxidant added to the film can change this parameter.

5.1.2.2 Optical properties. Regarding the effects of tocopherol on the optical properties, films with a yellowish color were reported (Yeamsuksawat and Liang, 2019; Agudelo-Cuartas *et al.*, 2020; Mirzaei-Mohkam *et al.*, 2020) and reddish-yellow (Mellinas *et al.*, 2020). The color of films and packaging can influence consumer acceptance and the commercial success of the final product, so it is considered an important parameter to be evaluated for packaging with the purpose of application in food (Mellinas *et al.*, 2020).

In the analyzed works, the increase in the opacity of the films was also widely reported (Darbasi *et al.*, 2017; Sun *et al.*, 2017a; Pérez-Córdoba *et al.*, 2018; Hamid *et al.*, 2019a; Yeamsuksawat and Liang, 2019; Agudelo-Cuartas *et al.*, 2020; Zhang *et al.*, 2020a, b; Dias *et al.*, 2021; Rosenbloom and Zhao, 2020); however, two articles reported a decrease in this parameter (Lopes *et al.*, 2020; Mirzaei-Mohkam *et al.*, 2020). The transparency was attributed to interference in the organization of the matrix, creating irregularities and favoring the transmission of light with an effect on the compaction of the polymeric network, increasing the free spaces.

Opacity is an essential parameter for food packaging films and coatings, as reduced light transmission can promote protection from photosensitive compounds. However, transparent films are also used in food to present the food inside the package better. Thus, the food industry guarantees both transparent and opaque packaging.

5.1.2.3 Barrier properties to water and gases. Barrier properties have also been extensively studied. Some articles have reported increased water vapor permeability (WVP) (Darbasi *et al.*, 2017; Martelli *et al.*, 2017; Sun *et al.*, 2017a, b; Dias *et al.*, 2018; Agudelo-Cuartas *et al.*, 2020; Lopes *et al.*, 2020; Ferreira *et al.*, 2021; Jiang *et al.*, 2021; Yeamsuksawat and Liang, 2019) others the decrease of this parameter, attributed to the tocopherol applied to the polymer (Li *et al.*, 2019; Mellinas *et al.*, 2020; Mirzaei-Mohkam *et al.*, 2020; Rosenbloom and Zhao, 2020; Yan *et al.*, 2019; Zhang *et al.*, 2020b).

The WVP is one of the most critical parameters for the characterization of a film because it provides an idea of whether the film will contribute to the neutralization of water loss from the packaged product (Sandoval *et al.*, 2019). It depends on the polymer/water interaction (Kocira *et al.*, 2021). It is noted that many articles reported increased permeability to water vapor, which ends up being an obstacle to the industrial use of some films or coatings. So it is necessary to overcome this challenge so that this type of packaging is adopted industrially, specifically in the food sector, because vegetables, in general, are necessary an adequate barrier to the passage of water into the package to keep the fruit fresh, where the hydration must be maintained. While for dry foods such as bread and flour, it is necessary to prevent water from entering the film or coating.

Another barrier property evaluated was the permeability to O_2 (Sun *et al.*, 2017a, b) for LDPE films with mesoporous silica nanoparticles added to tocopherol developed in the two articles. The increase in permeability was attributed to the uneven dispersion of the nanoparticles in the films, while in the article by Jiang *et al.* (2021) PLA-PHB films, increased oxygen permeability and also increased CO_2 permeability were reported. Films and coatings need to function as a barrier to gases because if the film or coating involves an oxidation-sensitive product, it must remain protected so that it does not suffer the action of oxygen. "Thus, when a polymeric film package has low oxygen permeability coefficients, the oxygen pressure inside the container drops to the point where oxidation is delayed, prolonging the product's shelf life" (Siracusa, 2012). Meanwhile, CO_2 permeation must remain within the desired levels inside the package to not harm the food.

5.1.2.4 Microestruture. The inclusion of tocopherol at different concentrations in starch and poly (butylene adipate-co-terephthalate) (PBAT) films altered the microstructure, causing heterogeneity of the polymer matrix regardless of the concentration used (Lopes *et al.*, 2020). The films developed with carboxymethyl cellulose and higher concentrations of polycaprolactone nanocapsules suffered cracks in the structure. However, the films were more uniform, containing 30% and 50% concentrations of nanocapsules (Mirzaei-Mohkam *et al.*, 2020). In monolayer and multilayer polyethylene terephthalate (PET)/polypropylene (PP) films, the films impregnated with tocopherol showed discontinuity of the film surface (Franco *et al.*, 2019).

The surface of the gelatin and chitosan films became roughened with the addition of nano-encapsulated active agents (α-tocopherol + cinnamaldehyde + garlic oil) (Pérez-Córdoba *et al.*, 2018), while in chitosan films, the surface was rough, with irregular spots, due to incorporation with α-tocopherol (Yeamsuksawat and Liang, 2019). Chitosan and zein films added with tocopherol showed cracks, heterogeneities or uniform spots (Zhang *et al.*, 2020b). However, chitosan films developed with different concentrations of montmorillonite nanocomposites added with 20% tocopherol showed heterogeneous characteristics (Dias *et al.*, 2021).

In semi-refined carrageenan films with different α-tocopherol concentrations, oil droplets were observed that increased with increasing tocopherol concentration (Hamid *et al.*, 2019a), as well as with hydroxypropylmethylcellulose (HPMC) or soy protein isolate (SPI) films that showed oil droplets attributed to the lipid phase used in the study (Rosenbloom and Zhao, 2020). Several structural behaviors of films and coatings are added with tocopherol. These are closely linked to the technique of preparing the films, the material used and the amount of each material in forming the polymer. What was possible to perceive in this study was that there were articles that reported a smooth, homogeneous or compact structure of the films (de Carvalho *et al.*, 2019; Agudelo-Cuartas *et al.*, 2020; Jiang *et al.*, 2021). The microstructure of a polymer can influence several other properties, such as mechanical, optical and barrier properties.

5.1.2.5 Mechanical properties. As for the tensile strength (TS), it was reported that after the addition of tocopherol to the polymeric matrix, the increase (Darbasi *et al.*, 2017; Li *et al.*, 2019; Sun *et al.*, 2017b; 2020) attributed to a good distribution of tocopherol in the film, to the fluidity and viscosity of α-tocopherol for being similar to a plasticizer and in the case of the study by Sun *et al.* (2020), this increase was attributed not only to the presence of α-tocopherol but the application of mesoporous silica nanoparticles with α-tocopherol in LDPE films.

As reported in other articles, the reduction of TS (Sun *et al.*, 2017a; Pérez-Córdoba *et al.*, 2018; Agudelo-Cuartas *et al.*, 2020; Hapsari *et al.*, 2020; Lopes *et al.*, 2020;

Mirzaei-Mohkam *et al.*, 2020; Zhang *et al.*, 2020b; Dias *et al.*, 2021; Jiang *et al.*, 2021; Rosenbloom and Zhao, 2020), also attributed to the similarity of α-tocopherol with a plasticizer improving the mobility of the polymer chains. However, the microstructure was primarily associated with the behavior of the films for TS; that is, most of the films or coatings added with tocopherol for food presented as less rigid and less resistant than their respective controls.

The elongation at break (EB) of the films increased in the studies of Darbasi *et al.* (2017), Pérez-Córdoba *et al.* (2018), Li *et al.* (2019), Agudelo-Cuartas *et al.* (2020), Mellinas *et al.* (2020), Mirzaei-Mohkam *et al.* (2020), Jiang *et al.* (2021) and Rosenbloom and Zhao (2020), the addition of α-tocopherol to the films increased the mobility of the polymeric chains. It generates more flexible films, contrary to the studies of Lopes *et al.* (2020), Martelli *et al.* (2017), Sun *et al.* (2017a, b), Yeamsuksawat and Liang (2019) and Zhang *et al.* (2020b), in which the reduction of EB and less flexibility of the films added with α-tocopherol were demonstrated.

The elasticity modulus (EM) increased, increasing the stiffness of the films (Martelli *et al.*, 2017; Mirzaei-Mohkam *et al.*, 2020; Sun *et al.*, 2020; Yeamsuksawat and Liang, 2019; Zhang *et al.*, 2020b). However, some articles reported a reduction in EM (Lopes *et al.*, 2020; Agudelo-Cuartas *et al.*, 2020) and the plasticizing effect of α-tocopherol was considered a determining factor in the modification of the antioxidant/polymer interaction, which increased the polymer mobility and influenced EM, reducing the rigidity of the films.

In the case of food packaging, flexibility is an important factor because if the intention is to manufacture trays, for example, the material must have little flexibility; however, for the manufacture of films, the flexibility must be adequate to levels that can actually be involved the food and seal it, or wrap the food product as a flexible film.

5.1.2.6 Thermal properties (TGA/DSC). It is essential to know TGA/DSC properties not to overheat or even reach the polymeric melting point when manufacturing the film or coating. In general, the works that evaluated the thermogravimetry of the films (TGA) (Pérez-Córdoba *et al.*, 2018; de Carvalho *et al.*, 2019; Franco *et al.*, 2019; Hamid *et al.*, 2019b; Villasante *et al.*, 2019; Lopes *et al.*, 2020; Mellinas *et al.*, 2020; Sun *et al.*, 2020, 2021; Encalada *et al.*, 2021; Ferreira *et al.*, 2021; Jiang *et al.*, 2021) do not observe thermal alterations attributed to the addition of tocopherol. However, Villasante *et al.* (2019) reported improved thermal stability of poly (α-Dodecyl-Glutamate) (PAAG-12) films added with α-tocopherol and stated that this allowed processability at higher film temperatures.

Ferreira *et al.* (2021), who produced thermoplastic starch and chitosan films with α-tocopherol/bentonite, observed a strong link between tocopherol and the other ingredients of the formulations that contained tocopherol and attributed it to the changes in the mass loss peaks. At higher temperatures, they observed a peak close to 437 °C, which was attributed to a break in the aromatic ring of the α-tocopherol structure, corroborating the article by de Carvalho *et al.* (2019) who developed poly (vinyl alcohol) (PVA) films added with α-tocopherol nanoparticles, which observed mass loss peaks near 430 °C.

On the other hand, studies evaluated DSC (Pérez-Córdoba *et al.*, 2018; de Carvalho *et al.*, 2019; Franco *et al.*, 2019; Villasante *et al.*, 2019; Mellinas *et al.*, 2020; Mirzaei-Mohkam *et al.*, 2020; Sun *et al.*, 2017a; 2020; Jiang *et al.*, 2021; Ferreira *et al.*, 2021). In general, adding tocopherol to the polymer matrix showed few changes in the melting point. Several articles observed a reduction in the crystallinity of the films as the inclusion or increase in the concentration of tocopherol in the films occurred; however, Jiang *et al.* (2021) observed an increase in crystallinity, attributed to the interaction between the plasticized PLA-PHB and α-tocopherol interface, corroborating Sun *et al.* (2020) who justified the increase of this parameter to the surface area of mesoporous silica nanoparticles added with tocopherol.

5.1.2.7 X-ray diffraction (XRD). As for the XRD, standards evaluated by the articles (Dias *et al.*, 2018; Pérez-Córdoba *et al.*, 2018; de Carvalho *et al.*, 2019; Lopes *et al.*, 2020; Sun *et al.*, 2017a, b, 2021; Zhang *et al.*, 2020b; Ferreira *et al.*, 2021), in the article by de Carvalho *et al.*

(2019), the PVA films added with α-tocopherol at different concentrations, 30%, 50% and 70%, showed better miscibility than the control sample and concentration of 50% presented more amorphous character. While in the article by Lopes *et al.* (2020) with starch/ PBAT films that processing conditions were similar for all formulations concluded that α-tocopherol induces crystallization of amylose complexes, producing semicrystalline materials. Sun *et al.* (2017a, b) described that the XRD standards for the formulation of the film included mesoporous silica nanoparticles added with α-tocopherol presented a reduction of the peak intensity after the use of the α-tocopherol, indicating the adsorption efficiency of the additive.

According to Pappas (2006), the XRD technique or diffraction patterns is based on information from the atomic structures of materials, which can be examined and characterized through the position of atoms, their arrangement in each unit cell and the spacing between the atomic planes. Knowing this property and the other properties mentioned here can contribute to designing a polymeric film or coating. However, from the analysis of the articles that evaluated this parameter, it is worth mentioning that the incorporation of α-tocopherol can contribute to obtaining more crystalline polymers.

5.1.2.8 Hydrophobicity. When developing a film or coating, it is necessary to evaluate the contact angle to know the hydrophobicity or hydrophilicity of the material. Freitas *et al.* (2022) stated that a contact angle below 90° denotes a low surface tension, so the lower the wettability, the more hydrophobic the surface. It is noted in the articles that the addition of α-tocopherol to the films or coatings produced polymers with greater hydrophobicity (de Carvalho *et al.*, 2019; Dias *et al.*, 2021) and hydrophilicity (Ferreira *et al.*, 2021; Jiang *et al.*, 2021). For use in food packaging, the film or coating must be more hydrophobic to function as a barrier to water, as greater humidity can cause deterioration of the food product—the incorporation of α-tocopherol precisely to combine a hydrophobic compound with the polymer matrix to increase hydrophobicity. However, the α-tocopherol molecule also has hydroxyl groups, which gives this antioxidant a hydrophilic character, so when applying it to a polymer, the condition of this interaction must be evaluated because, at the time of joining with the other assembly materials of the formulation, it can attribute a hydrophilic character to the material.

5.1.2.9 α-tocopherol migration. According to the Brazilian Health Regulatory Agency (Anvisa), migration is “the transfer of material components in contact with food to these products, due to physical-chemical phenomena.” Components used in materials intended to come into contact with food must be included in positive lists, which are lists of “substances that have been proven to be physiologically innocuous in animal tests and whose use is authorized for the manufacture of materials that will come into contact with food” (Brasil, 2001).

The advent of active packaging has become an indispensable assessment, as the incorporation of agents in films or coatings must be safe. Plastic packaging materials and articles must not transfer their constituents to food simulants in amounts more significant than 10 milligrams of total constituents released per dm^2 of the food contact surface. In addition, this regulation defines the use of α-tocopherol as an additive for the production of polymeric packaging and does not establish restrictions according to European Regulamentation (Regulation-N° 10/2011).

With the addition of tocopherol, the intention is precise that it is controlled release into the headspace around the product and generates a protective effect on the food at an adequate migration limit. A vast number of articles that evaluated the stability and migration properties of α-tocopherol added to films or coatings for use in food (Martelli *et al.*, 2017; de Carvalho *et al.*, 2019; Li *et al.*, 2019; Mirzaei-Mohkam *et al.*, 2019; Villasante *et al.*, 2019; Yeamsuksawat and Liang, 2019; Hapsari *et al.*, 2020; Lopes *et al.*, 2020; Mellinas *et al.*, 2020; Sun *et al.*, 2017a, b, 2020, 2021; Drago *et al.*, 2021).

Many behaviors have been observed from short-term releases to long-term releases, but what drew much attention were the films in which mesoporous silica nanoparticles were added with α-tocopherol. Compared to films incorporated directly with this active, the controlled release was mainly attributed to the mesoporous silica that prolonged the migration period of α-tocopherol due to its incorporation into the pore channel, making this release difficult (Li *et al.*, 2019; Mellinas *et al.*, 2020; Sun *et al.*, 2017a, b, 2020, 2021). Furthermore, it can be attributed to the adequate pore size of the mesoporous silica that controlled the release rate (Sun *et al.*, 2017a, 2021).

A controlled release package, added with an active compound, aims to delay spoilage and prolong the shelf life of the food. However, the concentration of the active agent can be released at different controlled levels (Vasile and Baican, 2021); this agent retained in the packaging must be properly released to the food product because when it occurs initially, soon after the food product is packaged, it can contribute to inhibiting the oxidation induction period (de Carvalho *et al.*, 2019), while if it is released at a slow rate, it may not delay the deterioration of the product (Vasile and Baican, 2021). Therefore, there is a need to evaluate this property in a film or coating added with an antioxidant such as tocopherol.

5.1.3 Properties of coatings added of tocopherol for food packing. As mentioned in Section 5.2 and in Table 1, only the articles by Ferreira *et al.* (2021), Shokri and Ehsani (2017) and Keshari *et al.* (2022) developed coatings; in Ferreira's work, only the compressive load borne by coated and uncoated green coffee beans was evaluated, while in Shokri and Keshari's work, the properties of the food systems to which the coatings were applied were evaluated.

Ferreira's results showed greater protection of coffee beans against breakage for beans coated with tocopherol-added coatings, preventing breakage in cases of large-scale storage. For uncoated beans, a force of 375.5 N was needed for breakage, while for beans coated with thermoplastic chitosan-based coatings with tocopherol, 496.9 N was needed.

In the case of the work of Shokri and Ehsani (2017), whey protein coating was applied to fish fillets conditioned at 4 °C for 16 days, and the coatings added of tocopherol showed antioxidant and antimicrobial action in the product. Keshari *et al.* (2022) applied sodium alginate coating on minimally processed carrots packaged at 10 °C for 15 days. They stated that the tocopherol-incorporated film maintained quality and nutritional value and minimized mass loss.

5.2 Possible foods for application of tocopherol films and coatings

According to the results (Table 1), some works that studied the application of films or coatings on food products, as is the case of the work with films: Dias *et al.* (2018) studied chitosan films on salmon fillet packaged at 4 °C for 8 days and reported that product oxidation was minimized by films added of tocopherol. Hamid *et al.* (2019a) developed semi-refined carrageenan films applied to beef hamburgers conditioned at 4 °C for 12 days. They observed that the film with tocopherol retained the pH and delayed the formation of methemoglobin and browning of the meat. Also, working with beef burgers conditioned at 4 °C for 14 days, Hamid *et al.* (2019b) applied semi-refined carrageenan films and reported it contributed to the delay of lipid oxidation and browning formation. Yan *et al.* (2019) applied chitosan nanocapsules with tocopherol in chitosan/montmorillonite films to sliced cured ham conditioned at 4 °C for 120 days and observed that the film containing tocopherol was antioxidant.

Rosenbloom and Zhao (2020) applied films of SPI or hydroxypropyl methylcellulose (HPMC to soybean oil packaged at 35 °C for 60 days. They observed that SPI films containing tocopherol minimized product oxidation. Zhang *et al.* (2020a) applied chitosan or chitosan/zein films to mushrooms packaged at 4 °C for 12 days and observed less mass loss, browning and higher firmness of mushrooms that were packaged with chitosan/zein films added of tocopherol. Jiang *et al.* (2021) applied PLA and PHB films on peaches packaged at 1 °C for

30 days and reported that PLA/PHB films incorporated of tocopherol extended product shelf life. In the case of the work with coatings: Shokri and Ehsani (2017) and Keshari *et al.* (2022) were mentioned in Section 5.2.2.

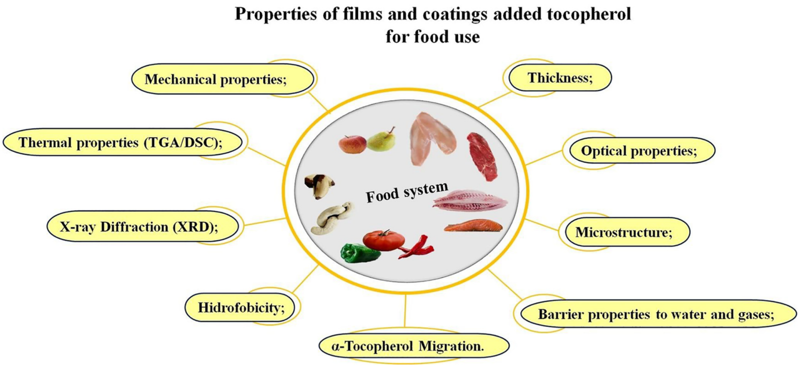
All the films or coatings applied demonstrated antioxidant action in the products they applied. Demonstrating a promising advantage in the application of films and coatings added of tocopherol for use as food packaging material, it is therefore highly necessary to evaluate the properties of films and coatings because depending on the connection between tocopherol and the polymer matrix, these properties are altered. Figure 4 shows some food systems that can be applied with coatings or films with tocopherol and the various properties that can be evaluated in these materials.

5.3 Keywords co-occurrence network

The data from the searched databases were extracted and analyzed by the VOSviewer tool, which allows the creation, visualization and exploration of maps based on network data, resulting in different map configurations (Van Eck and Waltman, 2021).

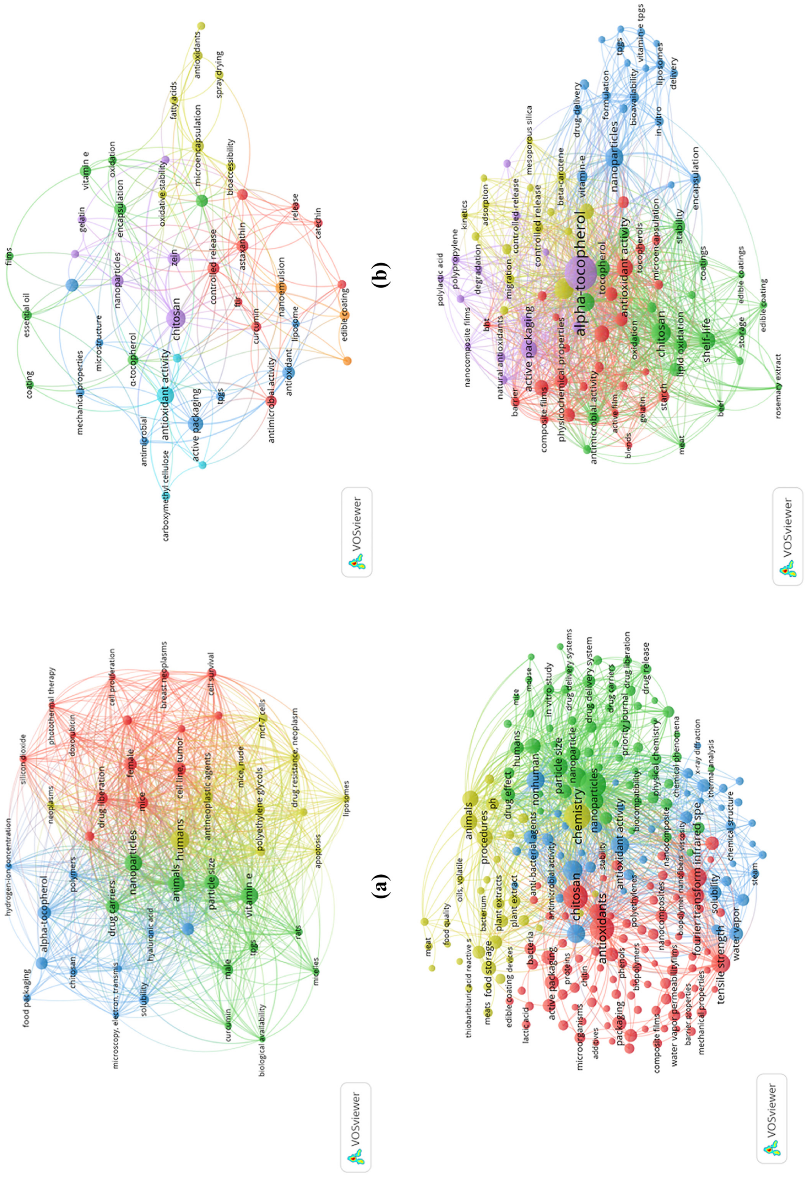
Figure 5 shows the visualization maps in co-occurrence networks of the keywords for the different bases studied. Figure 5 (a) presents the results for PubMed, where it is possible to observe 47 keywords, with at least 5 occurrences, forming 4 clusters, with 782 links or co-occurrence relations between the terms. Figure 5 (b) presents the visualization map for Science Direct, where 45 keywords were obtained, with at least 5 occurrences grouped in 7 clusters. In this database, the term “chitosan” presented a strength value of 34, evidencing the strength of co-occurrence links relationship with other terms. For the results in Scopus, Figure 5 (c), 234 keywords can be observed, with at least 20 occurrences, due to the high number of terms in the network and grouped into 4 clusters, the terms “chitosan,” “antioxidants” and “chemistry” set link value of 233, 233 and 232, respectively, showing a co-occurrence connection between the other terms of published research in this database. In the WOS data visualization, for the results in Web of Science Figure 5 (d), we have network formation for 94 keywords with the formation of 5 clusters among them and the term “alpha-tocopherol” appeared with 88 links, showing the importance of this term within the researches published in WOS. Therefore, when analyzing the network visualization in the different databases, one can notice the main search terms, their weights and clusters. The different colors and connections of the keywords in each database studied are shown in the graphs.

Figure 6 presents the keyword density visualization; the items are represented by their labels, similar to the network visualization. The color indicates the item density, so the



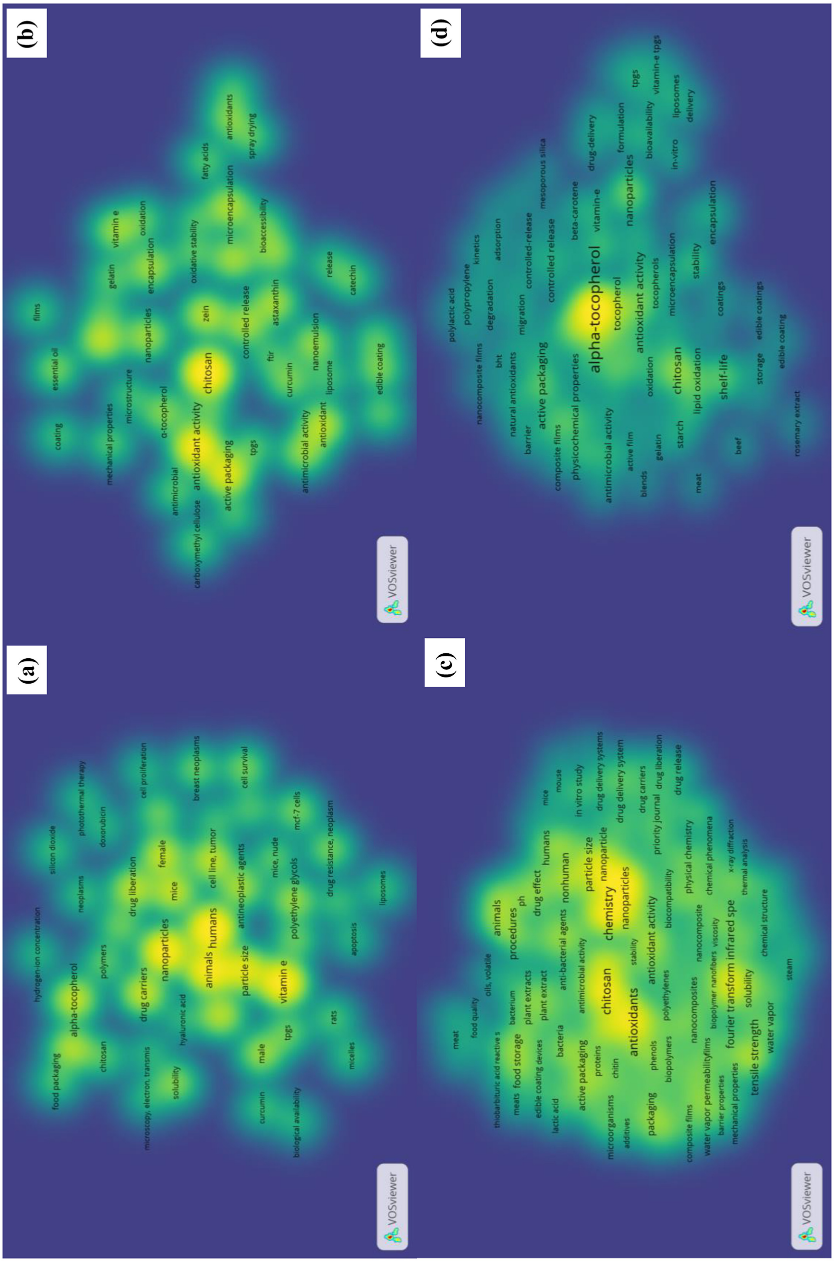
Source(s): Author

Figure 4.
Properties of the films and coatings added of tocopherol for food systems application



Source(s): Author

Figure 5.
Network view
of keyword
co-occurrence,
(a) PubMed, (b) Science
direct, (c) Scopus and
(d) Web of Science
databases



Source(s): Author

Figure 6.
Mapping density visualization of keywords (a) PubMed, (b) Science direct, (c) Scopus and (d) Web of Science databases

greater the number of items in the vicinity of a point and the greater the weights of neighboring items, the closer the point's color is too yellow (Van Eck and Waltman, 2021). Thus, it is possible to observe that the keywords with the highest density in the PubMed database searches, Figure 6 (a), are "nanoparticles," "animals," "humans," "particle size," vitamin E," which is consistent, as the PubMed publishes references and abstracts on life sciences and biomedical topics. For ScienceDirect, Figure 6 (b), the items with the highest density were "chitosan," "active packaging" and antioxidant activity. For Scopus, the keywords with higher density "chitosan," "antioxidants", "chemistry" and "nanoparticles" and "alpha–tocopherol" and "tocopherol" for WOS. Therefore, the terms with the highest density align with the results presented in the network visualization graph, showing the main keywords and their connections between publications in the period studied for the databases shown in this study.

6. Conclusion

In the area of food science and technology, it is sought to develop polymers capable of promoting the extension of the shelf life of the food product, so knowing the properties is vital for this area of research since combining a biodegradable polymeric material with a natural antioxidant activity is of great interest to modern society, as they associate environmental preservation with food preservation.

When carrying out this review, it was possible to find 33 articles published in the last five years on films and coatings added of tocopherol for use in food packaging. The main properties have been addressed. Thus, it was possible to observe that the properties, together or separately, can direct the application and the product for which it is intended. This review also made it possible to survey the co-occurrence networks of keywords related to this topic in each investigated database. Data analysis using the VOSviewer tool enabled a better visualization and exploration of these words and the development of maps that showed the primary connections between the publications.

Conducting this review provided the synthesis of knowledge about the properties of these polymers, which can contribute to further research on the desired technological properties of films and coatings added of tocopherol for use in the food industry.

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