Food Packaging and Shelf Life 35 (2023) 101026

Contents lists available at ScienceDirect

Food Packaging and Shelf Life

journal homepage: www.elsevier.com/locate/fpsl

Cinnamon: An antimicrobial ingredient for active packaging

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ARTICLE INFO

Keywords:
Active packaging
Chitosan
Pickering emulsion
Biopolymers
Preserving
Vosviewer

ABSTRACT

Cinnamon (Cinnamomum spp.) is one of the oldest *spices known* to humankind and is used in culinary and traditional medicine practices. It is obtained from the inner bark of cinnamon trees and contains cinnamaldehyde, cinnamic acid, and cinnamate responsible for its antimicrobial activities. The focus on agri-food industry challenges, such as sustainability, antibiotic-resistant, eco-friendly farming, and the clean label, has been highlighted and increased. Therefore, the review will give a critical snapshot of cinnamon's potential to respond to the agri-food industry challenge. Cinnamon essential oil, obtained from both bark and leave, has been widely used as an antimicrobial ingredient against spoilage microorganisms and foodborne pathogens in the formulations of biodegradative films, edible coating, and adhesive patches. In addition to antibacterial and antifungal activity shown by these packaging, the cinnamon essential oil can improve the barrier, thermal and mechanical properties of films and coatings.

1. Introduction

The agro-food chain is in constant evolution to answer the social demand. Nowadays, sustainability, antibiotic-resistant, eco-friendly farming, and zero-waste are the main challenge for the agro-food chain. Moreover, consumers' preferences point to clean labels and minimally processed fresh foods. Therefore, alternative strategies for food production, plastic substitute, and valorizing waste must be studied in this ever-changing and competitive environment without compromising food safety and economic rentability.

Some of these strategies concerning to delay senescence and food spoilage using food-friendly preservative compounds in active packaging (Kumar et al., 2022; Singh et al., 2021). Likewise, biodegradable polymers continue to gain popularity among the strategies to reduce petroleum plastic. These polymers are made mainly with vegetable sources, such as starch, chitosan, alginate, or animal source like collagen. The growing interest in ready-to-eat fruits, already peeled and cut to facilitate their consumption, also motivates the development of biodegradable and edible coatings (Shiekh et al.2021). In addition to polymer ingredients, researchers use plasticizer agents such as polyalcohols, and antibacterial agents, like essential oils, plant extracts or gaseous chlorine dioxide to develop film or coating with mechanical

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https://doi.org/10.1016/j.fpsl.2023.101026
Received 3 June 2022; Received in revised form 13 September 2022; Accepted 3 January 2023
Available online 6 January 2023

quality and active functions (El-Zehery et al., 2022; Kumar et al., 2022; Singh et al., 2021). The research about essential oil to guarantee food safety is not new since the antimicrobial activity of essential oil has been widely studied (van de Vel et al., 2019). However, the pervasive essential oil aroma, which impregnates foods and causes changes in taste and flavor, hydrophobicity and low stability, and the high price of some of those oils, has dissuaded the food industry from using them.

Nevertheless, consumers' tendency to buy foods with clean labels has reactivated their study (Tao et al., 2021). Furthermore, to avoid the flavor changes in foods due to contact with essential oils, different strategies such as nanoemulsions or using impregned patches, which do not in contact with food, are currently carried out (Li et al., 2020; Songtipya et al., 2021).

Cinnamon is an appreciated aromatic condiment obtained from the inner bark of various Cinnamomum tree genus. Among the about 250 species, the most preferred type in the food industry and accepted as true or Ceylon cinnamon is *Cinnamomum zeylanicum* (syn. *Cinnamomum* verum), which is native to Sri Lankan. Besides this specie, *Cinnamomum cassia* (Chinese cinnamon), *Cinnamomum burmanni* (Indonesian cinnamon) and *Cinnamomum loureiori* (Vietnamese cinnamon) are the other most common cinnamon species (Abeysinghe et al., 2020). Morevover, in addition to *C. zeylanicum*, seven other species of cinnamon are

Table 1
(Poly)phenol and volatile compounds of cinnamon powder and essential oil.

Species	Essential oil distillation process	Extraction method	Detection method	Main compounds	Reference
Bark powder					
C. burmannii	-	Acetone, methanol, ethanol, and water extracts under a magnetic stirrer or sonication	UPLC-HRMS	3,4-dihydroxybenzaldehyde (1138 ppm), Procyanidin B2 (1396 ppm), Cinnamic acid (934 ppm), Protocatechuic acid (193 ppm), Epicatechin (53 ppm), catechin (51 ppm), quercitrin (16 ppm)	(Muhammad et al., 2021)
C. cassia	-	The aqueous extract under magnetic agitation and dehydrated under vacuum	C-HRESIMS	trans-Cinnamic acid (1105 ppm), Protocatechuic acid (155 ppm), Rosmarinic acid (86 ppm), epicatechin (10 ppm), *p*-Coumaric acid (7 ppm)	(Sebai et al., 2019)
C. verum	-	Water extract lyophilized	LC-MS/MS	p-Hydroxybenzoic acid (321 ppm), p-Coumaric acid (291 ppm), Pyrogallol (142 ppm), Ferulic acid (89 ppm)	(Gulcin et al., 2019)
C. zeylanicum	-	Hydroethanolic extraction/ acidified sonication. Evaporated under nitrogen.	LC–ESI-MS/MS	Catechin (16.4 ppm), Protocatechuic acid (10 ppm), Quercetin (7.5 ppm), Epicatechin (7.3 ppm)	(Vallverdú-Queralt et al., 2014)
Bark oil					
C. burmanii L	Water and steam distillation	ND	GC/MS	Cinnamaldehyde (85.8%), Propenol (4.1%), Benzilpropanal (2.2%), Eucalyptol (1.2%), Terpineol-α (1.0%)	(Aliyah, Lintangsari, Maran, Hermawan, & Meiyanto, 2021)
C. cassia	Supercritical CO_2 and HD with CA	ND	FT-IR and GC–MS	Cinnamaldehyde (75.3%), (+)− 3-Carene (8.1%), Phenol, 2-methoxy-3-(2-propenyl) (3.9%), L-Linalool (2.4%), (-)-Methol (1.8%)	(Oyekanmi et al., 2021)
	USWE	50 mg/10 mL MeOH	GC-MS	E-Cinnamaldehyde (71%), Copaene (6.4%), α-Cubebene (6.1%), α-Calacorene (5.0%)	(Guo et al., 2021)
	HD with Ct-A and extracted with PE	ND	GC–MS	trans-Cinnamaldehyde (49.8%), Cinnamyl acetate (30.3%), Coumarin 11.9%, Eugenol (1.2%)	(Xie et al., 2017)
Unknow	HD with Ct-A	Hexane (10:90, v/v)	GC-FID/ GC/MS	trans-Cinnamaldehyde (91.0%), cis-Cinnamyl acetate (2.0%), Caryophylleneoxide (1.0%), γ-Terpinene (1.0%)	(Lazrak et al., 2021)
C. verum	HD with Ct-A	ND	GC-MS and GC-FID	Cinnamaldehyde (64.2%), Cinnamyl acetate (8.7%), β-caryophyllene (4.6%), β-phellandrene (4.2%), Eugenol (3.5%)	(Trifan, Zengin, Brebu, Skalicka-Woźniak, et al., 2021)
	Commercial oil (steam distillation)	Hexane (1:10, v/v)	GC-MS	Cinnamaldehyde (63.4%), eugenol (19.9%), Cinnamyl acetate (3.2%), Benzyl benzoate (1.7%), Linalool (1.7%)	(Ramli et al., 2021)
C. zeylanicum	Superheated water extraction (200 °C)	Hexane	GC-MS	E-Cinnamaldehyde (83.7%), Cinnamyl acetate (7.2%)	(Jayawardena & Smith, 2010)
	Commercial oil	Chloroform or hexane	GC-FID and GC-MS	Trans-Cinnamaldehyde (74.0%), Cinnamyl-acetate (5.3%), Linalool (3.8%), Eugenol (2.7%)	(Móricz et al., 2016)
	HD	PE (1 μL/mL)	GC–MS	trans-Cinnamaldehyde (69.7%), α-Pinene (3.7%), Borneol acetate (2.9%), Cinnamyl acetate (2.8%) and 1,8-Cineole (2.8%)	(Khanoonkon et al., 2022)
Leaves oil					
C. zeylanicum	HD with Ct-A	ND	GC–MS	(*E*)- Cinnamaldehyde (75.5%), α-Copaene (3.8%), α-Muurolene (2.7%), (*E*)-o-Melthoxy cinnamaldeyde (2.2%), trans-Calamene (1.4%), δ-Cadinene (1.2%)	(Raeisi et al., 2021)
C. zeylanicum	HD with Ct-A	ND	GC and GC/MS	Eugenol (76.60%), linalool (8.5%) piperitone (3.31%), Eugenyl acetate (2.7%), (*Z*)-Cinnamyl acetate (2.6%), α-Phellandrene (1.2%)	(Raina et al., 2001)
C. zeylanicum	Superheated water extraction (200 °C)	Hexane	GC-MS	Eugenol (98.2%)	(Jayawardena & Smith, 2010)
C. zeylanicum	HD	Chloroform (1%)	GC/FID	Benzyl benzoate (74.2%), α-phellandrene (6.9%), α-Pinene (3.0%) linalool (2.7%), p-Cymene (1.6%), α-Cadinene (1.1%), α-Pinene (1.1%), Limonene (1.0%), Camphene (1.0%)	(Ribeiro et al., 2020)

ND: no data; GC: gas chromatography; GC/MS: gas chromatography-mass spectrometry; GC/FID: gas chromatography with flame ionization detection; UPLC–MS/MS, ultraperformance liquid chromatography-tandem mass spectrometry; C-HRESIMS: liquid chromatography-high resolution electrospray ionization mass spectrometry. MeOH: methanol; CA: Clevenger apparatus; Ct-A: Clevenger type apparatus; HD: Hydrodistillation; USWE: Ultrasound-enhanced subcritical water extraction; High-resolution electrospray ionisation mass spectrometry (HRESIMS) endemic to Sri Lanka (Pathirana & Senaratne, 2020). Asia is the biggest producer worldwide. In 2020 its production was around 222,000 tons, concentrating on Indonesia and China for 41% and 33% of total production, respectively (FAOSTAT, 2022). Both *Cinnamomum zeylanicum* and *Cinnamomum cassia* (Chinese cinnamon) are the two species of the Cinnamomum genus accepted as medicinal herbs by scientific authorities. Since the chemical composition of cinnamon species varies, their biological activities and health effects may vary accordingly (Ali, Ponnampalam, et al., 2021; Gruenwald et al., 2010; Unlu et al., 2010). As primary resources of the cinnamon trees are the bark and the essential oil, which is extracted from bark and leaves. Cinnamon contains mainly volatile oils (cinnamaldehyde, eugenol, cinnamyl acetate) (Jayawardena & Smith, 2010; Ramli et al., 2021; Trifan et al., 2021) and some other active compounds (coumarin, cinnamic acid, protecatechuic and polyphenols) (Muhammad et al., 2021; Sebai et al., 2019), as well as macro and micronutrients (manganese, iron, calcium, and dietary fiber) (Chericoni et al., 2005; Hariri & Ghiasvand, 2016).

Cinnamon's global demand has risen in recent years due to its potential antioxidant, anti-inflammatory, and antitumoral properties, together with increasing the nutritional value of foods (Bertacchi et al., 2021; de Silva & Esham, 2020; Jafarizadeh-Malmiri et al., 2022). In addition to the antimicrobial (antibacterial and antifungal) and antioxidant (as a natural food preservative) properties, it has been demonstrated that the bioactive compounds obtained from cinnamon have many crucial roles in the food industry, such as being a potential alternative to antibiotics in the poultry industry, enhancing the sweet sensation in a food matrix or increasing in shelf life (Ali, Ponnampalam, et al., 2021; Suriyagoda et al., 2021). Considering the use of essential oils and condiment previously mentioned, the current review aimed to identify and describe key areas of cinnamon used in the agri-food chain to respond to new consumer demands. For that purpose, the VOSviewer software was used.

2. Material and methods

2.1. VOSviewer creating maps

VOSviewer software version 1.6.18 was used for creating maps based on text data (terms co-occurrence map) using a data source the "Title" or "Abstract" of publications provided to Scopus database search. Two maps were created, which were named "Map 1″ and "Map 2″. For constructed Map 1 was used Scopus Search 1 and the following steps: Field from which terms will be extracted: Title field; Counting method: Binary counting; VOSviewer thesaurus file (Supplemented Table 1); Minimal number of occurrences of a term: 10; and 60% of the most relevant terms based on the score calculated were selected. Only connecting terms were shown on the map. For constructed Map 2 was used Scopus Search 2 and the following steps: Field from which terms will be extracted: Abstract field; Counting method: Binary counting; VOSviewer thesaurus file (Supplemented Table 2); Minimal number of occurrences of a term: 10; 60% of the most relevant terms based on the score calculated were selected. Only connecting terms were shown on the map.

2.2. Scopus searches

Many different searches were carried out using the Scopus database. Only the documents that met the following criteria: Document type: Article; Source type: Journal, and Language: English, were selected for all searches. For carried out Search 1, "cinnamon" was used as a keyword. For Search 2, the two terms with the highest occurrences found in the selected cluster of Map 1 (clusters 1 and 3) were used as inclusion search terms. Furthermore, some of the terms with the highest occurrences of the not selected clusters (2, 4, 7, and 8) were used as exclusion terms. Therefore, the keyword search was "cinnamon," and the following inclusion terms were: "film", "cinnamon essential oil", "antimicrobial" and "antibacterial", while the exclusion terms were: "rat", "gene", "patient", "diabetes", "oxidative stress", "diet" and "soil".

Then for enclosed the relevant search for reviewed other three different searches were carried out using as inclusion words the words found in the selected cluster of maps 2 (clusters 2 and 3) and for word, exclusion was used terms of the other cluster, both map 1 and map 2). In all searches the keyword was "cinnamon," and to take information about packaging (cluster 2) the following inclusion terms "film" and "packaging", and the following exclusion terms were used "rat", "gene", "patient", "diabetes", "oxidative stress", "soil", "coating", "edible" and "biofilm". Regarding cluster 3, for shelf-life, the inclusion terms were "coating," and the exclusion terms were "rat", "gene", "patient", "diabetes", "oxidative stress", "soil", "film", "spice" and "biofilm". Due to the high number of published papers in chosen areas, only the publications in the range 2020–2022 were included in developing the current review.

3. VOSviewer results

In Search 1, 5398 documents were found. After deleting the terms not relative to cinnamon (Long-Evans Cinnamon rats and soil) (Supplemented Fig. 1), Map 1 was created 1 (Fig. 1A) (https://tinyurl.com/y6w9krgw). Clusters 2 and 4 had the most emergent and cited (normalized) terms (Fig. 1B). Therefore, both clusters were chosen to select the terms for Search 2.

Four clusters were detected in Map 2 (Fig. 2A) (https://tinyurl.com/ydd9lerd). In supplemented Table 3, the information about occurrence terms, strength links, and others can be consulted. As shown in Fig. 2B, clusters 2 and 3 have the most emergent terms. Furthermore, the main terms of cluster 2 and cluster 3, shelf life and coating, which have high occurrence, show the biggest normalized citation score. These results pointed out that these terms are relevant to the scientific community. Cluster 2 was related to food packaging with active films loaded with cinnamon essential oil, and the main terms are emulsions (nanoemulsion, surfactant, release) and film properties (thermal, mechanical, permeable). While clustering 3 concerns extending the shelf life of foods, especially fruit and meat, through cinnamon essential oil, where the main terms are related to sensory attributes and food quality (color, weight loss, firmness, oxidation). Therefore, considering VOSviewer results, the review was focused on active antimicrobial packaging using cinnamon essential oil. However, the introduction of bioactive compounds and antimicrobial activity was also included due to the strong relationship with the selected areas.

4. Active compounds

The composition of cinnamon and its dominant bioactive compounds differ according to the cinnamon specie, parts (fruit, leaves, twigs, and bark), and the extraction, separation, and purification methods (Błaszczyk et al., 2021). Although researchers have found different results because of the reasons above, it has been reported that the main volatile compound of cinnamon bark essential oil is the phenylpropanoid cinnamaldehyde, which values ranged between 49.8% and 91%, as can be seen in Table 1. The distillation process has been reported to modify cinnamaldehyde content significantly. Thus, Guo et al. (2021) investigated four distilled processes, steam distillation, ultrasound-assisted extraction, subcritical water extraction, and ultrasound-enhanced subcritical water extraction. The authors showed significant differences among the four methods, showing the highest cinnamaldehyde content with ultrasound-enhanced subcritical water extraction (71.3%) and the lowest with ultrasound-assisted extraction (46.3%). The second abundant compound usually is the monoterpene Cinnamyl-acetate (Jayawardena & Smith, 2010; Lazrak et al., 2021; Móricz et al., 2016; Trifan et al., 2021; Xie et al., 2017). Nevertheless, other compounds have been found as the second majority compounds, such as propanol, (+)− 3-Carene, Copaene, Eugenol, and α-Pinene (Table 1).

Table 2
Biodegradable antimicrobial active films loaded with cinnamon essential oil: inhibition microorganism and films properties.

Film components				Antimicrobial activity			Film properties			Tested food	Reference
Polymer	Plasticizer	Carrier /emulsifier	[CEO]	Microorganism	AAF*	Method	TS	EB	WVP		
Biopolymer											
Bombacaceae gum	Glycerol		0.75, 1.0, 1.25 * wt%	*E. coli O157:H7* *S. aureus* *L. monocytogenes* *S. Typhimurium*	35 mm 40 mm 40 mm 31 mm	DDT	-40	70	-20	Fresh salmon fillets	(Cao & Song, 2020)
Eucheuma cottoni	Glycerol	Cellulose nanofibres	1.0, 2.0, 3.0, 4.0 * %	*E. coli* *S. aureus*	27.0 mm 30.2 mm	ADT	30	-30	ND	ND	(Oyekanmi et al., 2021)
Chitosan Gelatin		Tween 80	2.0% wt	*E. coli* *L. monocytogenes*	~3 log CFU/mL ~3 log CFU/mL	TCCM	10	-40	30	ND	(Roy & Rhim, 2021)
Chitosan		Pickering emulsion with CNCs	0.3, 0.45, 0.6 * (v/v%)	*E. coli* *S. aureus*	~140.0 mm^2 ~140.0 mm^2	IZM	-40	-170	-10	Pork piece	(Liu et al., 2022)
SPN Cellulose SP fibre Starch	Glycerol Sorbitol	Tween 80	0.8, 1.2, 1.6, 2.0 * wt%	*E. coli* *S. aereus* *B. subtilis*	7.3 mm 6.6 mm 7.9 mm	ADM	10	-30	ND	ND	(Syafiq et al., 2021)
Starch	Glycerol	ChN Tween 80	1.0, 3.0, 5.0 * wt %* **	*E. coli* *B. subtilis*	0 mm 0 mm	DAM	ND	ND	20	Fresh strawberry	(Ferreira, Souza, Quispe, et al., 2021)
SP Starch SP nanocellulose	Glycerol Sorbitol	Tween 80	2.0 wt%	*E. coli* *B. subtilis*	6.9 mm 3.3 mm	ADM	ND	ND	ND	ND	(Syafiq et al., 2022)
Soy protein Gelatin			20% w/v	*E. coli* *S. aureus* *L. monocytogenes* *S. Typhimurium* *B. cereus*	8.0 mm 10.0 mm 12.0 mm 10.0 mm 12.0 mm	DDA	ND	ND	ND	ND	(Raeisi et al., 2021)
Pullulan	Glycerol	Nanoemulsion Tween 80	0.08, 0.16, 0.24 * wt%	*E. coli* *S. aureus*	~ 0.10 OD ~ 0.18 OD	LCT	-20	40	-50	ND	(Chu, Cheng, et al., 2020)
Whey protein Chitosan nanofiber	Glycerol	NSLC Cocoa butter Tween 80	0.2 wt%	*E. coli* *S. aureus* *P. aeruginosa*	13.1 mm 12.3 mm 12.2 mm	ADDM	-100	10	20	ND	(Mohammadi et al., 2020)
Synthetic polymers											
OSA Gum Arabic Chitosan	Glycerol	Emulsion	~0.55, 1.1, 1.7, 2.2 * %	*E. coli* *S. aureus*	~ 0.1 OD ~ 0.1 OD	LCT	-60	-30	-50	ND	(Xu et al., 2020)
SSOS Sodium alginate	Glycerol	Pickering emulsion SSOS Corn oil	0.5, 1.0, 1.5, 2.0 * , 2.5%	*E. coli* *S. aureus* *B. subtilis*	24.0 mm 25.6 mm 24.6 mm	DDT	-150	70	-100	ND	(Sun et al., 2020)
PBAT			2.0, 4.0, 8.0 * % d.w	*E. coli* *S. aureus*	9.5 mm 15.0 mm	DDT	-60	-140	ND	ND	(Moraes Filho et al., 2022)
PBAT		ChN Tween 80	2.0, 5.0, 8.0 * wt %* **	*E. coli*	~15% inhibition	LCT	30	20	ND	ND	(Ferreira et al., 2021)
PBAT		Cellulose nanofibers	~0.16 * *, 0.34, 1%	*E. coli O157:H7* *S. aureus* *L. monocytogenes* *S. enterica*	0 mm 0 mm 0 mm 0 mm	DDT	ND	ND	-2.9	Strawberry (*Fragaria ananassa*)	(Montero et al., 2021)
PCL Alginate			~6.7 wt %	Spontaneous fungal growth on the bread	Antifungal activity	Fungal growth recorded	-40	-100	ND	Bread	(Lim et al., 2022)
PVA		Pickering emulsion with CNCs	0.15, 0.3, 0.6 * % w	*E. coli* *S. aureus*	6 Log CFU/mL 6 Log CFU/mL	TVCCM	20	30	ND	ND	(Oun et al., 2022)
PVA Pinto bean starch	Glycerol	Tween 80	1.0, 2.0, 3.0 * % (v/v)	*E. coli* *L. monocytogenes* *L. sakei* *P. fluorescens*	25.4 mm 43.1 mm 35.4 mm 20.1 mm	ADT	20	281	-50	ND	(Khazaei et al., 2021)
PVP CMC Bacterial cellulose Guar gum			2.0%	*E. coli* *S. aureus* *B. cereus* *Klebsiella. Sp*	39.6 mm^2 21.7 mm^2 279.1 mm^2 45.6 mm^2 1041.0	IZM	30	70	ND	Gouda cheese	(Bandyopadhyay et al., 2020)

(continued on next page)

Table 2 (*continued*)

Film components				Antimicrobial activity			Film properties			Tested food	Reference
Polymer	Plasticizer	Carrier /emulsifier	[CEO]	Microorganism	AAF*	Method	TS	EB	WVP		
				C. albicans *Aspergillus. Sp*	mm^2 796.5 mm^2						

aThe values of TS, EB and WVP have been calculated as variations percentages using the values of the control film (without CEO) and the values of the film with the highest antimicrobial activity.
*The results are for the concentration with the highest antimicrobial activity.
* *The results are for the CEO concentration as the authors considered the best to use.
* **Concentration of chitosan capsules, the CEO is not clear in the work.
[CEO]: Cinnamon essential oil concentration; AAF: Antimicrobial activity of film; ADDM: agar disk diffusion method; ADM: agar disc method; ADT: Agar diffusion test; APM: Agar plate method; ChN: Chitosan nanocapsules; CMC: Carboxymethyl cellulose; CNCs: Cellulose nanocrystals; DAM: diffusion assay method; DDAM: Disk diffusion assay method; DDT: Disk diffusion test; EB: Elongation at Break; IZM: Inhibition zone method; LCT: Liquid culture test; ND: Not determined; NSLC: Nanostructured lipid carriers; OD: optical density a 650 nm; (%); OSA: Octenyl succinate anhydride PBAT: Poly(butylene adipate-co terephthalate); PCL: Poly-ε-caprolactone; PVA: Polyvinyl alcohol; PVP: Polyvinyl pyrrolidone; SP: Sugar palm; SPN: Sugar palm nanocrystalline; SSOS: Sodium starch octenyl succinate; TS: Tensile Strength; TVCCM: Total viable colony count method; WVP: water vapor permeability. Whole microorganisms name: *Bacillus subtilis, Bacillus cereus, Candida albicans, Escherichia coli, Lactobacillus sakei, Listeria monocytogenes, Pseudomonas aeruginosa*, *Pseudomonas fluorescens, Salmonella enterica* subsp. *enterica serovar Choleraesuis, Salmonella Typhimurium; Staphylococcus aureus.*

Regarding cinnamon leaf essential oil, researchers have mainly determined the volatile profile of *C. zeylanicum*. Among consulted works, two of them have shown the phenylpropanoid eugenol as the highest compound (Jayawardena & Smith, 2010; Raina et al., 2001), while Raeisi et al. (2021) reported (*E*)- Cinnamaldehyde and Ribeiro et al. (2020) showed Benzyl benzoate. These results point out the high volatile profile variability of cinnamon leaf essential oil.

Likewise, although usually only around four-six compounds are found in higher amounts than 1%, both the cinnamon bark and leaf essential oil up to 30 volatile constituents, of different chemical families, phenylpropanoid, terpenes, terpenoids, and esters have been reported (Denkova-Kostova et al., 2021; Guo et al., 2021; Raina et al., 2001).

Concerning (poly)phenols compounds of bark cinnamon powder, coumarin is one of the most common compounds in *C. cassia,* whereas it is found in trace amounts in *C. zeylanicum* (Gupta et al., 2021). Moreover, independently of the cinnamon specie, phenolic acids are the main compounds present in bark cinnamon, like, *p*-Hydroxybenzoic acid, protocatechuic acid (3,4-dihydroxybenzaldehyde) or cinnamic acid (Gulcin et al., 2019; Klejdus & Kováčik, 2016; Muhammad et al., 2021; Sebai et al., 2019). While the phenolic profile of cinnamon species is similar, its distribution in the cinnamon matrix differs among species. For example, *C. cassia* had the highest amounts of phenolic acids in the free fraction while *C. zeylanicum* showed in the cell wall-bound fraction (Klejdus & Kováčik, 2016). The following flavonoids, catechin, epicatechin, and quercetin, have also been found in cinnamon bark, but in fewer amounts (Table 1). Furthermore, many authors have detected more than 30 (poly)phenols in bark cinnamon corresponding to different families such as flavones, lignans, tyrosols, curcuminoids, and isoflavones (Ali, Wu, et al., 2021; Vallverdú-Queralt et al., 2014).

5. Antimicrobial activity

Among the foodborne pathogen and spoilage microorganisms, the cinnamon essential oil has shown antibacterial effect against both gram-positive bacteria (*Bacillus sp., B. cereus, E. faecalis, Leuconostoc sp., M. luteus, S. aureus, Streptococcus sp., L. monocytogenes, L. grayi*) and gram-negative bacteria (*E. coli, P. aeruginosa, P. fluorescens, S. dysenteriae, S. Typhimurium*). Recently, Vasconcelos, Croda, and Simionatto (2018) reviewed its antibacterial mechanism of action and pointed out the following effects when cinnamon or its components are in contact with bacterial: alterations in the cell membrane and its lipid profile, inhibition of ATPase, cell division, membrane porins, motility, and biofilm formation and anti-quorum sensing effect. Furthermore, Xie et al. (2017) studied the relation between the cinnamon essential oil phenylpropene compound's chemical structure and their antifungal activity. Elucidating that the presence of conjugated double bond, the length of carbohydrate chain outside the ring, and lipophilicity are key factors in its antifungal properties.

The minimal inhibitory and bactericide concentration of cinnamon essential oil against foodborne pathogens and spoilage microorganisms depend on factors such as essential oil type, variety, and extraction method. Moreover, knowing them allows for optimization of the dose to use it. For example, cinnamon leaves essential oil showed higher minimal inhibitory concentration against *L. monocytogenes* and *E. coli* O157: H7 than cinnamon bark essential oil. However, it had the least minimum bactericide concentration against both mentioned bacteria (Cava-Roda et al., 2021). Furthermore, the minimum inhibitory concentration of *C. zeylanicum* essential oil against *E.coli* is different between studies (El-Zehery et al., 2022; Khanoonkon et al., 2022). Likewise, cinnamon essential oil seems to be more effective against gram-positive bacteria than gram-negative. For example, when the same cinnamon essential oil is tested against *E. coli.* and *L. monocytogenes*, its minimum inhibitory concentration is lower for *L. monocytogenes* than *E. coli* (Cava-Roda et al., 2021; El-Zehery et al., 2022). Morevover, between *E. coli* and *S. aureus*, some authors have reported the highest inhibition activity from cinnamon essential oil against *E. coli* (Khanoonkon et al., 2022; Mohammadi et al., 2020). However, others have showed more efficiency against *S. aureus* (Khazaei et al., 2021; Raeisi et al., 2021; Songtipya et al., 2021; Xu et al., 2020).

Cinnamon essential oil also has antifungal activity against spoilage fungi and yeast such as *Aspergillus niger, Aspergillus flavus, Penicillium chrysogenum, Penicillium expansum, Penicillium citrinum Mucor circinelloides*, *Saccharomyces cerevisiae,* which is often best than other essential oil such as oregano, lavang, garlic, ginger, zataria multiflora, eucalyptus, rosemary or pure phenol like Carvacrol (Begum et al., 2022; Buendía−Moreno et al., 2020; Ebrahimzadeh et al., 2021; Khazaei et al., 2021; Radi et al., 2022; Syafiq et al., 2022).

6. Active packaging

Considering the broad antimicrobial spectrum and generally recognized as safe status (both cinnamon leaf and bark essential oil of *C. cassia* and *C. zeylanicum*) (FDA, 2020), cinnamon essential oil has the potential to be an excellent preservative for developing active antimicrobial packaging.

Nowadays, cinnamon essential oil, mainly cinnamon bark essential oil and in less amount cinnamon leaf essential oil, is widely used for designing active packaging for controlling or inhibiting the growth of microorganisms and the senescence process. However, authors like Ahmed Ismail et al. (2022) choose cinnamon powder to develop chitosan-based films. Regarding packaging type where cinnamon oil is used as active ingredient, biodegradable films and edible coating are the

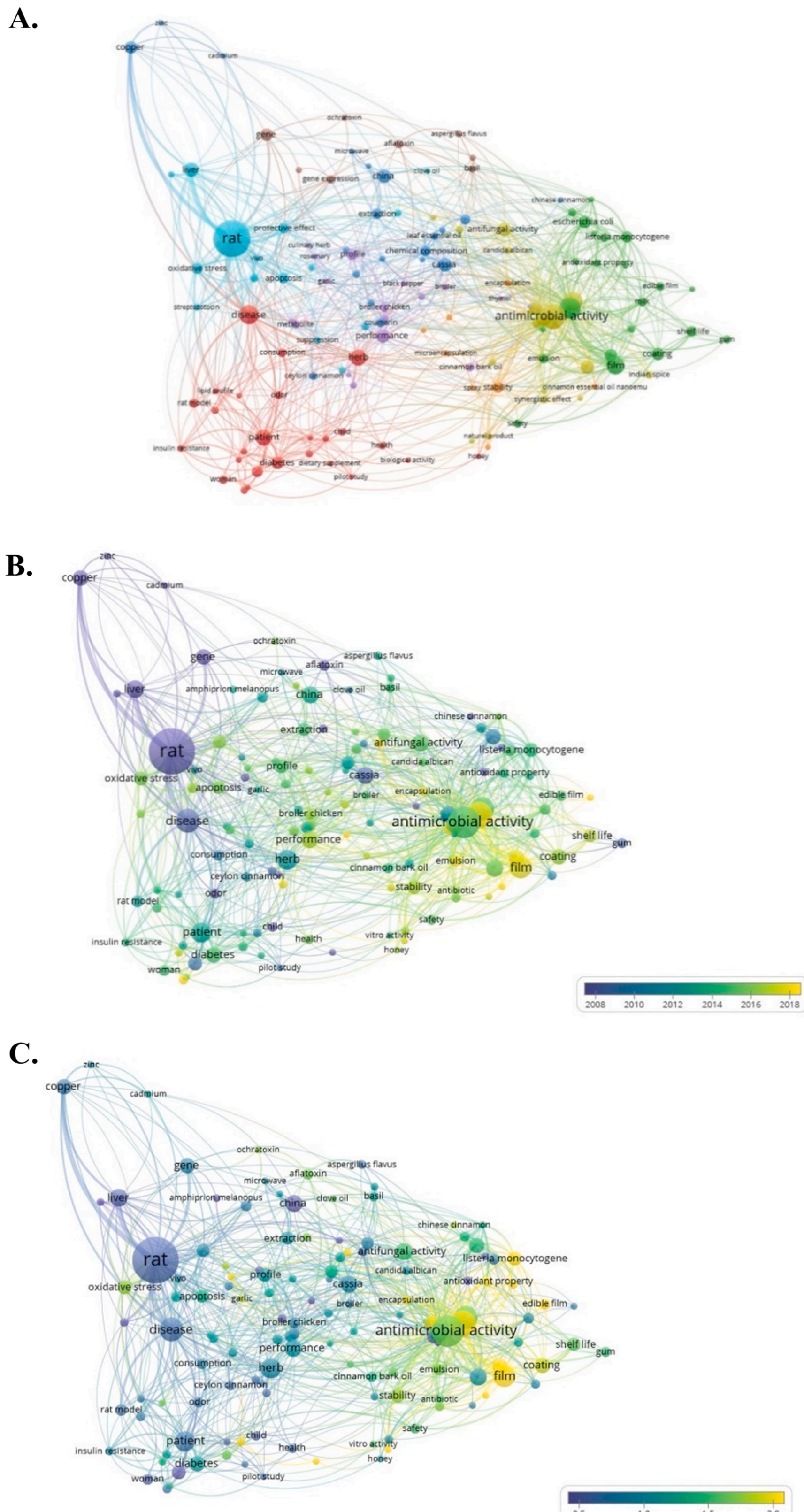

Fig. 1. VOSviewer MAP 1 A. Network. Cluster 1 (red), cluster 2 (green), cluster 3 (blue) cluster 4 (yellow); cluster 5 (purple); cluster 6 (light blue), cluster 7 (orange) and cluster 8 (brown). B. Overlay average years C. Overlay average normalization citations.

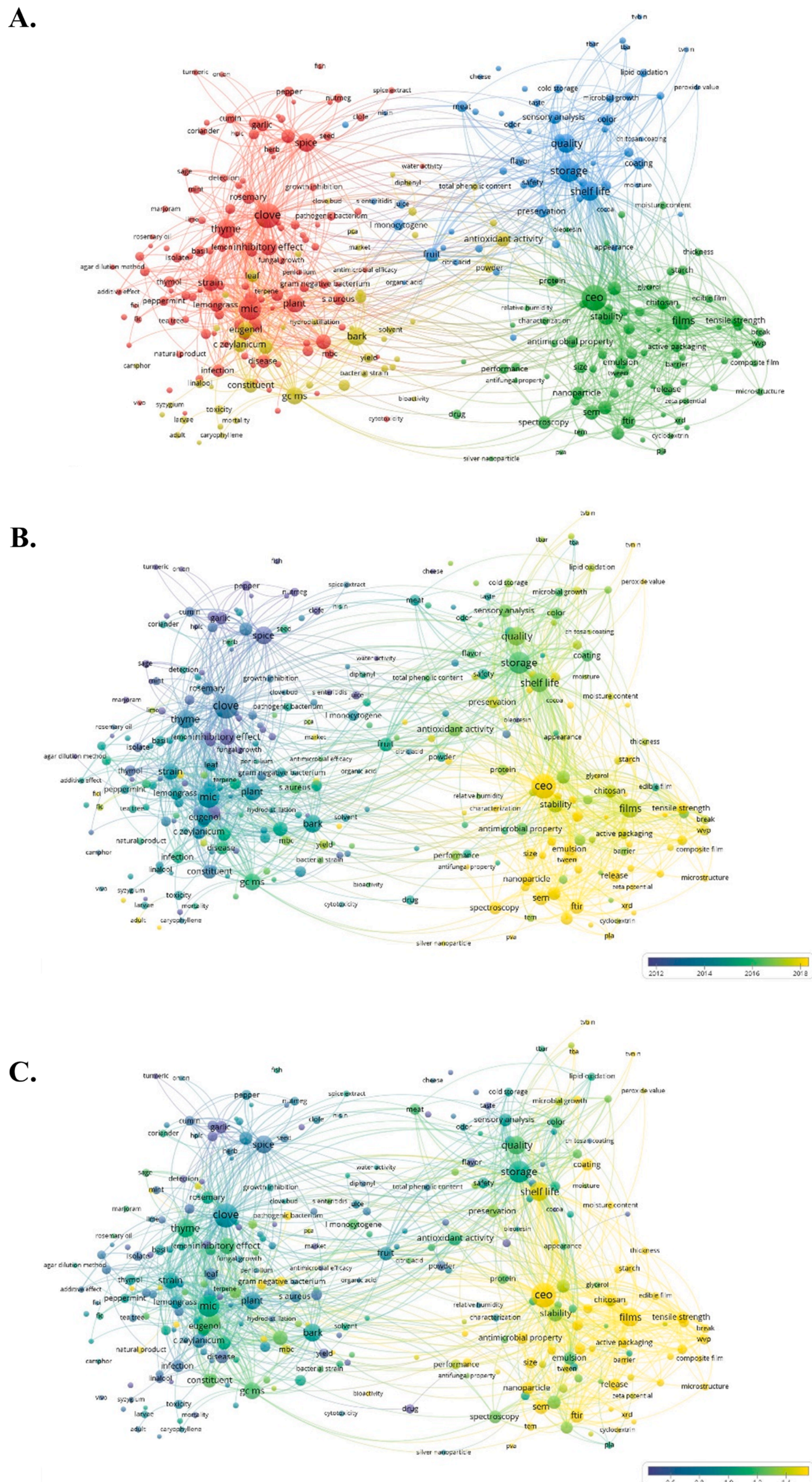

Fig. 2. VOSviewer Map 2 for A. Network. Cluster 1 (red), cluster 2 (green), cluster 3 (blue) and cluster 4 (yellow); B. Overlay average publication year; C. Overlay average normalization citation.

most recurrent and designed packaging, and in less amount packaging with no contact with food or other packaging techniques such as the modified atmosphere.

In addition to providing antimicrobial properties to films, the inclusion of cinnamon essential oil modified mechanical, optical, thermal, and water properties of films as described below.

6.1. Antimicrobial bio-degradable films

Biodegradable films are considered good alternatives to replace

Table 3
Edible coating loaded with cinnamon essential oil (CEO).

Biopolymer	Other Ingredients	[CEO] Concentration	Loaded CEO method	Food	Coating Method	Analysis test	Shelf-life	Reference
Pectin	Glycerol, Tween 80	0.7% v/v	Emulsion and Nanoemulsion	Apples Golden delicious (*Mauls domestica*)	Dipping	9th day of storage period. Higher acceptance than control (Without coating)	Shelf-life extension	(Naqash et al., 2022)
Chitosan	Cellulose nanocrystals	0.2% (v/v)	Pickering emulsion	Mangoes (*Mangifera indicaLinn.Tainung*)	Dipping	ND	Shelf-life extension	(Yu et al., 2021)
Chitosan	Tween 80, ethanol	140, 240, and 320 ppm	Emulsion	Mangoes	Dipping	ND	Shelf-life extension over 12 days of storage at 30 °C.	(Lieu & Dang, 2021)
Chitosan	Glycerol Tween 80	0.6% v/v	Mixed with the rest of the ingredients	Roast ducks	Dipping	Good acceptance in the last days of storage	Shelf-life extension	(Chen et al., 2021)
Chitosan		0.5% and 1%	Mixed with the rest of the ingredients	Pineapple (*Smooth cayenne)*	Dipping	Good acceptance	Efficient conservation of minimally processed pineapple	(Basaglia et al., 2021)
Chitosan	Sugarcane ethanol, Tween 20, Canola oil, Tween 80, Gglycerol	0.1% v/v	Nanostructure	Cucumber (*Cucumis sativus L.*)	Dipping	ND	Control growth of yeast and molds	(Istúriz-Zapata et al., 2020)
Chitosan		1%, 3% and 5%		Apple	Dipping	Apples treated with 3% and 5% of CEO showed the best overall acceptability and the highest scores in flavor, color, and firmness during the time (2 months)	Shelf-life extension and inhibition of fungi growth for 2 months a 5ºC. The most efficient treatment is 5% of CEO.	(Rashid et al., 2020)
T1. Chitosan T2. guar gum- T3. guar gum- starch-	Glycerol	0.06% v/v (T1); 10% v/v (T2 and T3)	Mixed with the rest of the ingredients	Golden Delicious apple slices	Dipping	Slightly unpleasant acceptability in terms of the flavor attribute	Retarded senescence process and microbial growth during storage (25-days)	(Solís-Contreras et al., 2021)
Persian gum	Cumin oil	0.25%, 0.50%, and 0.75% (v/v	Mixed with the rest of ingredients	Pomegranate (*Punica granatum*) arils	Dipping	Similar acceptance to untreated arils	Shelf-life extension around 3 months under cold storage (0.75%)	(Jokar et al., 2021)
T1. Sodium alginate,	Glycerol Tween 80	0.75%	Emulsion	Peach (*Prunus persica* L. Batsch)	Dipping	No negative effect on the sensory attributes of peach	Enhance shelf life of under ambient storage conditions	(Ayub et al., 2021)
Pullulan	Glycerol, Tween 80	8% with respect to the mass of pullulan (0016%)	Nanoemulsion	Strawberries *Fragaria×ananassa*	Dipping	ND	Prolonged shelf-life and slowed down senescence process during room storage	(Chu, Gao, et al., 2020)
Gum Arabic,	Glycerol oleic acid Tween 80	1% v/v	Emulsion	Guava (*Psidium guajava L.*)	Dipping	ND	Reduce senescence process	(Etemadipoor et al., 2020)
Soy Lecithin		1% v/v	Nanoemulsion	Mufflins	Dipping	Less acceptance than uncoated mufflins	Extended shelf-life 3 days	(Kaur & Singh, 2022)

[CEO]: Cinnamon essential oil concentration; ND: Not determined; T: Treatment

plastic in the agri-food chain, from active food packaging even silage covers (Borreani & Tabacco, 2015; Cao & Song, 2020). The Cinnamon essential oil is added to films to extend the shelf-life of foods due to its antimicrobial activity and antioxidant capacity. The concentration of cinnamon essential oil loaded into the films ranged between 0.1% and 7.0% (Table 2). However, in a few papers the authors only reported the concentration of the nanocapsules. (Ferreira et al., 2021; Ferreira et al., 2021).

Active biodegradable films have been tested for extended shelf life in animal foods, such as fresh salmon fillets, pork pieces, gouda cheese, fruits, like strawberries, or bakery foods like bread (Table 2). Regarding active packaging for strawberries, the use of films loaded with cinnamon essential oil has been positively associated with extended shelf life and improved quality of strawberries due to preventing fungal growth and weight loss of fruit. These effects have been related to the ability of active films to maintain moisture in the packaging. Furthermore, the best effect has been shown when cinnamon essential oil have been tested in low concentrations in starch-based films and Poly(butylene adipate-co terephthalate) (Ferreira et al., 2021; Montero et al., 2021). The antifungal effects of film have also been reported by Lim et al. (2022) who have not observed fungal growth in bread packaging in Poly-ε-caprolactone and alginate films due to cinnamon essential oil antifungal activity. In origin animal foods, for determining the preventive effects of active films, lipid oxidation (peroxide value and thiobarbituric acid reactive substance) and protein and amine degradation (total volatile basic nitrogen) were investigated. For example, Liu et al. (2022) reported effective presentive applications to pork pieces to chitosan-based films loaded with Pickering emulsion (cellulose nanocrystal + cinnamon essential oil (0.45%, v/v). Since the lowest total volatile basic nitrogen in pork and the highest film integrity were shown in this film. While Bombacaceae gum films containing 1.25% of cinnamon essential oil effectively reduced lipid oxidation in fresh salmon fillets (Cao & Song, 2020).

6.1.1. Antimicrobial activity of cinnamon essential oil loaded films

As mentioned before, the cinnamon essential oil has great antimicrobial activity against foodborne bacteria and spoilage microorganisms. However, among the limitations of its direct use in food have been pointed out its hydrophobic nature, characteristics aroma, and chemical instability when it is exposed to oxygen, light, and high storage temperatures (Ebrahimzadeh et al., 2021). Therefore, its inclusion in the films could impulse the real use of the cinnamon essential oil as a preservative in the food industry. Fig. 3 shows the scheme of production of edible coating using cinnamon essential oil and its effect as barrier against spoiling microorganisms.

As can be appreciated in Table 2, the antimicrobial effects of active films have been tested for a wide range of foodborne bacteria and spoilage microorganisms. Furthermore, it is more recurrent to test them against on bacteria than on fungi. Likewise, *E. coli* is frequently used as a gram-negative bacterium model, while *S. aureus* is used as a gram-positive bacterium model. The films loaded with cinnamon essential oil showed different antimicrobial activity among both bacteria models. These were more effective against *S. aureus* (Cao & Song, 2020; Liu et al., 2022; Moraes Filho et al., 2022; Oyekanmi et al., 2021; Sun et al., 2020). However, some authors showed the opposite behavior (Bandyopadhyay, Saha, Zandraa, Pummerová, & Sáha, 2020), even the same inhibitory effect against *E. Coli* and *S. aureus* (Khazaei et al., 2021; Mohammadi et al., 2020).

Generally, growth inhibition effects of loaded biodegradable films with cinnamon essential oil increase in a concentration-dependent (Table 2). That effect is well observed by Cao & Song (2020), who reported significant differences in the inhibition zone diameter for the four bacteria studied with an increase of 0.25%. Nevertheless, while the main works observed antimicrobial film activity, both Ferreira, Souza, Quispe, et al. (2021) and Montero et al. (2021) did not report inhibition halo against foodborne bacteria. Ferreira et al. (2021) confirmed, throught FT-raman techniques, that the strong interaction between the chitosan nanocapsules and the thermoplastic starch matrix results in slow active compounds diffusion to the agar limiting the antimicrobial activity. In addition, Montero et al. (2021) also reported no oil migration to the agar medium due to well-embedded cellulose nanofibers into the film matrix. However, the authors observed a growth inhibition within the film region against *Salmonella* and *Listeria*. Therefore the authors pointed out that the low cinnamon essential oil loaded into the film

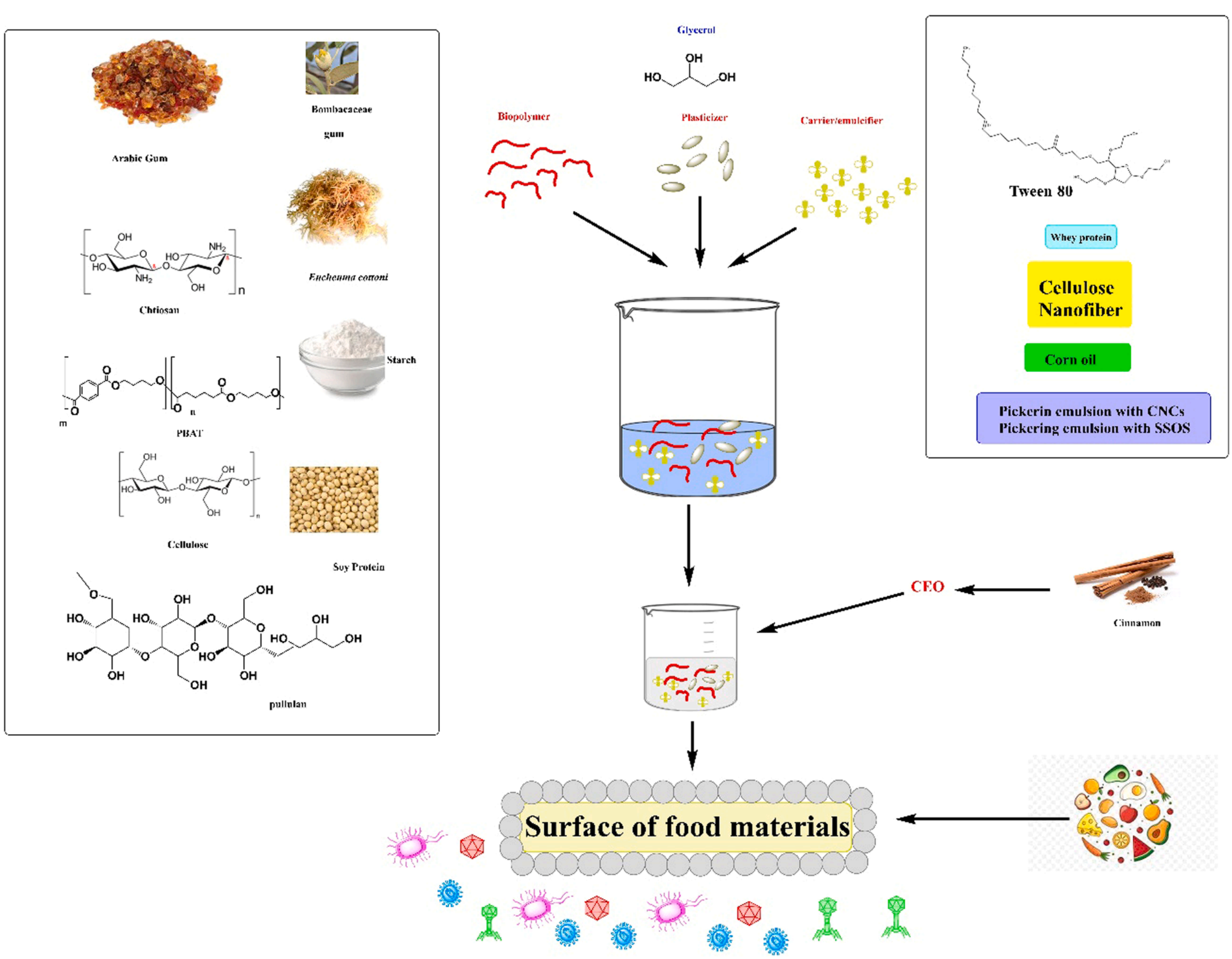

Fig. 3. Scheme of production of edible coating using cinnamon essential oil and its effect as barrier against spoiling microorganisms. CEO: Cinnamon essential oil. CNCs: Cellulose nanocrystals; PBAT: Poly(butylene adipate-co terephthalate); SSOS: Sodium starch octenyl succinate.

(0.16–1.0%) could also be responsible for the inefficient antimicrobial effects shown. Opposite other authors have observed bactericide activity against *E. coli* and *S. aureus* with films made with cellulose nanofibers loaded with high cinnamon essential oil concentrations (1–4%) (Oyekanmi et al., 2021).

Regarding improving the inhibitory effect on microorganisms' growth of active films, adding cinnamon essential oil into films through Pickering emulsion, nanostructured lipid carriers or, nanoemulsions have superior antimicrobial activity than including it as an emulsion, particularly when it is stabilized with Tween 80. Among the reason, (Chu, Cheng, et al., 2020) considered that the low drop oil size and its homogeneous distribution into film increase surface area and therefore improve the contact between active compounds and microorganisms. In addition, Feng et al. (2020) also observed that films loaded with nanoemulsions with the most petite particle sizes showed the highest nanoemulsions antibacterial activity. In contrast, Mohammadi et al. (2020) focus on the gradual and sustained release of cinnamon essential oil mediated by nanocapsules, compared with the facility that shows tween 80 to diffuse cinnamon essential oil in the medium. Likewise, Xu et al. (2020) associated the low release rate of cinnamon essential oil with the continuous destruction of microorganisms. Furthermore, Liu et al. (2022) reported the highest antimicrobial activity by chitosan-based films when cellulose nanocrystal-stabilized was added in the lowest amount in Pickering emulsion, pointed out the need to estimate a proper cinnamon essential oil / cellulose nanocrystals to improve the release pathway of cinnamon essential oil. Reinforcing the idea that controlled cinnamon essential oil release is essential to increase bactericide activity and prolong the effect during storage.

The effectivity against microorganisms' growth to films also can improve mixing cinnamon essential oil with other ingredients. Recently some authors have informed synergistic effects of cinnamon essential oil among the flavonoid rutin, clove oil, oregano oil, carvacrol, and rambutan peel extract (Buendía-Moreno et al., 2020; El-Zehery et al., 2022; Khanoonkon et al., 2022; Roy & Rhim, 2021). Furthermore, the synergetic effects can also be observed with film-forming components like chitosan or bambacaceae gum (Cao & Song, 2020; Ferreira *et al.* 2021). Nontheless, the synergistic effects not always are observed as Bandyopadhyay et al. (2020) reported. While authors showed that mixed cinnamon essential oil with clove essential oil has synergetic effects against *S. aureus* and *Aspergillus*; however, no enhancement was shown for other microorganisms such as *E Coli* or *B cereus.*

6.1.2. *Effect of film properties*

Mechanical properties of films are an essential quality parameter determining their quality, applications, and viability. A good film is considered when it withstands external stress and does not break easily. As shown in Table 2, the cinnamon essential oil can improve or weaken biodegradable films' tensile strength. Oyekanmi et al. (2021) reported increased tensile strength when cinnamon essential oil concentration was raised in the film (ranged 1–3%); however, that tendency was not observed when 4% cinnamon essential oil was added to Eucheuma Cottonii based films. Khazaei et al. (2021) also observed the effects of dose-dependent plasticizing on cinnamon essential oil with the same range of concentrations of 1–3%. In the same line, the inclusion of Pickering emulsion with cinnamon essential oil improved the plasticizing properties of poly(vinyl alcohol) films, but no dose-dependent concentration was observed. Interestingly cinnamon essential oil Pickering emulsion has the best plasticizing effects than oregano essential oil Pickering emulsion (Oun, Shin, & Kim, 2022). Other authors have elucidated the increase in tensile strength of different biodegradable films due to cinnamon essential oil (Bandyopadhyay et al., 2020; Roy & Rhim, 2021; Syafiq et al., 2021). The reason for the increase in the tensile properties may be due to the following factors: (i) the strengthening effect created by the rearrangements of the polymer network with the addition of the cinnamon essential oil; (ii) robust cross-linking interactions among cinnamon essential oil and biopolymer; (iii) strain drop during to the film-forming process due to the lower moisture content of cinnamon essential oil-loaded films (Bandyopadhyay et al., 2020; Khazaei et al., 2021). Contrary, other studies have revealed that cinnamon essential oil reduced in a dose-dependent manner tensile strength of Bombacaceae gum, chitosan, pullulan, or sodium starch-based films (Cao & Song, 2020; Liu et al., 2022; Sun et al. 2021; Xu et al., 2020). The reason why the maximum braking force of films decreases with the addition of cinnamon essential oil has been related to creating discontinuous matrix films, molecule slipping due to volatile molecules in the film matrix, increased mobility chain due to the ability of cinnamon essential oil to create empty spaces in biopolymer network or the decreased moisture content in film (Liu et al., 2022; Moraes Filho et al., 2022; Xu et al., 2020). Other authors also pointed out that the reduced tensile strength derived from cinnamon essential oil presence in films is due to the high oil drop size that generated coalescence phenomenal and homogeneous cinnamon essential oil dispersion in the matrix (Chu, Cheng, et al., 2020).

Water barrier properties, which refer to water exchange between food and the environment, are another critical film property that determines film viability and use. As shown in Table 2, the cinnamon essential oil can modify biodegradable films' water vapor permeability. Typically, adding a cinnamon essential oil to films generates a decrease in the water vapor permeability. The presence of cinnamon essential oil in the pullulan-based-films and Octenyl succinate anhydride-based film decreased water vapor permeability values (Chu, Cheng, et al., 2020; Feng et al., 2020). Many authors considered that the increase of hydrophobic substances in the film matrix and the covalent bond with hidrogen limit the free diffusion of water vapor (Cao & Song, 2020; Chu, Cheng, et al., 2020; Khazaei et al., 2021). Nevertheless, other authors have reported a water vapor permeability increase in films loaded with cinnamon essential oil (Liu et al., 2022; Mohammadi et al., 2020; Roy & Rhim, 2021). Roy & Rhim (2021) hypothesized that the increase in the water vapor permeability could be caused by the asymmetric microstructure, bubbles, and oil droplets in the polymer matrix, which weakens the intermolecular interactions between polymer molecules and increases the water vapor transmission through the film.

Cinnamon essential oils can also modify optical properties to films, such as opacity, which has been positively correlated with cinnamon essential oil concentration (Cao & Song, 2020; Khazaei et al., 2021; Xu et al., 2020). The opacity and yellowness increase in active films are related to the typical yellow color of cinnamon essential oil. (Arezoo et al. 2020). Likewise, these changes in optical properties make films apt for packaging food susceptible to photo-oxidation (Roy & Rhim, 2021). Regarding to thermal properties, Cao & Song (2020) observed that cinnamon essential oil can be enhanced it due to the presence of the benzene rings. Nonetheless, in other tested active films the inclusion of cinnamon essential oil not modified its thermal properties (Bandyopadhyay et al., 2020; Roy & Rhim, 2021). Another parameter less studied is the biodegradation rate of films. Bandyopadhyay et al. (2020) carried out a biodegradation study of films loaded with cinnamon essential oil. Authors buried films in a controlled pH and moisture soil and controlled the degradation of films every 15 days for 60 days. As a result, the incorporation of cinnamon essential oil delays the biodegradable rate of films due to inhibiting the soil microbiota. Nevertheless, after 45 days, the film loaded with cinnamon essential oil was disintegrated.

6.1.3. *Retention and release of cinnamon essential oil*

Among the challenges researchers found when developing films loaded with cinnamon essential oils is the retention and release equilibrium of oil into the film. Since the antimicrobial effectiveness and sensory acceptance are strongly related to that equilibrium. Cinnamon essential oil losses are produced during its fabrication, mainly in the drying film step, and during the storage period, due to the volatile nature of its main components (Chu, Cheng, et al., 2020; Liu et al., 2022). Many authors had reported fast cinnamon essential oil release (ranging from minutes to hours) followed by a gradually slow release when food simulators were used (Liu et al., 2022; Montero et al., 2021; Xu et al., 2020). The diffusion mechanisms of cinnamon essential oil are not well elucidated, as Chen et al. (2020) pointed out that knowing diffusion factors of essential oil is fundamental for designing active packaging with controlled cinnamon essential oil release. Furthermore, those authors determined that among the mechanism that influenced molecules' film release, the size and distribution of diffusion channels and the intermolecular forces jointly determine the diffusion ability of molecules. The main factor affecting cinnamon essential oil release kinetics (rate and amount) is increasing relative humidity followed by raised temperature (Lee et al., 2021). To control cinnamon essential oil release in films, many authors have researched the inclusion of cinnamon essential oil in emulsion, nanoemulsion, or reinforcement strategies. For example, both Liu et al. (2022) and Oun et al. (2022) added cinnamon essential oil to film through a Pickering emulsion made with nanocellulose crystals. Increasing solid stabilizing in cellulose nanocrystal Pickering emulsion improves retention of cinnamon essential oil during the dry process.

6.2. Edible coating

Edible active coatings are mainly used on fruit (Shiekh et al., 2021), especially apples, but also in mangoes, pineapple, cucumber, pomegranate, peach, strawberries, and guava (Table 3). Dipping fruits only with cinnamon essential oil has been tested by Khorram & Ramezanian (2021) who investigated the best choice for coating oranges with the final purpose of delaying Green mold decay. In both acceptability and storage, the mix of cinnamon essential oil with a polymer (shellac) is superior to use alone cinnamon essential oil. Etemadipoor et al. (2020) reported that mixed cinnamon essential oil with gum Arabic and oleic acid conferred superior quality attributes related to weight loss, firmness, and browsing index than coating guava alone with cinnamon essential oil. Nevertheless, as below shown, most authors use biodegradable polymers loaded with cinnamon essential oil to coat foods.

6.2.1. Antimicrobial activity

Some authors test the potential of coating to inhibit foodborne growth by inoculating these microorganisms in the fresh sample. For example, Naqash et al. (2022) inoculated *Escherichia coli* and *L. monocytogenes* into apple-cut pieces. Then, the authors studied the antimicrobial effect of two pectin coatings loaded with a cinnamon essential oil emulsion and nanoemulsion. Both coatings showed the ability to reduce microbial burden, being the most inhibition ability on *L. monocytogenes*. Furthermore, the authors reported that the reduced size of cinnamon essential oil droplets improves the antimicrobial activity of coatings. Other authors determined the microbial burden in coating food. So, Istúriz-Zapata et al. (2020) reported huger antifungal activity of nanostructured chitosan coating loaded with cinnamon essential oil applied to cucumber than the same coating loaded with the main bioactive compound of cinnamon essential oil, trans-cinnamaldehyde. However, to inhibit the growth of the *Fusarium solani*, coated with trans-cinnamaldehyde was the most efficient. The chitosan base-coating loaded cinnamon essential oil has also efficiently prevented fungal growth in minimally processed pineapple. The authors reported the combination of 2% chitosan and 0.5% cinnamon essential oil as the best for inhibiting fungal growth (Basaglia et al., 2021). Another coating that prevented fungal growth in minimally processed fruit was Persian gum coating incorporated with 0.75% cinnamon essential oil, which maintained pomegranate arils for 3 months under cold storage without visible fungal growth (Jokar et al., 2021). (Chu, Gao, et al., (2020) also reported antifungal and antibacterial activity for pullulan coatings incorporated with cinnamon essential oil nanoemulsion added on strawberries. Furthermore, coated strawberries did not change their size and unique red-colored appearance throughout the six storage days. Solís-Contreras et al. (2021) reported a decrease in one log of mesophilic bacteria and yeast and molds in apples dipping with different edible coating films loaded with cinnamon essential oil after 25 days of storage. However, the authors did not control the edible coating without the cinnamon essential oil. Therefore the antimicrobial effects could be due to both coating and cinnamon essential oil. Likewise, Chen et al. (2021) reported the decline in total viable counts (one logarithm) in roast duck meat coated with chitosan incorporated with cinnamon essential oil in comparison with roast duck meat coated with chitosan after 21 storage days; however, chitosan-cinnamon essential oil coating was not adequate to maintained low lactic acid bacteria during storage time. While Kaur & Singh, (2022) reported antimicrobial properties of nanoemulsion of soy lecithin and cinnamon essential oil coating used in muffins. Furthermore, the authors pointed out that the slow microorganism growth after 6 days of storage compared to uncoated muffins could be related to the controlled liberation of bioactive active compounds. However, these authors also studied the ability of clove oil to improve the shelf-life of muffins, and among both studied essential oils, clove oil showed the best ability to extend shelf-life, antioxidant activity, and sensory acceptance. Similar results have been shown by others authors when the antibacterial effects of cinnamon essential oil were compared with other essential oil. Cinnamon essential oils often did not show the best results in extending shelf-life. Ayub et al. (2021) compared preventing peach deleterious among three essential oil, cinnamon, thyme, and basil. Concluding that thyme essential oil showed the best results for maintaining quality and shelf life (up to 13 days).

6.2.2. Senescence delay

The shelf life increases of coating loaded with cinnamon essential oil also have been associated with the ability to delay the senescence process, which is associated with the respiration process in fruits and vegetables during the storage period. Many authors have associated the barrier properties of coating to gases and water with reduced respiration rate, raising the shelf life of fruits, and inhibiting enzyme activity. For example, Yu et al. (2021) have reported the ability of chitosan coating with cinnamon essential oil Pickering emulsion with cellulose nanocrystals to delay the maturation process and senescence of mangos due to the reduction of enzymes activity, such as polyphenol oxidase and phenylalanine ammonia-lyase.

Both weight loss and color modification during storage time are considered important aspects of economically meaningful buying decisions (Lieu & Dang, 2021). Edible coating loaded with cinnamon essential oil prevents weight loss of fruit during storage. Although many authors have reported that the highest cinnamon essential oil levels in coating formulations show the less weight loss values (Rashid et al., 2020), others reported that the effect is not dependent on concentration. In this context, Basaglia et al. (2021) observed that less weight loss in minimally processed pineapple coated with chitosan the lowest cinnamon essential oil concentration. Other factors such as the inclusion of other ingredients like oleic acid and ethanol or Pickering emulsion have been reported to improve weight loss and therefore maintain the weight of coated fruits (Etemadipoor et al., 2020; Lieu & Dang, 2021; Yu et al., 2021). The barrier to gases and water provided by coating reduces weight loss in fruits. Hence, the reduction in water vapor permeability has been associated with improving this attribute (Yu et al., 2021). Moreover, coated firmness is also improved since this attribute is strongly negatively correlated with weight loss (Ayub et al., 2021).

Regarding color, higher cinnamon essential oil concentration in the edible coating negatively affects mangoes' color (Lieu & Dang, 2021). Whereas at low concentration maintained, the mangoes color was during storage time. Likewise, coated chitosan-based cucumber presented a stable color during cold storage, and the presence of cinnamon essential oil in pullulan-based coating kept the red-colored appearance of strawberries (Chu, Gao, et al., 2020; Istúriz-Zapata et al., 2020). Another parameter regarding color disturbance is browing. Etemadipoor et al. (2020) reported that browning was reduced by 33.8% after 7 days in coated guava with gum arabic, oleic acid, and cinnamon essential oil compared to uncoated guava. The reduction in gasesosos exchanged and antioxidant compounds of the cinnamon essential oil could be responsible for reducing the browning index (Yu et al., 2021).

6.2.3. Sensory analysis

When edible film or coating is developed, sensory considerations must be considered, mainly when the essential oil is used. The acceptability of sensory attributes, color, odor, firmness, taste, and overall preference in whole coated apples was better than in uncoated ones. Moreover, the highest scores were shown by the coated apples with the coating with the highest cinnamon essential oil concentrations (5%) (Rashid et al., 2020). Ayub et al. (2021) also reported great acceptability to coated peach, but according to the authors, due to the low cinnamon essential oil concentration use (0.75%), that does not mask typically peach aroma and taste. While Basaglia et al. (2021) reported good acceptance of minimally processed pineapple. However, the sensory assay only included sight, smell, and touch. Whereas unpleasant acceptability was reported in terms of the flavor attribute in apple slices, and the characteristic aroma and taste were masked by cinnamon essential oil's presence in cut apple (Naqash et al., 2022; Solís-Contreras et al., 2021). Likewise, the taste of cinnamon was felt in coated pomegranate, but the fruit obtained sensory acceptability (Jokar et al., 2021). Regarding visual appearance, it has been reported that the cinnamon essential oil incorporation into oranges were negative effects, due to the surface burn created by high cinnamon essential oil. While when the biopolymer combination was used, the appearance of oranges had high acceptability (Khorram & Ramezanian, 2021). The appeaprence of muffins also improved due to coating with the cinnamon oil-based nanoemulsion stabilized with soy lecithin (Kaur & Singh, 2022).

The acceptability of animal food in contact with edible films and coating has been related to the antioxidant properties, especially against lipid oxidation of cinnamon essential oil. As in the works carried out by Zhao et al. (2022) and Chen et al. (2021) who reported good sensory acceptance in red sea bream fillets stored in contact with edible films and in roast duck slices dipping with an edible chitosan-cinnamon essential oil film. Moreover Chen et al. (2021) informed that in the first storage days, the special flavor of the essential oil affected the unique aroma of the roast duck, which caused a lower acceptance in comparison with duck without coated and with chitosan coating. However, the acceptability of roast duck increases in chitosan coating with cinnamon essential oil. Hence, the authors reported that lipid oxidation reduced by cinnamon oil was responsible for maintaining acceptability in roast ducks in the last days of storage compared to ducks without coated and with chitosan coating. Therefore, many aspects can increase or decrease the acceptability of coated foods. Usually, weight loss reduction in fruit and bakery products is related to improving coated fruits' acceptability, appearance, and texture. At the same time, the most unpleased sensory aspect is associated with the loss of natural aroma of foods due to volatile compounds of cinnamon essential oil.

6.3. Non-contact with foods

Considering the volatile compounds present in cinnamon essential oil with antimicrobial activity and the effects of sensory quality of foods in contact with essential oils, many authors have evaluated the active antimicrobial packaging developing materials non-contact with foods. Authors such as Ali et al. (2021) have designed a Self-stick membrane with different cinnamon oil concentrations, 4%, 8%, and 10% (v/w), for packing cheese. These authors determined the cinnamon extract release from adhesive patches made with the 4% and 10% concentrations. The release of the cinnamon essential oil was around 66% and 75%, and an equilibrium state was reached after two days. Moreover, the authors reported antimicrobial activity of membranes against four foodborne microorganisms, *E. coli*, *S. Typhimurium*, *L. monocytogenes*, and *S. aureus*. The inhibition of bacterial growth was equal among 8% and 10% oil concentrations, which showed the highest activity. The Self-stick membranes loaded with cinnamon oil were used for prevented microbial contamination of cheese. The authors stuck the membrane in the plastic box where cheese samples were stored (not to change the cheese flavor). Work concluded that all concentrations of cinnamon essential oil incorporated in the self-stick membrane showed antimicrobial activity against *E. coli* O157:H7, which was inoculated in string cheese. Moreover, the self-life of cheese was extended for eight weeks since the membranes suppressed total mesophilic bacteria, psychrotrophic bacteria, yeast, and mold growth. Other authors, such as Songtipya et al. (2021), have observed a lower retention rate of cinnamon essential oil in a natural rubber pressure-sensitive adhesive patch than Ali et al. (2021) (around 35–45%). Furthermore, the release of the cinnamon essential oil was gradually on time, and the equilibrium rate was reached around 30 days. The authors informed of the antimicrobial properties of these patches against *E. coli*, *S. aureus*, and *A. niger*. These parches were tested to prevent the spoilage microorganism growth in the banana cake. The parches increased in 5 days of banana cake shelf-life (compared to control banana cake) since the parches with the highest cinnamon essential oil inhibited the growth of the microorganism after 9 days of storage under 30 °C 75% room humidity (Sengsuk et al., 2021; Songtipya et al., 2021).

Cellulose stickers impregnated with cinnamon essential oil have been tested to inhibit the growth of *Listeria grayi* in green peppers. For that purpose, the authors inoculated *L. grayi* in pepper and evaluated the burden during the time. After two storage days, the microorganism was reduced to the detected limit, and after 8 days, all microorganism was killed. Authors checked the antimicrobial ability of oregano essential oil and carvacrol, and among these, the cinnamon essential oil showed the best results (Tao et al., 2021). Although the main mentioned works pointed out the use of adhesive parches or stickers to avoid the production of off-flavors and off-odors derived from cinnamon essential oil, no sensory analysis was carried out.

7. Future prospects

The interest in cinnamon essential oil as an antimicrobial and preservative ingredient in food packaging has risen in the last few years. Its antimicrobial properties have been widely studied and confirmed in many spoilage microorganisms and foodborne pathogens. Furthermore, positive results have been reported for cinnamon essential oil active packaging.

However, for proper use in the packaging industry is necessary to establish the optimum or correct concentration to improve: the mechanical, thermal and barrier properties of films, increase storage food time, and not interfere with food taste. With the current published data is difficult to elucidate the proper concentration, due to the diversity of biopolymers tested to make films and ways to include them in the films (emulsion, nanoemulsion, Pickering emulsion, etc.). Furthermore, the final concentration in the films not always was reported.

Another challenge is determining the kinetics and pathway release of bioactive compounds of cinnamon essential oil to predict the best food for packaging, storage time and conditions, and even the rentability against other natural and synthetic preservatives. Likewise, in the investigations, more tests on degradability and sensory should be carried out to have a whole vision of the advantages or difficulties of using cinnamon essential oil in the design of films, coatings, and non-contact food packaging.

8. Conclusion

Cinnamon essential oil, mainly derived from bark, is widely used to develop active antimicrobial films and edible coating. While a high variability of biopolymers has been used to develop biodegradable films incorporated with cinnamon essential oil, chitosan has been reported as the main biopolymer for developing edible coatings. The inclusion of cinnamon essential oil into Pickering emulsion, nanoemulsion, or nanocapsules improves films' antimicrobial activity and coating. However, an equilibrium between release and strong film-link must be achieved to avoid low cinnamon essential oil diffusion. Furthermore, the mechanical, water, optical and thermal properties (tensile strength, flexibility, water vapor permeability, opacity) of biodegradable films can be modified with the inclusion of the cinnamon essential oil. In an optimum concentration, these mentioned properties could be improved and provide a film with more plasticity and a better exchange of water and gases between packaging and the environment. Furthermore, the coatings make with polymers and cinnamon essential oil has the ability to extend shelf life to fruit and other foods, such as meat or fish, due to their ability to reduce the senescence process and lipid oxidation. Regarding sensory concerns, edible coating loaded with cinnamon essential oil improves fruits' texture and appearance but can mask their characteristic aroma and taste.

In conclusion, the cinnamon essential oil has the potential to be used as an active ingredient for food packaging and, therefore, respond to the agri-food industry challenge. However, if the mentioned challenges not be faced, its use as an antimicrobial ingredient in the packaging industry will be replaced by other compounds or techniques.

Funding for open access charge

Universidade de Vigo/CISUG.

Declaration of Competing Interest

The authors declare no conflict of interest.

Data Availability

No data was used for the research described in the article.

Acknowledgments

Thanks to GAIN (Axencia Galega de Innovación) for supporting this research (grant number IN607A2019/01). Raquel Lucas-González would like to thank the Spanish "Ministerio de Universidades" for his "Margarita Salas" postdoctoral fellowship (funded by the European Union – Next Generation EU). José M. Lorenzo is member of the HealthyMeat network, funded by CYTED (Programa Iberoamericano de Ciencia y Tecnología para el Desarrollo) (ref. 119RT0568).

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.fpsl.2023.101026.

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