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A review of plant extracts and essential oils as bio-based additives in biodegradable polymer coatings for food packaging

Marjan Nouri [1*]

[1] Department of Food Science and Technology, Roudehen Branch, Islamic Azad University, Roudehen, Iran

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ABSTRACT

Edible films and coatings have attracted extraordinary consideration due to rising demands for ready-to-eat foods with extended quality standards and shelf lives. Packaging without additives or pigments is insufficient to preserve substrates due to several drawbacks. As a solution, free or encapsulated extracts and essential oils with antioxidant, antimicrobial, and emulsifying attributes effectively improve coatings. Significant influence is distinguished by the type, shape, and level of extracts and essential oils in reducing the microbial load of edible packaging and extending food shelf life. Applying novel methods, such as nanocapsules surrounding plant extracts or essential oils, affects packaging stability due to the preservation of biologically active compounds against environmental factors such as oxygen, light, moisture, and pH. This procedure involves manipulating atoms and molecules that lead to the formation of nanoscale structures and protecting optimal features such as higher biological activity for extracts or essential oils over time. The aim of the present study is to highlight coated substrates, natural packaging, and additives, which demonstrate significant influences when applied with free or encapsulated extracts and essential oils. Furthermore, distinct packaging films are particularly important to indicate antimicrobial and antioxidant agents in coated substrates. Additionally, the benefits and disadvantages of antimicrobial packaging and combined antimicrobial and antioxidant packaging are examined in the current research. The biogenic smart coating has been introduced as an approach requiring fewer carbon footprints and ensuring food safety; therefore, these films are less expensive, environmentally friendly, biodegradable, and beneficial.

1. Introduction

The demand for products with minimal processing has increased, which can compromise food safety and environmental quality standards (1). Maintenance procedures include freezing tolerance, heating rate, irradiation conditions, cold plasma treatment, pulsed electric field, pressure distribution, direct preservation, and packaging (2). These processes have received considerable attention for food packaging and quality improvement (3). Notable attention has been drawn to enhancing industrial packaging standards by developing demand management strategies for ready-to-consume products with broad environmental quality and extended storage (4). Ecological concerns have been identified in conventional polymers due to their non-biodegradability (industrial materials) and inherent properties; therefore, biopolymers are proposed to prolong shelf life and can be applied as edible films (EF) and coatings (EC) in food (5). EF and EC are layers of substances used on edible products, which play a prominent role in their distribution, preservation, and marketing (6). EC is applied as a liquid crystal on food by submerging the material into a solution and creating components through structural integrity such as protein, lipid, carbohydrate, or multi-composition; EF, on the other hand, is initially formed as solid sheets, which are used for wrapping (7). These differences are considered significant distinctions among food structures (3). Each substance is applied for enrobing (wrapping and coating) various food products to prolong storage, which is referred to as EF or EC (8). Nevertheless, a film is frequently distinguished from a coating

[*]Corresponding author: Department of Food Science and Technology, Roudehen Branch, Islamic Azad University, Roudehen, Iran.

E-mail address: marjan.nouri@ut.ac.ir (Marjan Nouri).

because it is an independent wrapping substance, while a coating is applied and produced directly on food packaging (1). EFs and ECs have been used for years (e.g., wax on different fruits) to prevent moisture loss and create an aesthetic surface (9). Several factors, including substance type, film formation conditions (pH, solvent, temperature, and composition level), cross-linking reagents, and components such as plasticizers, antioxidants, antimicrobials, and emulsifiers, have further beneficial impacts on the packaging, including environmental protection, anti-corrosion, self-healing, non-toxicity, UV-shielding, and antifouling activity (2, 3). However, packaging films have several drawbacks; for instance, they can be fragile and rigid, creating severe restrictions on food technology (10). Negative environmental aspects are observed when non-recyclable, lightweight, brittle packaging is replaced with easily recyclable alternatives (5). A fundamental hazard of nanocomposite substances is mainly related to human ingestion and the risk of nanoparticle migration from nanocomposites onto the food interface EC (1). These materials' type, size, and shape demonstrate a considerable impact, which can prolong food storage and reduce microbial survival in edible packaging (11). General foods such as fruits, vegetables, meat, dairy, and bakery products could delay spoilage using antimicrobial packaging, as these are affected by microorganisms (9). The prevalence of foodborne pathogens in packaging is recognized as one of the most prominent factors driving innovation (12). Non-toxic and natural additives have been improved and could play a pivotal role compared to synthetic additives with a toxic nature, which are more expensive (2). Nowadays, organic compositions, including plant extracts (Es) and essential oils (EOs) as green additives, have drawn noticeable attention from researchers to enhance packaging (13). Biopolymers as biodegradable constituents have several limitations, e.g., instabilities, short-term applications, and limited shelf life. Consequently, plant Es or EOs are applied to overcome these drawbacks (5). The use of absorbent or sachet pads for Es and EOs, including (a) direct application of these factors into polymers, (b) addition onto polymer surfaces, (c) immobilization using covalent or ionic bonds, and (d) incorporation by creating films, are the categories of antimicrobial food packaging concerning formation approaches in water (1). The purpose of the present research is to investigate coated substrates, natural food packaging, and additives, which demonstrate better impacts when used with free or encapsulated Es and EOs such as cinnamon, clove, ginger, green tea, peppermint, thyme, sage, rosemary, Satureja, and ginseng. Moreover, considerable attention is drawn to different packaging patterns, including chitosan, gelatin, pullulan, starch, cassava starch, zein, soybean, cellulose, carboxymethyl cellulose, whey protein, polyvinyl alcohol, ethylene/vinyl alcohol, polylactic acid, polyethylene terephthalate, sodium alginate, sodium caseinate, gum Arabic, guar gum, hydroxyapatite polymer, hydroxypropyl-β-cyclodextrin, konjac glucomannan, quinoa, and furcellaran to adsorb antimicrobials onto coating substrates. Additionally, migration flow, advantages /drawbacks of antimicrobial packaging, and quantitative monitoring are examined in the present study, and as a result, demand and industry trends in edible packaging are investigated.

2. Quantitative and chemical composition of Es and EOs

The extraction of bioactive substances from plant sources is investigated using innovative procedures in current research, and a vast global market is observed for polyphenols (4). Es are components extracted from plant tissues using solvents, including distinct chemical substances with beneficial attributes (13). These chemicals contain organic acids, resins, volatile oils, sugars, alkaloids, glycosides, amino acids, tannins, plant pigments, oils, proteins, and enzymes (14). As complex structures, EOs consist of flavonoids, isoflavones, terpenoids, phenolic acids, carotenoids, alkaloids, and aldehydes (15). EOs and Es possess several bioactive compounds; their polyphenol components (major compounds of vegetable EOs and Es) are portrayed in Fig. 1.

2.1. Different forms of Es and EOs to extend shelf life

Nanoemulsions (NEs) are considered a group of multiphase colloidal dispersions. In contrast, several lyotropic liquid crystallines (recognized as micellar systems), mesophases, and microemulsions could be similar to NEs in components and nanoscale frameworks (16). NEs could be applied as a film layer for pesticides that provide more protection against photodegradation and as carriers for nano-delivery systems or plant defense for agrochemicals in the agricultural industry (4). Encapsulation (EP) is a procedure to trap active factors within a carrier material, and it is a beneficial approach to improving the delivery of bioactive components and living cells into food products (17). Nanoparticles exhibit a more excellent ratio of surface area to volume with a core-shell structure; consequently, a heterogeneous regulation from core chemistry is observed at the surface (18). Nanocapsules (NPs) could have an oleic core that is more suitable for the EP of lipophilic molecules. NPs are unique nanoparticles with superior nanostructure, including a liquid or solid core with polymeric shells (19). In general, NPs with a hollow core are formed by producing a solid sphere, which is then sacrificed after the polymeric shell structure; thus, its application as a sacrificial template could especially provide a strong spherical structure for NP assembly in multiple polymers (1). Liposomes (LPs) are small spherical structures consisting of amphipathic lipids arranged in single or multiple concentric bilayers with an aqueous system between the lipid bilayers (20). One of the most innovative approaches is the EP of bioactive substances with antimicrobial factors into lipid structures called LPs. It is extensively applied as carriers due to their specific attributes (17). An inner aqueous phase is created by packing amphipathic lipids, an EP source for hydrophilic constituents (21). Nanoliposomes (NLPs) produce an enriched source of phospholipids such as phosphatidylcholine for EP and can also encapsulate hydrophilic and hydrophobic compositions individually and simultaneously (20). This section of the present article is divided into two main parts: A) chemical structures of natural polymers with environmental quality standards in packaging and corresponding figures (Table 1), and B) Free or encapsulated Es and EOs of target plants.

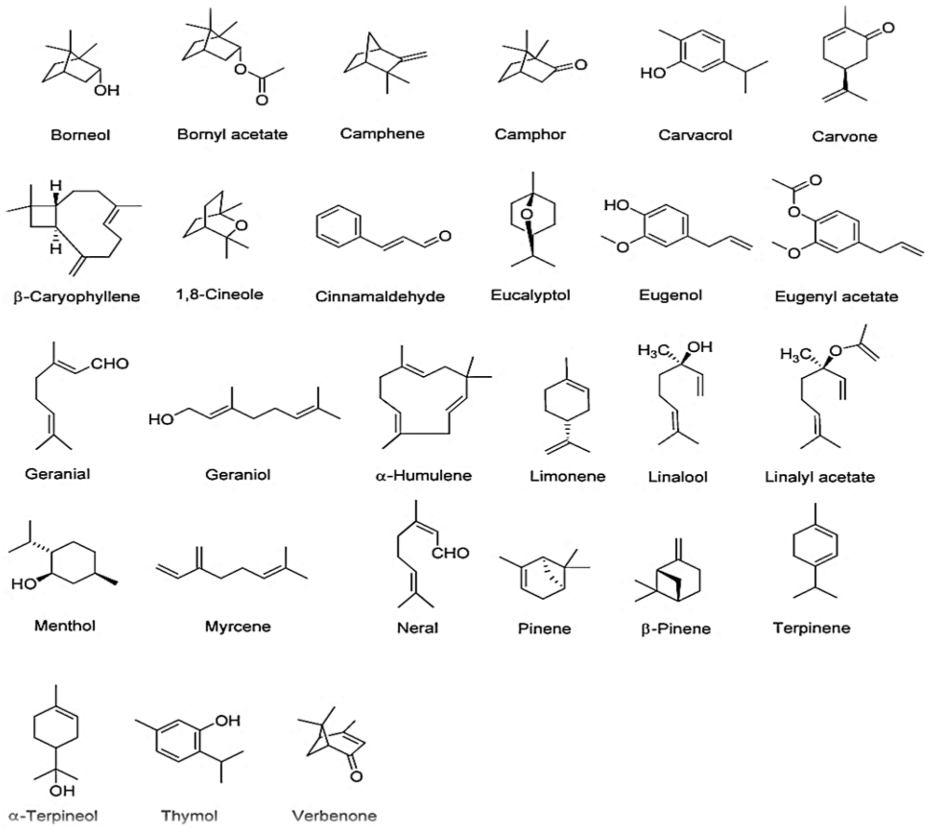
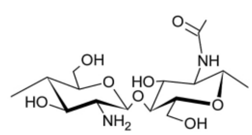
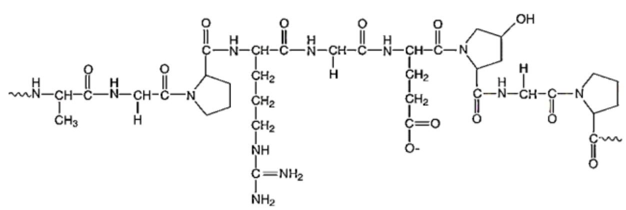
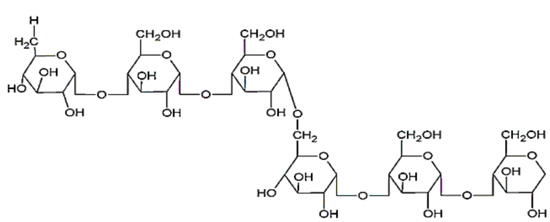
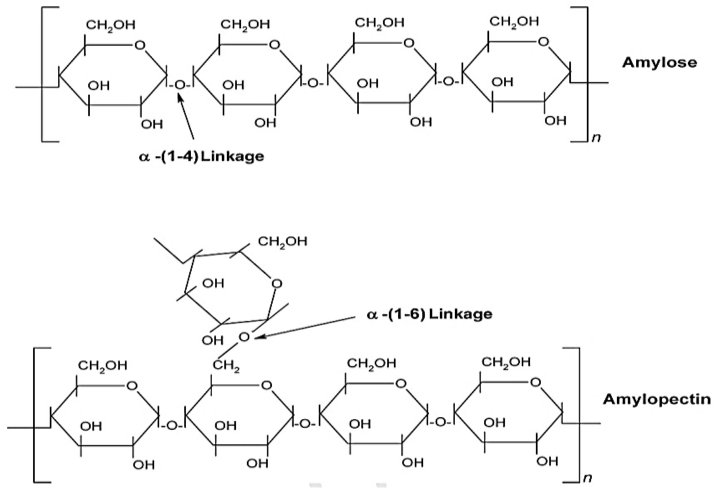
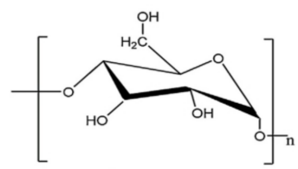
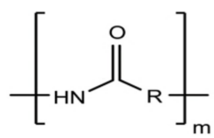
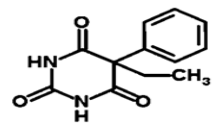
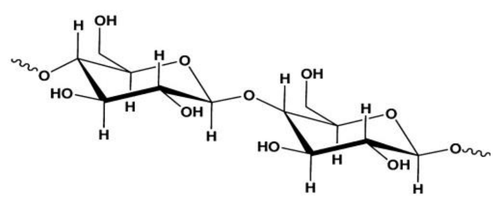
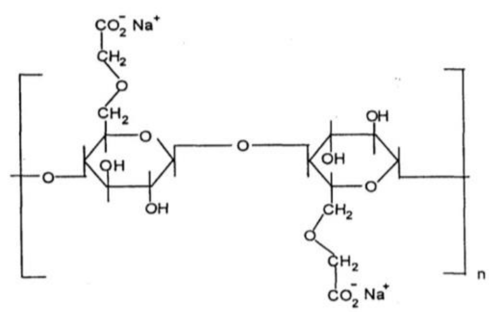
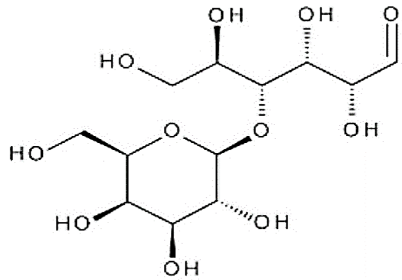
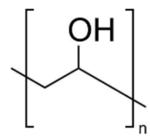
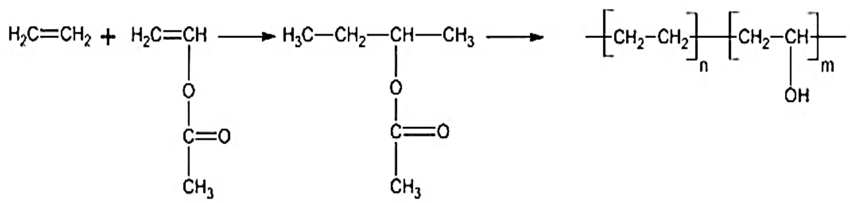
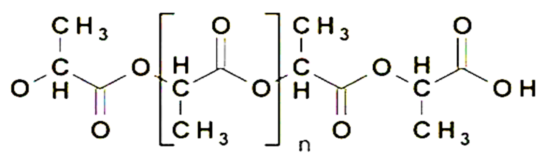
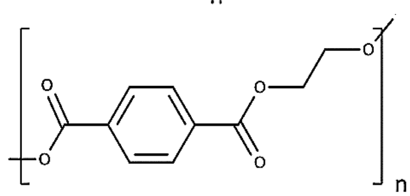
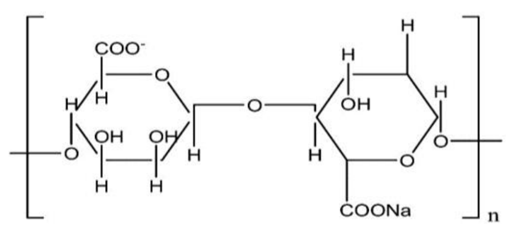


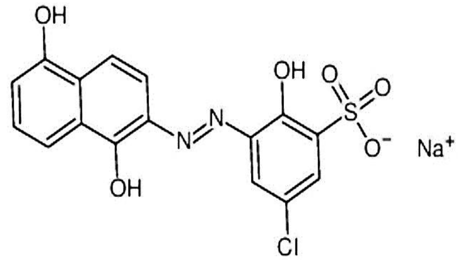
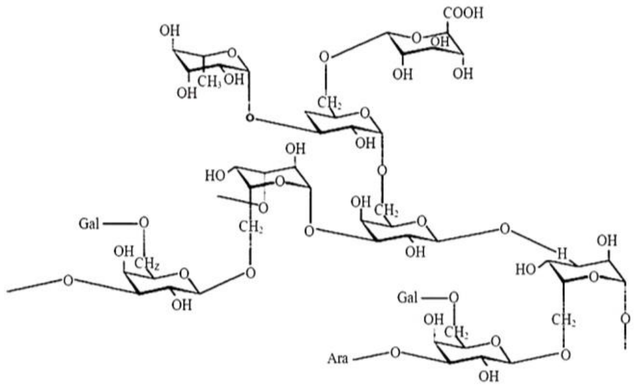
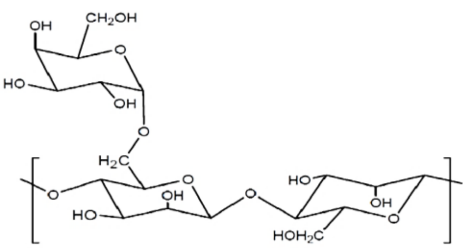
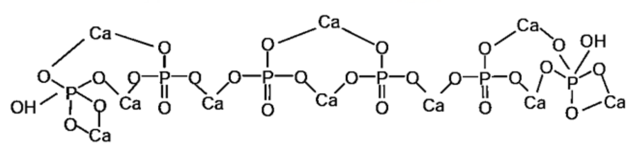
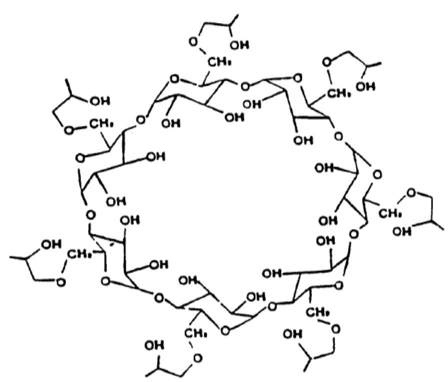
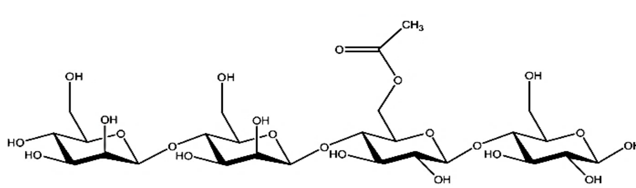
Fig. 1. Chemical structures of major bioactive compounds in EOs and Es.

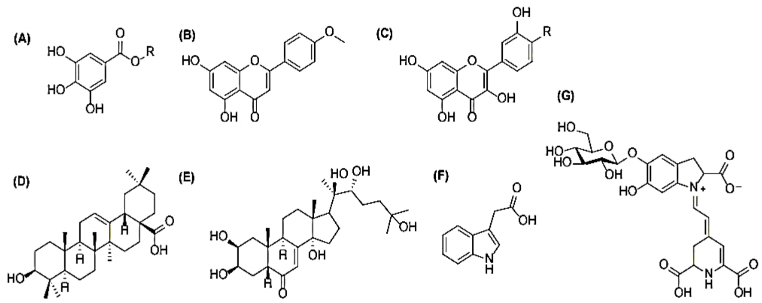
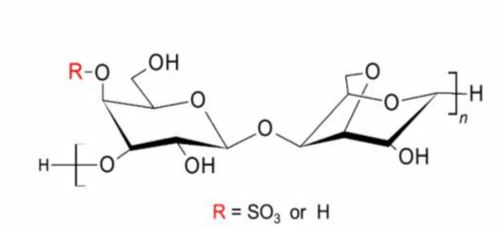
Table 1. Natural biopolymers applied as biodegradable and organic coatings with their corresponding structures reported in present research.

Polymers	Structures	References
Chitosan		(4)
Gelatin		(22)
Pullulan		(16)

Polymers	Structures	References
Starch		(23)
Cassava starch		(11)
Zein		(8)
Soybean		(24)
Cellulose		(25)
Carboxymethyl cellulose		(26)

Polymers	Structures	References
Whey protein		(6)
Polyvinyl alcohol		(27)
Ethylene/vinyl alcohol		(28)
Polylactic acid		(29)
Polyethylene terephthalate		(15)
Sodium alginate		(30)

Sodium caseinate		(25)
Gum Arabic		(5)
Guar gum		(29)
Hydroxyapatite polymer		(31)
Hydroxypropyl-β-cyclodextrin		(18)
Konjac glucomannan		(9)

Quinoa		(32)
Furcellaran		(33)

3. A Brief Overview of Applied Polymers

-*Chitosan*, a poly-α (1,4)-2-amino-2-deoxy-β-D-glucan, is achieved by N-deacetylation of α-chitin. The inherent drawbacks are the restricted chain flexibility, weak mechanical bond, less thermal sensitivity to water, or low adsorbent selectivity, causing a shorter shelf life and restricted uses in food packaging (4).

-*Gelatin* contains distinct polypeptide chains such as α, β, and γ-chains with a molar mass and indicates suitable mechanical and barrier functions, while being biodegradable, environmentally friendly, and less expensive (22). Gelatin hydrolysate from *Nile tilapia* skin is formed through hydrolysis with proteases containing flavourzyme, papain, bromelain, trypsin, alcalase, and neutrase. Gelatin hydrolysate films have higher solubility; thus, their employment as a physical barrier for edible packaging is extremely restricted (33).

-*Pullulan* is a linear glycan with repeating maltotriose units, which forms α-(1→4) bonded glucopyranose rings interlinked through α-(1→6) linkage. Pullulan films have distinct advantages, for example, less toxicity, more transparency, biodegradability, fine mechanical behavior, and reduction in oxygen permeability, while they have the inherent drawback of water solubility improvement (16).

-*Starch* polymer consists of α-D-glucopyranose units occurring in the structure of closed six-carbon rings, creating a chain and branched matrix. Starch-based fibers have been produced mainly using modified starches mixed with polymers, cross-linkers, plasticizers, and other additive components (23). Cassava starch is hydrolyzed through a combination of α-amylase and glucoamylase with unstable paste and weak gelling properties. Furthermore, flavorless, low odor, non-toxic, colorless, and biodegradable are described as the characteristics of cassava starch films (11).

-*Zein* belongs to the prolamin group with molecular weight (about 40 kDa), which is categorized into four classes, including α, β, γ, and δ-zein, indicating distinct amino acid sequences, molecular weights, and solubilities. Aggregating active zein as packaging films is challenging because of flexibility and brittleness limitations (8).

-*Soybean* polysaccharide, as an anionic polyelectrolyte, possesses a viscous structure with a galacturonan backbone that is formed by short homogalacturonan and long rhamnogalacturonan chains. The coatings of soybean protein demonstrate excellent transparency, flexibility, oxygen barrier, and interface hydrophobicity (24). D-glucopyranosyl units link cellulose through β-1,4-glycosidic bonds with excellent chemical resistance, strength, good durability, high thermal stability, lack of thermoplasticity, poor antibacterial activity, and dimensional stability (25).

-*Carboxymethyl cellulose* (CMC) is a linear polysaccharide of anhydro-glucose whose repeating units are linked using β-1,4-glycosidic bonds. It is usually applied as a sodium salt, chains are dispersed molecularly in solution, and its action conforms to the same scaling laws as synthetic polymer matrices (26).

-*Whey protein*, as globular proteins, is fabricated by α-helix patterns, acidic and essential amino acids along their polypeptide chain, as well as main components, e.g., bovine serum albumin, immunoglobulins, bovine lactoferrin, bovine lactoperoxidase, α-lactalbumin, β-lactoglobulin, and glycomacropeptide (6).

-*Polyvinyl alcohol* (PVA) is formed mainly of 1,3-diol linkage [-CH2CH(OH)CH2CH(OH)-] and a low percentage of 1,2-diol linkage [-CH2CH(OH)CH(OH)CH2-] relating to polymerization conditions. Wound dressings based on this polymer possess an incomplete hydrophilic activity with insufficient elasticity and rigid structure, which limits their employment alone as wound dressing scaffolds (27).

-Ethylene/vinyl alcohol (EVA) has recently become a popular flexible thermoplastic oxygen barrier material and a prominent factor for shelf-stable foods where oxygen deteriorates the quality of packaged products.

EVA copolymers have been identified as active films on distinct substrate coatings (28).

-*Polylactic acid* (PLA) is known as the most innovative material for distinct approaches, and it is synthesized through the ring-opening polymerization of lactide. It is cost-efficient because of its suitable molecular weight and application for fixing inner immobilization of bone and joint destruction (29).

-*Polyethylene terephthalate* (PET) is achieved by monomer polymerization of terephthalic acid and ethylene glycol, which could be depolymerized as a more efficient substitution for mechanical recycling. PET coating exhibits beneficial influences like toughness, mechanical behavior, higher melting temperature (270°C), safety, and uncomplicated procedures in food packaging (15).

-*Polyethylene* is a generally applied thermoplastic with abundant supply, lower price, unique processability, less energy for treatments, and higher specific modulus and strength. Nevertheless, low-density polyethylene (LDPE) is a hydrophobic polymer and requires modification for antimicrobial packaging activity (34).

-*Sodium alginate* is formed by alginic acid, including 1,4-β-d-mannuronic and α-l-guluronic acids. It is a linear polysaccharide with good properties like ease of gelation, mucoadhesion, stabilizing nature, high viscosity in water, chelating agent, thickening ability, and gelling negotiator; however, it has an acidic character, low mechanical strength, and cell adhesion (30). Sodium caseinate is a component consisting of major subunits, e.g., αs1-, αs2-, β- and κ-casein that is frequently found in polydisperse packages with a (10 to 100 nm) hydrodynamic radius. It is achieved by drying casein micelles coagulated in a sodium hydroxide solution, which has a high nutritional level and great film-forming properties (25).

-*Gum Arabic* consists of β-1,3-linked D-galactose units with branched structures as leading chains along with 3-linked arabinose and also rhamnose and glucuronic acid as terminators at the end of chains. Gum Arabic possesses film-producing ability in edible packaging and has poor mechanical stability, weak barrier functions, and more hydrophilicity after drying and casting (5).

-*Guar gum* is obtained from the embryos of Cyamopsis tetragonolobus and belongs to the Leguminosae family. Linear chains of (1→4) form it-β-d-mannopyranosyl and α-d-galactopyranosyl units interacting with (1→6) linkages. Guar gum is soluble in water and possesses the capability to produce coatings from its solution (29).

-*Hydroxyapatite polymer*, which is a hydrated calcium phosphate, is fabricated using apatite mineral material. It has been applied as a bone replacement to fill defects, for example, in structure scaffolding for tissue engineering and as a film on biomedical implants (31).

-*Hydroxypropyl-β-cyclodextrin* (HPβCD) contains highly hydrophilic and hydroxyalkyl cyclodextrin derivatives with more hydroxyl groups. Its particles are constituted by supercritical assisted atomization that could be applied as carriers of pulmonary drugs. HPβCD films were hydrophilic and possessed better compatibility, thermal stability, and ultraviolet-blocking ability, with a smooth and uniform structure (18).

-*Konjac glucomannan* (KGM), a natural polysaccharide and dietary fiber hydrocolloid, is formed from tubers of the *Amorphophallus konjac* herb, a suitable factor for edible packaging. The major chain is bonded through D-mannose and D-glucose units by β-1,4-linking, and the side chain is linked by β-1,6-glycosyl units (9).

-*Quinoa*, a member of the goosefoot family (Chenopodiaceae), is enriched with starch and could be applied in chemically modified starches because of its excellent stability in freezing and retrogradation. Some quinoa proteins are employed to make the coating of edible products and illustrate significant results in their physical activities (32).

-*Furcellaran* comprises sulfated polysaccharides with high molecular weight and gel-forming ability obtained from red algae *Furcellaria lumbricalis*. It is similar to carrageenan, which fabricates powerful and brittle gels with a tendency towards syneresis and less stress susceptibility to low deformations (33).

3.1. Release of Es and EOs from packaging

The main factor in designing active packaging is to control component release for developing function (12). The controlled release of EOs and Es from edible packaging and stimulative features can be significantly important for the practical applications of novel biocomposites (22). Current methods in packaging include microencapsulation and nanoencapsulation of EOs and Es into a solution and emulsion to be coated on film to control release for active substances (1).

4. Free or EPEs and EPEOs of target plants

4.1. Cinnamon

Cinnamon (*Cinnamomum verum* J. Presl, Lauraceae family) has the main chemical constituents like (E)-cinnamaldehyde (71.50%), linalool (7.00%), β-caryophyllene (6.40%), eucalyptol (5.40%), and eugenol (4.60%); therefore, considerable attention has been paid to cinnamon in food preservation (35). The loaded coating of chitosan/gelatin nanofiber, including 4% cinnamon extract (CE), indicated antibacterial activity against *Staphylococcus aureus* (90 ± 6%) and *Escherichia coli* (82 ± 5%); however, it was not detectable in the control. This could occur because the main chemical components in these coatings elevated antibacterial traits (22). The microbial combination of molds and yeasts was found to be 5.30 (log CFU/g) for control by enhancing growth compared to 3.80 (log CFU/g) for the coated sample with 2% chitosan and 1% cinnamon EO (CEO), which had occurred owing to antimicrobial traits of chitosan and CEO in treated pineapple (36). The mold and yeast counts were 1.958 ± 0.03 (log CFU/g) for pullulan coating based on NEs loaded with 8% CEO in contrast to 4.657 ± 0.08 (log CFU/g) for pure pullulan and 4.778 ± 0.05 (log CFU/g) in control for strawberries since NEs loaded with EO were more efficient in inhibitory activities against mold and yeast because of their compositions (16). The bioactive coating of soluble soybean polysaccharide incorporated loaded NEs with (0.8%) CEO elevated antioxidant activities 10.8 ± 0.17% compared to control 1.04 ± 0.51% in meat products due to coating acting as a barrier against the migration of active packaging materials and increasing these features (24). The coating containing NEs loaded with 5% (w/w) CEO and 2.5% (w/w) cellulose nanofiber increased antioxidant function (66.04±4.22%) compared to 5% (w/w) sodium caseinate (26.1±1.58%) in perishable foods, indicating that coatings blocked oxygen, inhibited the activity of ascorbates, and delayed oxidation. This could be related to the possible contact of CEO components with cellulose nanofiber hydroxyl structures, causing their lower function (25).

4.2. Clove

Clove (*Syzygium aromaticum* L. Myrtaceae) is recognized as an aromatic plant that is extensively cultivated in tropical and subtropical regions (39). It is applied as volatile substances, e.g., eugenol, β-caryophyllene, and α-humulene in perfume, cosmetic, health, medical, and flavoring industries (23). The growth of *Salmonella* Typhimurium (7.1 log CFU/g) and *Listeria monocytogenes* (5.7 log CFU/g) was detected in chicken samples packed with low-density polyethylene film (LDPE) at the end of storage; however, they were not observed in LDPE film incorporated with chromic acid and 0.5 (g) clove EO (CLEO). The major functional compounds, such as eugenol and carvacrol, were represented in EO, so they penetrated the membrane of bacterial cells and damaged the structure. This is possibly due to an additional exterior wall for bacteria that restricts the distribution of hydrophobic components by the cytoplasmic wall (34). *E. coli* O157:H7 count was the highest for control 8.1 (log CFU/g). Still, the lowest was observed for silver carp fillet coated with 3% (w/v) carboxymethyl cellulose and 1.5% (w/v) sodium alginate containing 1.5% CLEO, showing that the presence of several components in CLEO, for example, eugenol, propylene glycol, and benzothiophene. Previous research expressed that CLEO presented an inhibition effect versus *E. coli* O157:H7, and the antimicrobial capacity was dependent on the amount of oil (36). Antioxidant activity of starch EF incorporated with 3% CLEO was 85.96±0.14% and 0.7 ± 0.057% in control after 90 min incubation, which could be related to increased phenolic contents in CLEO like eugenol, caryophyllene, humulene, and caryophyllene oxide (23). The ratio of (1:1) HPβCD coating with encapsulated CLEO (EPCLEO) had higher antioxidant behavior 28.70 ± 0.77%. In comparison, this feature was 25.20 ± 1.02% for free CLEO (0.01 g), which was due to an increase in water solubility of EPCLEO. CLEOs were found not to reveal antioxidant capacity specifically. However, the particles produced with cyclodextrin significantly influenced this feature. It corresponded to the higher solubility of low-polar substances in EPCLEO because of their interaction with cyclodextrins. Furthermore, the formulations produced with HPβCD represented further antioxidant capacity (18).

4.3. Ginger

Ginger (*Zingiber officinale* L.) is generally regarded as an herbal plant composed mainly of α-zingiberene, α-curcumene, and β-sesquiphellandrene. Its volatile and non-volatile components are candidates for improving active packaging compared to biopolymers (27). The treated meat with zein coating, including 3% ginger extract (GE) and 1.5% *Pimpinella anisum* EO, showed the highest reduction rate of mesophilic bacteria 4.13 (log CFU/g), lactic acid bacteria (LAB) 2.68 (log CFU/g), *Enterobacteriaceae* 3.84 (log CFU/g), *Pseudomonas* spp. 2.74 (log CFU/g), molds and yeasts 1.99 (log CFU/g) compared to control. The antimicrobial activity of GE was enhanced by higher concentration, and a synergistic influence was found when GE was mixed with *Pimpinella anisum* EO (8). The mentioned nanofiber (0.21, 0.31, and 0.41 g) in suspensions with PVA gel was blended using ultrasonication. The bionanocomposite coating with ginger nanofibers exhibits antibacterial function; however, fungal inhibition is not found. The microbial inhibition of Bacillus subtilis was distinguished as 14.2 ± 1.3 (mm) in biocomposite of 10 g PVA coating with 20% ginger nanofibers (GF) but was not detected in PVA as control. The antibacterial impact occurred because of bioactive substances in GF and coating. Nonetheless, total bionanocomposite coatings could not prevent the Candida albicans population, possibly owing to less ginger fiber with bioactive components. A correlation was not detected between the inhibition area's diameter and fiber loadings (27). The antioxidant feature was not changed in the EC of gum Arabic (10%) with GE and garlic extract at the same level (100 g) for Gola guava fruits. The distinct bioactive components, for example, flavonoids, ascorbic acid, and phenolics, assist the antioxidant potential of fruits, and their deterioration results in lower antioxidant status. Even though gum Arabic and garlic extract prevented the reduction in phenolics, flavonoids, and ascorbic acid, all antioxidants were elevated approximately in guava fruits with no additives (5). The highest antioxidant activity (50.5 μmol TE/g) was reported in strawberries by incorporation of (1 and 2%) nanofibrillated cellulose coating with green tea extract (GTE) and GEO at the same concentration (1%). The efficacy of ECs as oxidation protectors is related to their capacity and oxygen barrier performance (37).

4.4. Green tea

Green tea (*Camellia sinensis*) has numerous bioactive components that can provide beneficial health effects, such as antioxidative, anti-inflammatory, anticarcinogenic, antiproliferative, antihypertensive, and anti-thrombogenic properties (28). The colony diameter of *Penicillium expansum* was measured for EVA copolymer as control (2.97 ± 0.13 cm) and was not observed in a film loaded with oregano EO (OEO) or complex of GTE and OEO (at the same concentration 5%) during 12 days. Therefore, OEO and GTE had better antifungal impact due to carvacrol's presence, which damaged the cell membrane by increasing fluidity and passive permeability (volatile phenolic with powerful antibacterial activity) reacted with the cell wall. It created a deformity of the physical framework and non-steady wall, developing penetration and fluidity. According to GTE, the antifungal and antimicrobial compositions could require a liquid culture to be released and produce any detectable impact (28). Microbial bactericidal concentrations of *S. aureus* 0.57 (mg/ml) and *E. coli* 1.15 (mg/ml) were found for EP of green tea EO (GTO) with 1% chitosan nanoparticles against EP of peppermint EO (PEO) 1.11 (mg/ml) and > 2.72 (mg/ml), respectively. It is related to lipophilic oil interaction and phospholipid membranes, which induce permeability for EP of GTO (17). The antioxidant capacity in terms of DPPH was detected 8.525 ± 0.384 (mg VC/dm^2) in coated pork meat with PET and 8% GTE in contrast to PET 0.010 ± 0.002 (mg VC/dm^2) as a control, which was attributed to high catechins in GTE (15). The PVA film incorporated with 2% GTE showed 68% antioxidant function compared to 37% in PVA film with 0.5% GTE on dried eel. It corresponded to distinct catechin components by adding more GTE. When the H2O molecule was connected to water, it transferred into the structure of PVA packaging, causing the inflation of the film. Also, GTE was released from packaging to contribute to the activity of scavenging DPPH radical (10).

4.4. Peppermint

Peppermint (*Mentha piperita* L.) is recognized as a plant with functional characteristics belonging to the Lamiaceae family (38). Peppermint extract (PE) includes polyphenolic components, mainly flavonoids, phenolic acids, lignans, and stilbenes. Considerable antibacterial, antioxidant, anti-inflammatory, and antiallergic activities are observed (31). Total coliforms were observed at 4.4 (log10 CFU/g) for 1.5% chitosan-based coating enriched with 10% PE in carp fillet, while control without coating and PE reached 6.3 (log10 CFU /g) at the end of the period, because the interaction of PE occurred between molecules in the microbial membrane, causing leakage of cell proteins and intracellular substances (21). The hydroxyapatite coated with 1% PEO had inhibition zones for *S. aureus* ATCC 25923 (10 ± 0.5 mm) and *Pseudomonas aeruginosa* ATCC 27853 (7 ± 0.5 mm) compared to 12 ± 0.3 and 10 ± 0.5 mm in pure PEO, respectively. The presence of menthol and menthone components in PEO and hydroxyapatite acted to damage the cell membrane and led to its destabilization (31). Antifungal activity against both *Botrytis cinerea* and *Rhizopus stolonifer* was measured at 2.0 ± 0.1 (cm) for 4% (m/v) gelatin film incorporated with mint EO (MEO) at 0.38 and 0.50% concentrations but this feature was not found in MEO below the minimum level of 0.25% as control. Adding more MEO could be attributed to increased menthol (38). TBARS assay values were observed at 29.21 (mM MDA/mg protein) for 1.5% chitosan-based coating enriched with 10% PE in carp fillet and 33.44 (mM MDA/mg protein) for control. This could be due to the antioxidant rate of chitosan that fabricated a stable fluorosphere with aldehydes and positive charges in amine structures to perform as a chelating factor of metal ions, avoiding lipid peroxidation (21). The DPPH scavenging activity was 69.79% for (2% w/v) chitosan film based on the mixture of PEO and fennel EO (FEO) at the same concentration (1% v/v) in contrast to 54.88% for control without film, PEO, and FEO. It was associated with moderate levels of phenolics, which were reported in PEO and FEO, and chitosan reacted with hydrogen molecules in a solution to fabricate ammonium groups NH^{3+} (39).

4.5. Thyme

Thyme (*Thymus vulgaris* L.), an annual plant cultivated in the Mediterranean region, belongs to the Lamiaceae family and is consumed mainly for cooking and flavoring (26). It is applied in folk medicine for several purposes, such as respiratory inflammation, urinary infection, gastric inflammation, atrophic arthritis, and oral infections, and for its antispasmodic, diuretic, and expectorant activities (9). The growth of Aspergillus in coated fresh hazelnut incorporated with 1.5% (w/v) CMC and 1% (v/v) thyme extract (TE) was not found at the end of storage, compared to 78% in the control without coating. It was observed that moisture loss prevented oxygen penetration to nut texture, and the antifungal impact of TE was evident (26). Inhibition zones were determined for *L. monocytogenes* (163.68±10.89 mm^2), *S. aureus* (115.65±10.66 mm^2), and *E. coli* O157:H7 (59.53±8.44 mm^2) in 0.8 (g) KGM-based film loaded with 1.6% (v/v) thyme EO (TEO), while they were not present in pure film. This corresponded to carvacrol and thymol in TEO, which could be distributed in the lipid phase of the bacteria membrane, thereby changing the calcium environment and preventing the transport of potassium and calcium (9). The antioxidant activity in terms of DPPH for nanofiber-based on PLA/guar gum with a ratio of 85:15 and 30% TEO was indicated (68%) compared to pure film (32%) because of high total phenolics in TEO. When thyme is added to the nanofibers framework, the antioxidant potency is significantly ($p<0.05$) enhanced up to 55% and 75% in nanofibers consisting of 10% and 30% thyme, respectively. In addition, DPPH scavenging ability was developed by adding TEO (29). The EC50 of film containing 0.2 g chitosan and 0.8 g starch incorporating 0.15 g TE was calculated as 0.90 (kg film/mol DPPH) against control without TE 1.061 (kg film/mol DPPH). Better antioxidant activity was shown by film with added TE due to more polyphenol release and potential oxidation of substances (40). The NP of (40%) TEO in (2% w/v) chitosan/ (9% w/v) gelatin nanofibers had an antioxidant feature (30%) compared to pure TEO (8%) in sausages after 18 days because the phenolic compounds in NP were better protected against oxygen. The antioxidant effect of TEO was enhanced noticeably towards the encapsulated structure for the 1st day of shelf life, and phenolic contents were immediately accessible to free radicals. EP of TEO improved antioxidant features compared to control after the 18th day because the phenolic compositions were better supported against oxygen (41).

4.6. Sage

Sage (*Salvia officinalis*), belonging to the Lamiaceae family, is cultivated in several countries as a medicinal herb. Phytochemical analysis shows that the main constituents are monoterpenes (α/β-thujone, 1,8-cineole, camphor, and linalool), sesquiterpenes (α–humulene), and important phenolic components such as carnosol, carnosic acid, and rosmanol (32, 43). The growth of Salmonella enterica was observed at 6.00 ± 0.00 (log CFU/ml) in EC of 25% (w/w) zein enriched with 20 and 30% (w/w) sage extract (SE) and 10.51±1.07 (log CFU/ml) in control without SE, which was related to total phenolic content by destroying cell wall, changing the structure and permeability of cytoplasmic membrane (42). The rainbow trout fillets covered with quinoa as a polymer and 2% sage EO (SEO) showed 4.34±0.01 (log CFU/g) Enterobacteriaceae compared to 5.89±0.05 (log CFU/g) for control without coating and SEO on 15 days of storage. The phenolic structure of SEO prevented functional activities by destroying the cell membrane and causing leakage, so an antimicrobial response was observed (32). The antioxidant feature was assessed at 85.27% for 10% (w/w) -based films enriched with 20% SE compared to 6.12% in control with no film and SE after 24 h. The SE neutralized free radicals and prevented oxidation processes by releasing bioactive components. The antioxidant feature of sage extracts was distinguished by most efficient substances with free radical scavenging activities such as phenolic compositions, i.e., abietane diterpenoids (carnosic and carnosol acid) with caffeic acid derivatives including chlorogenic, rosmarinic, and caffeic acids (13). The whey protein isolates (5% w/v) based EF incorporated with SE (4%) in cooked meatballs had higher DPPH radical scavenging activity at 63.30 ± 3.19% than cooked meatballs as control at 45.78 ± 2.04% on 60 days. Bioactive components such as carnosol, carnosic acid, and rosmarinic acid caused antioxidant activity in sage (6).

4.7. Rosemary

Rosemary (*Rosmarinus officinalis*) belongs to the Lamiaceae family and is applied as a herbal remedy and spice. Rosmarinic acid, diterpenes (carnosic acid, rosmanol, and carnosol) as well as non-volatile triterpenic components (betulinic and ursolic acids) are detected (3). The population of LAB was evaluated at 5.74±0.18 (log CFU/g) for 2000 (ppm) rosemary EO (REO) entrapped in carboxymethyl cellulose EC for smoked eel fillets compared to 6.48 ± 0.06 (log CFU /g) for control fillets. This could be attributed to rosmarinic acid against free radicals in REO (16). The 20% RE incorporated within cassava starch film increased the antioxidant effect (81.9±1.7%) compared to film with 5% RE (28.6±0.3%), indicating phenolic contents were enhanced by adding more RE (11). The trolox equivalent antioxidant capacity was detected at 1.9 and 0.32 (mg/L) for the ratio of gelatin/chitosan EF (50:50) mixed with rosemary extract (RE) and CE at the same concentration 1% after 6 min, respectively. This illustrated that the capacity of polymer and RE was elevated to interact with free radicals using ionic interactions with amino substances (3). The FRAP assay was distinguished at 207.08 ± 1.30 (μmol Trolox/g of dried film) for film based on 0.73% (w/v) furcellaran / 1.46% (w/v) gelatin hydrolysate with 20% RE in contrast to 2.78 ± 0.04 (μmol Trolox/g of dried film) for control coating without RE due to a high level of polyphenol compounds observed in EOs (33).

4.8. Satureja

Satureja (*Satureja spp.)* belongs to the Lamiaceae family, which is observed to contain several components, including γ-terpinene, borneol, carvacrol, p-cymene, and thymol in its different species (49). The distinct species of Satureja are known for different therapeutic effects on wounds, gastroenteritis, and respiratory tract infections (19). The coated treatment with 2% (w/v) chitosan solution containing 1% (v/v) *Satureja khuzestanica* EO (SKEO) loaded NLPs had 3.2 (log CFU/g) total bacteria count in contrast to lamb meat as a control at 7.5 (log CFU/g) after 10 days. A synergistic effect was observed by chitosan coating with lipophilic bioactive substances incorporated in SKEO because of its intrinsic antimicrobial characteristics (43). The antioxidant function was detected at 60% and 43.5% in chitosan nanoparticles (5% w/v) loaded with 1.5% and 1% Satureja hortensis L. EO (SHEO), respectively. Higher total phenolics, e.g., thymol, γ-terpinene, and carvacrol, are present in SHEO at higher concentrations. Some phenolic compounds have also been applied to regulate the leakage of bioactive substances from NPs with remarkable antioxidant potential (19).

4.9. Ginseng

Ginseng (*Panax ginseng*), a traditional herb, includes distinct active ingredients such as protopanaxadiols, steroidal saponins, and protopanaxatriols in Asian countries, collectively recognized as ginsenosides. It has various beneficial effects, including anti-stress, antioxidative, anti-inflammatory, and antidiabetic features (30). Sodium alginate film (2 g) containing 1% extruded white ginseng extract (GSE) showed an inhibition effect on *L. monocytogenes* (13.83±0.10 mm), but no activity against this strain was observed in the control film. This is related to components and the interaction between film and GSE (44). Antioxidant activities of 2 g sodium alginate film incorporating 0.5 g/mL GSE was found to be 18.5% by DPPH compared to 1.5% in the control film. This ability is mainly due to phenolics and their redox features, which allow them to act as reducing factors, hydrogen donors, and oxygen quenchers (30).

5. Concerns and Solutions for Using EOs and Es in Polymers

Edible packaging is prominent for reducing post-harvest loss through protecting quality during transportation and controlling (2). Nowadays, biodegradable packaging from natural substances and the implementation of recycling technologies have been improved in advanced countries (4). Leaf packaging is rejected in the environment, where it undergoes anaerobic and aerobic decomposition through microorganisms and helps soil fertilization; therefore, it is the best approach to reduce fossil-based plastics (12). Biogenic smart packaging has been illustrated as an approach required to reduce carbon footprints and protect the safety of food products; thus, these films are less costly, environmentally friendly, beneficial, and biodegradable (4). Integrating bionanocomposites and their application as biosensors can be a milestone for developing smart EFs in the packaging industry (12). Therefore, it is important to detect biosensors and bionanocomposites to improve affordable and sustainable smart packaging (1). Distinct nanoparticle-based delivery systems are accessible to incorporate active factors into biodegradable packaging, including NEs, NLPs, biopolymer nanoparticles, nanogels, solid lipid nanoparticles, and nanostructured carriers (5).

6. Conclusion

Nowadays, EOs and Es as natural resources from plants are suitable alternatives to synthetic chemical nanoparticles that resist pathogenic microorganism strains and have antioxidant traits, which do not exhibit any toxic and irreversible effects on human health. Therefore, attention is paid to presenting science with novel approaches, and these EOs and Es are classified as Safe. Particularly, the antibacterial and antioxidant functions of bio-based polymers e.g., chitosan, gelatin, gelatin hydrolysate, pullulan, starch, cassava starch, zein, soybean, cellulose, CMC, whey protein, PVA, EVA, PLA, PET, sodium alginate, sodium caseinate, gum Arabic, guar gum, hydroxyapatite, HPβCD, KGM, quinoa and furcellaran are associated with EOs and Es, e.g., cinnamon, clove, ginger, green tea, peppermint, thyme, sage, rosemary, satureja, ginseng, *Eucalyptus globulus*, basil, lemongrass, oregano, fennel, and *Tribulus terrestris* L. are explained. Moreover, clinical research [their ability] as controlled drug delivery systems and [be applied] to humans.

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