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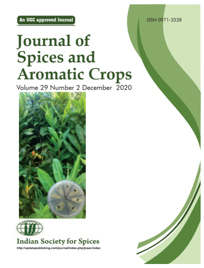

Spice bioactives in edible packaging

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Abstract

Edible packaging received significant attention in recent years. The main advantage of edible packaging over synthetic packaging is that they are environment friendly. The material used in edible packaging (lipids, polysaccharides, proteins) is generally recognized as safe and it acts as a barrier to gases, light and moisture. Spices have been traditionally used for its medicinal value. Spice extract or its essential oil possesses various bioactive compounds which are known for their antioxidant and antimicrobial property. Incorporation of spice extract or its essential oil into edible packaging exerts antimicrobial activity against the food pathogens thus preventing food spoilage and enhances the shelf-life and also increases the nutritional value of the final product. Antioxidant properties of spices retard the lipid oxidation. Dietary allergy and intolerance are also associated with packaging material and spices. Because of the high cost of film-forming material, scaling-up of edible packaging has remained a problem.

Keywords: antimicrobial activity, bioactive compound, edible coating, edible film, spice constituents, spice essential oil

Introduction

Global consumption of plastic is about 285 million metric tons (MMT) per year and India contributes about 12.8 MMT annually. In India, more than 40% of packaging needs are catered by plastics (FICCI 2016). Every year plastic wastage of about 8 MMT enters the ocean and it takes 400 years for their breakdown which pollute the cities and harm animal life. To overcome these environmental effects companies are trying to substitute edible packaging as an alternative for plastic packaging (Spencer 2018). Food and pharmaceutical industries have recognized edible packaging as an alternative to plastic packaging. Environmental Protection Agency reported that containers and packaging of food contribute about 30.2% of household waste. Milk proteins, vitamins, proteins and probiotics are the raw materials used for edible packaging which acts as a barrier for gaseous concentration thereby preventing food products from contamination (Mamtani 2017). The primary functions of edible packaging are represented in Fig. 1.

The two main classifications of edible packaging are edible coating and edible film. The edible coating is applied as a skinny layer on the food products which is in direct contact with the food. A thin layer of edible material in which the food is being packed is known as edible films. Edible packaging helps in minimizing environmental pollution by reducing plastic waste (Ghosh *et al*. 2020).

To achieve better organoleptic characteristic and increased shelf-life, spices have been used as a food additive. Reduction in lipid oxidation and antimicrobial activity of the spices is due to the presence of flavonoids, terpenoids and phenolic compounds (Negi 2012; Tajkarimi 2010). To improve the stability of oxidation-sensitive food, antioxidants have been incorporated in the edible packaging material, whereas incorporation of synthetic antioxidants exert toxicological effects. Hence, natural antioxidants extracted from spices and its essential oils (EOs) can be recommended (Silva-Weiss 2013). Spices also act as a potential alternative to food synthetic preservatives (Gomez-Estaca *et al*. 2014). Spices can be incorporated in the form of powder/aqueous extracts/EOs into natural or synthetic polymer matrices of edible packaging. Avila-Sosa *et al*. (2012) noted that an edible film incorporated with essential oil provides the microbiological stability to the food and it can extend the shelf-life of the food.

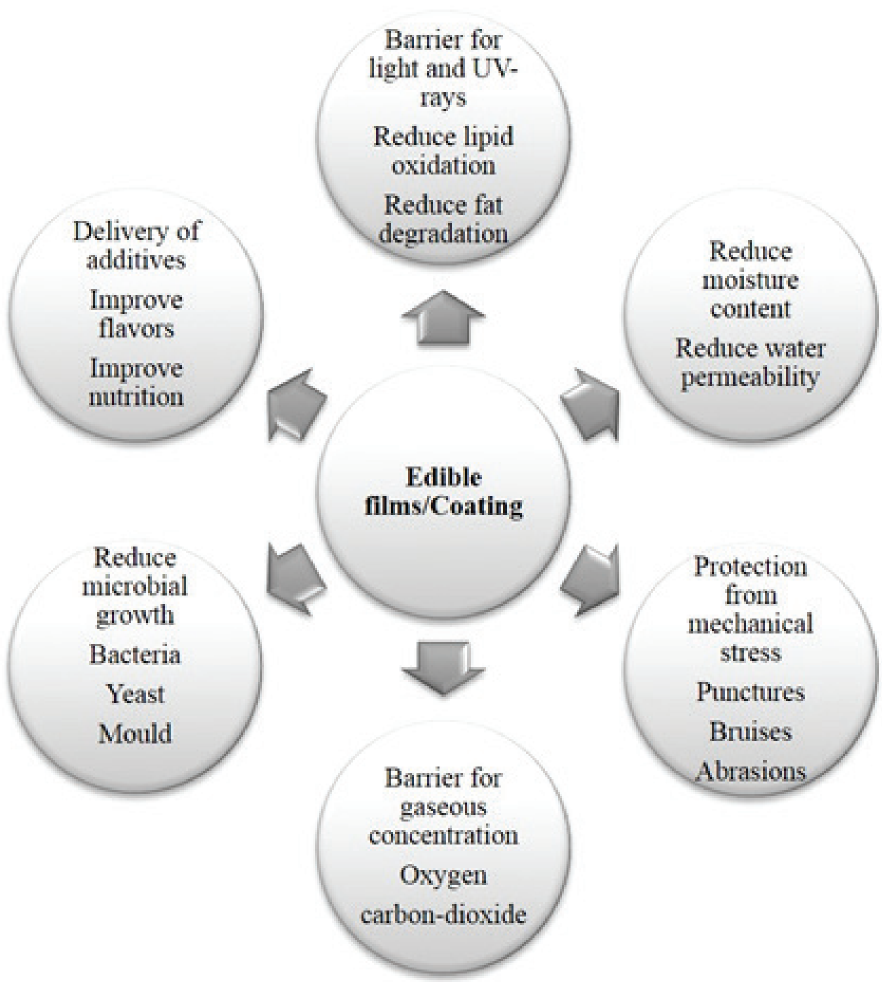

Fig. 1. Functions of edible packaging (Ghosh *et al*. 2020)

Incorporation of essential oil helps to minimize the water vapour pressure (WVP) of the edible film (Tongnuanchan *et al*. 2013).

Materials used in edible packaging

Polysaccharides based edible packaging

In the edible packaging, plastic is replaced by carrageenan, starch, alginate, pectin and xanthan gum (Espitia *et al*. 2014). Chitosan films are resistant to fat, oil and oxygen but they are highly permeable to moisture (Nayik *et al*. 2015). Almasi *et al*. (2010) reported that carboxy-methyl cellulose (CMC) has an excellent film-forming property with a water-soluble polymer. Starch-based films are colourless, flavourless and tasteless (Skurtys *et al*. 2011). Pectin films are effective in the protection of low moisture food (Liu *et al*. 2007). Pectin films are highly suitable for the packaging of fruits and vegetables (Valdes *et al*. 2015a). Fruits coated with arabic or almond gum resulted in a significant decrease in the ethylene production and respiration rate (Mahfoudhi & Hamdi 2015). Addition of calcium in alginate films decreases the permeability of water vapour (Olivasa *et al*. 2008). Carrageenan films prevent the superficial dehydration in meat, poultry, fish and oily foods (Karbowiak *et al*. 2006). Pullulan is highly capable of preparing the odourless, colourless, tasteless and heat-sealable edible film. However, pullulan is water permeable, low oil and oxygen permeable (Diab *et al*. 2001; Kanmani *et al*. 2013). Gellan films are hard and brittle (Lee *et al*. 2004). Fresh-cut vegetables coated with gellan gum have better quality and shelf-life (Dalanche *et al*. 2016). Quality and shelf-life of fresh-cut fruits were improved by applying a xanthan gum-based edible coating (Freitas *et al*. 2013).

Lipid-based edible coatings

The edible film made up of lipids provides gloss, reduction in moisture loss and reduced cost (Huber & Embuscado 2009). Pork meat hamburger coated with sunflower oil enhanced the quality of the food (Vargas *et al*. 2011). Hassani *et al*. (2012) observed that rice bran oil extended the shelf-life of kiwi fruit with good taste, colour, and firmness. Fresh cut fruits coated with candelilla wax extended the shelf-life of fruits. It also increased the antioxidant potential and nutritional quality of the fruits (Saucedo-Pompa *et al*. 2007). Plasticizer increases the flexibility and strength of the edible packaging material (Han 2014). Addition of diverse plasticizers to edible packaging material increases the moisture content and thickness of the film (Razavi *et al*. 2015).

Protein-based edible packaging

Protein films have better mechanical properties than polysaccharides (Bourtoom 2008). Milk protein acts as a good carrier for antioxidant and antimicrobial agents. Milk protein forms flexible, flavourless and transparent films (Wagh *et al*. 2014; Sabato *et al*. 2001). Fabra *et al*. (2010) reported that sodium caseinate films have a good optical property and tensile property. Oses *et al*. (2009) noted that whey protein films (90% protein) are impermeable to oxygen at a low/intermediate relative humidity. While making the edible film 50% of calcium caseinate is replaced by whey protein isolate without reducing the puncture strength of the film. In the meat industry, collagen is used as an edible film for meat product cooking (Jeevahan *et al*. 2017). Jongjareonrak *et al*. (2006) noted that gelatin films with increased protein content exhibit increased film thickness and mechanical properties. Denavi *et al*. (2009) described that the edible film of soy protein is more flexible than other protein films from plant sources.

Spice bioactives and their antimicrobial activities

The addition of bioactive compound directly to food packaging material exerts antimicrobial activity against the targeted microorganisms and prevent the oxidative degradation which results in the shelf-life extension of the food (Manzanarez-Lopez *et al*. 2011). Bioactive compounds from various spices and their antimicrobial activity are given in Table 1. Incorporation of the bioactive compound in packaging material altered the thermal, morphological and mechanical property of the edible film. Ramos *et al*. (2014) noted that bioactive compounds of spices act against the lipid auto-oxidation in the food.

Basil

The main constituent of basil essential oil (*Ocimum basilicum* L.) is linalool, followed by epi-a-cadinol, α-bergamotene and c-cadinene (Hussain *et al*. 2008). Lee *et al*. (2005) noted that eugenol and 4-allylphenol as the main constituents responsible for the antioxidant activity of the volatile extract of basil. Antimicrobial property of basil essential oil is mainly due to the presence of higher content of linalool.

Cinnamon

Vallverdu-Queralt *et al*. (2014) noted that the major bioactive compounds of cinnamon (*Cinnamomum* spp.) include cinnamic acid, cinnamyl aldehydes, protocatechuic acid, rutin, quercetin and epicatechin. Cinnamaldehyde is reported to exhibit antibacterial activity against *Staphylococcus aureus*, *Bacillus cereus*, *Escherichia coli*, *Salmonella anatum* and *Listeria monocytogenes* (Shan *et al*. 2007). El-Baroty *et al*. (2010) reported that cinnamaldehyde and eugenol are the most active antioxidant and antibacterial compounds in the cinnamon bark oil.

Clove

Clove (*Syzygium aromaticum*) contains various antioxidant substances and phenolic components which can potentially be used in the food products (Zengin & Baysal 2015). Eugenol is the compound mainly responsible for the antioxidant property of the clove extract. Bioactive compounds of clove include eugenol, α-cubebene, iso-eugenitol, α-copaene, β-caryophyllene, β-bipinene (Harlina *et al*. 2018). Lee & Shibamoto (2001) reported that the other major constituents of clove in addition to eugenol are eugenol acetate and β-caryophyllene. Eugenol in clove delays the lipid oxidation activity (Krishnan *et al*. 2014).

Coriander

The main bioactive compounds of coriander (*Coriandrum sativum* L.) are quercetin, kaempferol, apigenin and rhamnetin. Basilico & Basilico (1999) reported that coriander essential oil exhibit inhibitory effects on the mycelial growth and toxic substances produced by *Aspergillus ochraceus*. Meena & Sethi (1994) reported that coriander essential oil has the potential to control *Mycoderma* sp., *Lactobacillus acidophilus, Saccharomyces cerevisiae, Aspergillus niger* and *Bacillus cereus*. Caffeic acid, a phenolic compound in coriander is responsible for its antioxidant activity (Meloa *et al*. 2005). A new molecule (Heneicos-1-ene) responsible for radical scavenging activity was identified in coriander foliage and reported to exhibit comparable radical scavenging activity with BHA at 200 ppm level (Priyadarshi *et al.* 2018).

Cumin

Alcoholic extract of cumin (*Cuminum cyminum* L.) and its essential oil shown antimicrobial activity against *Klebsiella pneumoniae* ATCC 13883 (Derakhshan *et al*. 2007). 3-caren-10-al, cuminal and 2-caren-10-al are the bioactive compounds involved in the antifungal activity of cumin essential oil. Chemovar of cumin is responsible for the higher antioxidant activity of cumin essential oil (Ghasemi *et al*. 2018).

Fennel

Trans-anethole is the main component of fennel (*Foeniculum vulgare* Mill) followed by estragole, limonene and fenchone (Diao *et al*. 2014). Antioxidant and antimicrobial activity of fennel is mostly due to the higher concentration of trans-anethole (Shahat *et al*. 2011; Senatore *et al*. 2013). Fennel essential oil was reported to possess antifungal activity by reducing the growth of mycelium and germination of *Sclerotinia sclerotiorum* (Soylu *et al*. 2007).

Garlic

The major bioactive compounds of garlic (*Allium sativum* L.) are diallyl disulfide, S-allyl-cysteine, diallyl thiosulfonate (allicin), E/Z-ajoene, diallyl sulfide, S-allyl-cysteine sulfoxide (alliin) and diallyl trisulfide (Kodera *et al*. 2017; Mansingh *et al*. 2018; Yoo *et al*. 2014). The major phenolic compounds found in garlic are rutin, quercetin, pyrogallol, protocatechuic acid, gallic acid and β-resorcylic acid (Nagella *et al*. 2014). Biological activity of the garlic is mainly due to organosulfur compound allicin. Allicin has

Table 1. Bioactive compounds from spice essential oils and their antimicrobial activity against several microorganisms (Froiio *et al*. 2019)

Spice essential oil	Bioactive compound	Microorganisms
Cinnamomum osmophloeum	Linalool	*Aspergillus niger, Escherichia coli, Staphylococcus aureus*
(Cinnamon)	Trans-Cinnamaldehyde	*Antrodia taxa, Coriolus versicolor, Lenzites betulina, Oligoporus lowei, Pycnoporus coccineus, Trichaptum abietinum*
	Carvacrol, Eugenol	*Phaeolus schweinitzi, Laetiporus sulphureus, Fomitopsis pinicola*
	Eugenol	*Bacillus subtilis, Campylobacter jejuni, Escherichia coli, Fusarium graminearum, Fusarium proliferatum, Klebsiella pneumoniae, Listeria monocytogenes, Proteus vulgaris, Pseudomonas aeruginosa, Salmonella enteritidis, Staphylococcus aureus*
Coriandrum sativum L. (Coriander)	α-Pinene, Linalool	*Staphylococcus aureus, Saccharomyces cerevisiae, Listeria monocytogenes, Escherichia coli*
	Linalool	*Staphylococcus aureus, Rhodotorula, Geotrichum, Aspergillus niger*
	E-2-decanal	*Staphylococcus aureus, Saccharomyces cerevisiae, Listeria monocytogenes, Escherichia coli*
Curcuma longa L. (Turmeric)	Turmerone	*Bacillus cereus, Escherichia coli*
Ocimum basilicum L. (Basil)	Linalool	*Staphylococcus aureus, Yersinia enterocolitica, Aspergillus niger, Rhodotorula, Lactobacillus plantarum, Listeria monocytogenes, Escherichia coli, Pseudomonas aeruginous, Salmonella typhimurium*
Origanum spp. (Oregano)	Neral	*Fusarium proliferatum*
	Geranial	*Fusarium graminearum*
	Carvacrol, Eugenol	*Aspergillus niger, Escherichia coli, Geotrichum, Rhodotorula, Lactobacillus plantarum, Salmonella typhimurium, Staphylococcus aureus, Y. enterocolitica,*
	Thymol	*Listeria monocytogenes*
	Carvacrol	*Staphylococcus aureus*
Pimpinella anisum (Anise)	Trans-anethole	*Yersinia enterocolitica, Staphylococcus aureus, Salmonella typhimurium, Lactobacillus plantarum, Geotricum candidum, Aspergillus niger*
Rosmarinus officinalis L. (Rosemary)	Camphor/1,8-Cineole/ Borneol	*Aeromonas hydrophila, Escherichia coli, Listeria monocytogenes, Pseudomonas fluorescens, Salmonella enteritidis, Staphylococcus aureus, V. parahemolyticus*
	1,8-Cineole, Borneol, Camphor, Myrcene, Verbenone, α-Pinene, β-Pinene	*Bacillus subtilis, Escherichia coli, Klebsiella pneumoniae, Staphylococcus aureus*
Syzygium aromaticum L. (Clove)	Carvacrol, Eugenol	*Fusarium proliferatum, Fusarium graminearum*
	γ-Terpinene, Thymol, Carvacrol	*Pseudomonas fluorescens*
	Eugenol	*S. typhimurium*
Thymus vulgaris L. (Thyme)	Camphor	*Salmonella typhimurium*
	1, 8-Cineole, α-Pinene, β-Pinene	*Staphylococcus aureus*
	Thymol	*Listeria monocytogenes, Escherichia coli, Salmonella typhimurium, Staphylococcus aureus*

antimicrobial property and also prevents lipid oxidation (Lanzotti *et al*. 2014).

Ginger

Gingerols, paradols and shogaols are the major phenolic compounds present in the ginger (*Zingiber officinale*) (Prasad & Tyagi 2015). The most active antibacterial components in ginger rhizome oil are β-sesquiphellandrene, caryophyllene and zingiberene (El-Baroty *et al*. 2010). Manasa *et al*. (2013) reported that 6-gingerol is the major bioactive compound present in the ginger. Antimicrobial properties of the ginger are desirable for edible packaging.

Nutmeg

Arshad *et al*. (2020) reported that the major compounds in nutmeg (*Myristica fragrans* Houtt) include α-terpinolene, β-pinene, γ-terpene, α-longipinene and safrole. Nutmeg oleoresin contains considerable amounts of α-terpineol, α-pinene, carane, myristicin and limonene. Nutmeg is reported to exhibit antibacterial and antifungal activity against *Staphylococcus aureus* and *Aspergillus niger* (Gupta *et al*. 2013). Nakai *et al*. (2003) reported that the antioxidant property of the nutmeg is due to catechol produced by the nutmeg lignan after absorption.

Oregano

Origanum essential oil contains γ-terpinene, *p*-cymene, thymol and carvacrol. The essential oil of oregano also has antimicrobial, antioxidant, antiviral and anticancer activity (Beltran *et al*. 2016; Kaefer *et al*. 2008; Guldiken *et al*. 2018). Kavoosi *et al*. (2013) described carvacrol incorporated gelatin films exhibited an excellent antioxidant property and antibacterial property against both gram-negative and gram-positive bacteria.

Rosemary

The rosemary extract (*Rosmarinus officinalis* L.) is used as a natural food antioxidant in pork sausage, large yellow croaker and chicken (Georgantelis *et al.* 2007; Bolumar *et al*. 2011; Li *et al*. 2012). Carnosol, ursolic acid, carnosic acid, rosmaridiphenol and rosmanol are the phenolic diterpenes responsible for the antioxidant property of rosemary extract (Georgantelis *et al*. 2007).

Star anise

Star anise (*Illicium verum*) has various beneficial functions such as antioxidant, antimicrobial and insecticidal activities (Zhang *et al.* 2018). Trans-anethole, estragole, and limonene are responsible for the antimicrobial properties of star anise essential oil (Wang *et al*. 2011). Therefore, star anise essential oil has the potential to be used as an alternative to synthetic compounds as a natural antimicrobial in edible food packaging.

Tarragon

Chaleshtori *et al*. (2013) reported that the major bioactive compounds in tarragon (*Artemisia dracunculus*) are methyl chavicol, trans-ocimene, z-β-ocimene, limonene and α-pinene. Antioxidant activity of tarragon essential oil is due to the high level of methyl chavicol. Ayoughi *et al*. (2011) reported that linalool, limonene, spathulenol and eugenol are the compounds associated with the antioxidant activity of tarragon essential oil. Behbahani *et al*. (2017) stated that linalool is responsible for the antibacterial and antifungal activity of tarragon essential oil.

Thyme

The essential oil from thyme (*Thymus vulgaris* L.) has a higher content of thymol and carvacrol, which is responsible for its antioxidative and antimicrobial properties (Marino *et al*. 1999; Sacchetti *et al*. 2005). Burt *et al*. (2005) reported that carvacrol and thymol in thyme essential oil exhibited favourable bactericidal and bacteriostatic properties. Thyme essential oil possesses an antagonistic effect against *Botryodiplodia theobromae* Pat. and *Colletotrichum gloeosporioides* Penz.

Essential oil and their constituents in edible packaging

Spice extracts or its essential oils are reported to exhibit a broad spectrum of antimicrobial activities which make them a suitable candidate for edible packaging. Table 2 shows various spice constituents which are generally used in edible packaging and the use of spice essential oils as a natural antimicrobial in edible packaging of food is given in Table 3.

Clove and Cinnamon essential oil

Spice (*S. aromaticum* and *C. cassia*) incorporated edible film was found to inhibit the growth of the microbes through the diffusion of cinnamaldehyde and eugenol. Thus, it extended the shelf-life and was effective in controlling the lipid and protein oxidation in chicken meat (Chandra 2019). Corn starch film incorporated with clove and cinnamon essential oil exhibited antimicrobial activity against *Salmonella typhimurium* and *Lactococcus lactis* in raw beef. Eugenol in clove essential oil is identified as the most active antimicrobial component which resulted in a reduction in lipid oxidation (Radhakrishnan *et al*. 2015). Tamarind seed starch film incorporated with a spice mix of *S. aromaticum* and *C. cassia* has antioxidant and antibacterial properties. Hence, it can be used as good packaging material for food products (Chandra *et al*. 2016). Edible film supplemented with *S. aromaticum* (clove) and *C. cassia* (cinnamon) exhibited significant release of active compound about 42-51% for cinnamaldehyde and 38-48% for eugenol into mutton at the storage temperatures of 4-15°C. Cinnamaldehyde and eugenol diffusion increased the shelf-life of meat by one week at a storage temperature of 10°C and three weeks at a storage temperature of 4°C (Chandra *et al*. 2017).

Fish gelatin incorporated with cinnamon essential oil provides the flexible film with decreased water solubility and water vapour permeability (Salgado *et al*. 2013; Bahram *et al*. 2014; Teixeira *et al*. 2014; Wu *et al*. 2015). The composite film consisting of potato dextrose agar medium combined with gum arabic and cinnamon oil prevented the post-harvest anthracnose in the tropical fruits (papaya and banana) (Maqbool *et al*. 2011). Apple based films with cinnamon, allspice and clove bud oils exhibited antimicrobial activity against *Salmonella enterica, Escherichia coli* O157:H7 and *Listeria monocytogenes* (Du *et al*. 2009).

Clove and Oregano essential oil

The edible film incorporated with 0.5% (v/v) of clove and oregano oil extended the shelf-life of paneer by 4 days at 4 ± 1°C. Paneer packed in oregano essential oil-treated edible film showed more significant and desirable value for consumption than paneer sample packed in edible film treated with essential oil of clove (Karunamay *et al*. 2020).

Curcumin

Curcumin nano emulsion loaded gelatin composite film exhibited antimicrobial activity against *Escherichia coli* and *Salmonella typhimurium* in fresh broiler meat. Thus, the film extended the shelf-life of fresh broiler meat up to17 days (Khan *et al*. 2020).

Curcumin nano emulsion based pectin coating fused with cinnamon and garlic essential oils displayed the lowest total plate count (TPC), psychrophilic bacteria, yeast and mould growth in chilled chicken fillets. Reduction in microbial spoilage increased shelf-life of chicken fillets up to 12 days (Abdou *et al*. 2018).

Fennel extract

Guar gum-based edible coating fused with ethanolic and methanolic extract of fennel extended the shelf-life of lemons up to 180 days at 10°C (85% relative humidity) without any loss in phytochemical components and also delayed ripening process in the lemons (Naeem *et al*. 2019).

Garlic and pepper powder

Whey protein-based edible film fused with garlic and pepper powders displayed improved mechanical and barrier properties. At the end of the storage test, allicin (81%) and piperine (37%) was retained in the spiced film (Ket-On *et al*. 2016).

Garlic/Oregano and ginger essential oil

Achira starch-based edible coating containing garlic/oregano oils on double cream cheese

Table 2. Spice extracts or its essential oil incorporated in edible packaging (Valdes *et al*. 2015b)

Spice constituent	Polymer	Effect on food packaging
Italian (lemongrass and oregano) and Asian spice EOs (citral, lemongrass and nutmeg)	Polycaprolactone/Alginate, Methylcellulose	Antibacterial effect on pre-cut broccoli
Clove bud, cinnamon and allspice EOs	Edible apple film	Antimicrobial activity
Ginger, clove and cinnamon (EOs)	Polypropylene	Antioxidant
Cinnamon, clove and red pepper powders	Cassava starch	Antimicrobial effect on bread slices
Cumin and cinnamon (EOs)	Whey protein	Antimicrobial activity on fresh beef
Cinnamon EO	Cassava starch	Antimicrobial
	Cellulose acetate	Alteration of microstructures and mechanical properties
	Chitosan	Antimicrobial
	Polypropylene coated with an organic-based formulation with EO	Antifungal, antimicrobial
	Polypropylene	Sensory evaluation: increase in shelf-life from 3-10 days
	Self-adhesive PP active label inside a Polyethylene terephthalate(PET) tray	Antioxidant, antifungal and inhibition of oxidative enzymes
Cinnamon EO fortified	Polypropylene	Anti-mycotoxigenic, antifungal
Cinnamon EO microencapsulated	Low-density polyethene-Polypropylene	Insect-repelling agent to protect food from Indian meal moth (*Plodia interpunctella*)
Cinnamon EO nanoliposomes	Fish gelatin	Antimicrobial stability and decrease of release rate
Clove EO	Bagasse/Polyvinyl alcohol/Glycerol (Trays)	Antimicrobial
	Cassava and fish protein	Antimicrobial/antioxidant
	Chicken feather protein/gelatin	Antimicrobial and antioxidant activity on smoked salmon
	Chitosan/ gelatin	Antimicrobial on fish during chilled storage
	Sunflower protein	Antimicrobial, antioxidant and lipid oxidation on sardine patties
Clove EO (coarse and nanoemulsion)	Polyethylene glycol/ methylcellulose	Antimicrobial activity on sliced bread
Ginger extract	Fish skin gelatin/ glycerol 30% (w/w)	Antioxidant, physical and mechanical changes
Turmeric oleoresin encapsulated	Gelatin: gum Arabic	Improve stability to light

Table 3. Use ofspice essential oils as natural antimicrobials in edible packaging (Sanchez-Gonzalez *et al.* 2011)

Food group	Food	Essential oil	Microorganisms
Cereals	Maize grain	Thyme, Clove, Anise	*Aspergillus*
Dairy	Mozzarella cheese	Clove	*Listeria monocytogenes*
Fish	Mediterranean swordfish fillet	Thyme	Natural flora
	Salmon fillet/cod fillet	Oregano	*Photobacterium phosphoreum*
Fruit	Strawberry	Thyme	*Rhizopus, Botrytis*
	Peach		*Rhizopus, Penicillium*
Meat	Mortadella (bologna-type sausage)	Thyme, Rosemary	Natural flora
	Minced mutton	Clove	*Listeria monocytogenes*
	Minced beef	Oregano	Natural flora
		Thyme	*Escherichia coli*
	Hot dog	Thyme, Clove	*Listeria monocytogenes*
	Cooked chicken sausage	Mustard	*Escherichia coli*
	Beef fillet	Oregano	*Listeria monocytogenes*
Vegetables	Tomato paste	Thyme, Clove	*Aspergillus*
	Lettuce	Oregano	Natural flora
	Eggplant salad	Oregano	*Escherichia coli* O157:H7
	Carrot	Thyme	Natural flora

displayed the lowest weight loss values and it could control variations in the physico-chemical properties such as hardness, water activity and colour. It preserved the microbiological characteristics and sensory quality of the double cream cheese after 42 days of storage at 5°C (Molina-Hernandez *et al*. 2020).

Alginate film incorporated with garlic essential oil has a significant inhibitory effect on *B. cereus* and *Staphylococcus aureus* (Pranoto *et al*. 2005). Chitosan film incorporated with nanoencapsulated garlic essential oil (2% v/v) exhibited the peroxide value, thiobarbituric acid reactive substances, aerobic plate count of 0.37 meq/kg lipid, 0.47 mg malondialdehyde/kg and 3.69 log CFU/g at the end of 50th day of vacuum-packed sausages and it has no significant differences in the sensory properties (Esmaeili *et al*. 2020).

Chitosan film incorporated with ginger oil inhibited the growth of *E. coli* in chicken meat due to the active components in ginger (shogaol and gingerol) (Irawan *et al*. 2017).

Rosemary extract

Nanoemulsion based gelatin and chitosan coating fused with a mixture of rosemary extract and ε-poly-L-lysine (ε-PL) exhibited the lowest total viable bacterial counts (TVC), mould and yeast counts and thiobarbituric acid reactive substance (TBARS) values under 4°C refrigeration over 16 days in ready-to-eat carbonado chicken (Huang *et al*. 2020).

Star anise essential oil

Nanoemulsion prepared with soy protein isolate (SPI), polylysine, nisin and star anise essential oil showed good stability and better antimicrobial effect in ready-to-eat Yao meat products for 45 days. Nanoemulsion based edible coating has no effect on the moisture content of the meat samples for 20 days and shelf-life was extended from 8 to 16 days with good retention of colour and odour (Liu *et al*.2020). Whey protein edible film incorporated with anise essential oil at 4% (v/v) exhibited antimicrobial activity against major moulds (*Aspergillus flavus*, *Penicillium* sp.)

found on dried fish (*Decapterus maruadsi*) and shelf-life was extended up to 21 days at 30°C (Matan 2012).

Tarragon essential oil

Incorporation of nano-encapsulated (NP) tarragon essential oils (TEO) in the chitosan-gelatin edible coating could extend the shelf-life of fresh pork slice by eight days and also resulted in an improved antioxidant, antibacterial and sensory properties (Zhang *et al*. 2020).

Thyme oil

Thyme essential oil incorporated starch-gellan films exhibited antifungal activity against *Botryotinia fuckeliana* and *Alternaria alternata.* To control the loss of essential oil, lecithin was encapsulated in the starch-gellan film (Sapper *et al*. 2018).

Toxicological effects of some spice constituents

Estragole in the essential oil of *Ocimum basilicum* exhibited carcinogenic property in rats and mice (Miller *et al*. 1983; Anthony *et al*. 1987). Toxic effects of bioactive compounds such as carvacrol, thymol, cinnamaldehyde and carvone was observed at cellular level (Stammati *et al*. 1999). Ginger has some minor antagonistic effect. In a clinical study, 12 healthy volunteers were given 400 mg of ginger orally for two week (3 times/day). In initial 2 days, mild diarrhoea was observed while dosage greater than 6 g can cause gastric irritant (Ali *et al.* 2008). Safrole present in black pepper, cinnamon and nutmeg is identified as a weak hepatocarcinogen. It can be related to formation of safrole DNA adducts (Liu *et al.* 1999). Aydin *et al.* (2005) noted that thymol and γ-terpinene when used at concentration higher than 0.2 mM induced DNA damage. Carvacrol induced DNA damage at a concentration of 0.01 mM, where it is non-toxic at concentration <0.05 mM. Hence essential oils at lower concentration have higher beneficial effects whereas higher concentration may cause serious toxicological effects and allergic reactions.

Advantages of spice edible packaging

Spices and its essential oil contains volatile constituents which are mainly responsible for health benefits such as antimicrobial, digestive stimulant, antioxidant, anti-inflammatory activites (Kulisic *et al*. 2004). Decrease in the diffusion rate of antimicrobial compound of spice essential oil was observed in edible packaging. Thus higher concentration of active compound was seen on product surface. Hence it reduced microbial contamination and extended the shelf-life of product (Quintavalla *et al.* 2002; Kristo *et al*. 2008).

Limitations of edible packaging

The commercial use of edible films and coatings has many limiting factors such as the complexity of the production process and the huge investment necessary to install new film production or coating equipment (Han 2014). The other limitations are while labelling the final product food manufacturers should include all the ingredients used in film formation on their label and no-objection notifications have to be obtained by edible film and coating material suppliers (Han 2001; Han 2002; Krochta 2002). Laboratory-scale film making methods cannot make large-sized edible films (> 25 cm) and it also takes very long drying time (2-3 days) and error in thickness control. Hence, it is unbefitting for industrial scaleup. It is necessary to develop a continuous film making equipment with high production rate and low production time for making a scaled-up production (Zhang *et al.* 2014). Essential oils are incorporated in edible films to improve the antimicrobial properties because essential oils are generally regarded as safe (GRAS). A major limitation in the usage of spice essential oil as a food preservative is their aroma which affects the organoleptic characteristics of the food product. By trained individuals or by using instrumental analysis, sensory tests need to be carried out to meet product acceptance and customer satisfaction (Sanchez-Gonzalez *et al.* 2011). Gutierrez *et al.* (2009) reported that ready-to-eat lettuce and carrot treated with thyme and oregano essential oil was rejected at the end of storage due to development of strong aroma of the spices at sensory test. While drying the edible film, significant loss of volatile compounds occur. The low stability and volatility of spice essential oil against light and gaseous concentration during processing and storage limit their usage as a preservative. Micro and nano-encapsulation results in the controlled release of EOs onto food surfaces and also increases the film stability against environmental factors (Sanchez-Gonzalez *et al.* 2011).

Conclusion

Environmental issues caused by the usage of plastic packaging are the accumulation of plastic wastage on land which reduces soil fertility, emits hazardous volatile organic compounds during incineration etc. Considering these environmental effects and to reduce the plastic usage, edible packaging of food has been developed. The spices contain various bioactives like flavonoids, terpenoids and polyphenol. The incorporation of spices or essential oil in edible packaging exert antioxidant, antimicrobial activity and also extend the shelf-life of the product. Spice bioactives also replaces the usage of synthetic preservatives in food. However, in comparison with plastic packaging materials, edible packaging materials are highly sensitive to water, permeable to gaseous concentration and unstable thermally and mechanically. These negative effects have an impact on the scaling-up of edible packaging. Laboratory-scale production of edible packaging has some disadvantages which should be addressed before industrial level production. Therefore, further research should be carried out on edible packaging to facilitate their large-scale production and utilization as packaging material.

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