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**

Valverdu-Queralt et al. (2014) noted that the major bioactive compounds of cinnamon (Cinnamomum spp.) include cinnamic acid, cinnamyl aldehydes, protocatechuic acid, rutin, quercetin and epi-catechin. 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-cubebeene, 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 (Froio 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, Pyenopus coc-cineus, 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, Escherichia coli, Pseudomonas aeruginous, Aspergillus niger |
| Rosmarinus officinalis L. (Rosemary) | Camphor/1,8-Cineole/ | Aeromonas hydrophila, Escherichia coli, Listeria monocytogenes, Pseudomonas fluorescens, Salmonella enteritidis, Staphylococcus aureus, V. parahaemolyticus |
|                           | Borneol            | Bacillus subtilis, Escherichia coli, Klebsiella pneumoniae, Staphylococcus aureus |
|                           | 1,8-Cineole, Borneol, Camphor, Myrcene, Verbenone, α-Pinene, β-Pinene | |
| 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 to 17 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
| Spice constituent | Polymer | Effect on food packaging |
|-------------------|---------|-------------------------|
| Italian (lemon grass 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 | Sensory evaluation: increase in shelf-life from 3-10 days |
| | Polylactic acid | Antifungal, antimicrobial |
| | 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 polyethylene-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 |
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 nanocapsulated 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.*).

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**Table 3. Use of spice 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                      | Thyme, Rosemary                | *Listeria monocytogenes*     |
|             | Minced beef                        | Clove                          | *Escherichia coli*           |
|             | Hot dog                            | Oregano                        | *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*              |
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). Saffrole present in black pepper, cinnamon and nutmeg is identified as a weak hepatocarcinogen. It can be related to formation of saffrole 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 activities (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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