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Review on Use of Bioactive Compounds in Some Spices in Food Preservation

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Abstract
Spices contain chemical substances such as polyphenols, quinines, flavonols/flavonoids, alkaloids, polypeptides or their oxygen-substituted derivatives. These bioactive compounds are used in food preservation through their antioxidants and antimicrobials activities. The bioactive compounds extracted from them prevent the oxidation of different meat products, oils and dairy products. These compounds also used for increasing shelf life of meat and meat products, milk and milk products, and fruits and fruit products through killing or retarding the growth of both pathogenic and spoilage microorganisms. In addition, they are used as insecticides which provide an opportunity to replace the synthetic compounds which affect human health. Generally, because of their preventing ability and health benefits, bioactive compounds found in spices can be used in food industries as preservative substances.
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Introduction

Spices origin has been known to date back to ancient times in Egypt as valuable trade items. The advantage of these spices increasing in Middle East and spread to the Mediterranean and Europe. Now day spices top ten producing countries as at FAO (2011) report were India, Bangladesh, Turkey, China, Pakistan, Iran, Nepal, Colombia, Ethiopia and Sri Lanka. Ethiopia is a homeland for many spices, such as korarima (*Aframonum korarima*), long red pepper, black cumin, white cumin/bishops weed, coriander, fenugreek, turmeric, sage, cinnamon and ginger (International Trade Centre, 2010).

Spices could be obtained from any part of plant as fresh or dried seeds, kernels, bulbs, stalk, roots, barks, leaves, pods or buds. The medicinal value of them, which include leaves (coriander, mint), buds (clove), bulbs (garlic, onion), fruits (red chili, black pepper), stem (cinnamon), rhizomes (ginger), star anise, cinnamon (bark) and other plant parts, have been defined as plant substances from indigenous or exotic origin, aromatic or with strong taste, used to enhance the taste of foods. Spices are important bio-nutrients for both food ingredients and nutritional supplements. Because of this they are said to be pungent or aromatic substances which are used as additives for the purpose of flavoring, coloring and preserving foods (Dalby, 2002; Abishek *et al*., 2009). However, the use of these spices in food preservation as natural preservative and their advantage over synthetic antioxidants and antimicrobials are not aware. Therefore, the objective of this is to review the use of bioactive compounds in spices in food preservation.

Bioactive Compounds Constituent of Spices

Spices contain chemical substances such as polyphenols, quinines, flavonols/flavonoids, alkaloids, polypeptides or their oxygen-substituted derivatives (Cowan, 1999; Perumalla and Hettiarachchy, 2011; Negi, 2012). Spices such as ginger contain bioactive compounds such as gingerols, shogaols, paradols and zingerone that produce a 'hot' sensation in the mouth. From three of these compounds, gingerol is the most abundant and active compound in ginger. Curcumin and Piperine are the major bioactive compounds found in turmeric and black pepper, respectively (Kunnumakkara *et al*., 2009; Li *et al*., 2011; Puvaca *et al*., 2014). However, both of them contain other many phytochmicals in which their contents and bioactivities vary depend on species, varieties and geographical conditions.

To date, approximately 235 compounds, primarily phenolics and terpenoids, have been identified from various species of turmeric, including twenty two diarylheptanoids and diarylpentanoids, eight phenylpropenes as well as other phenolics (Li *et al*., 2011). From those compounds curcuminoids (mostly curcumin) and essential oils (primarily monoterpenes) are the major bioactive constituents showing different bioactivities.

Volatile oil in Nigela Sativa contains active basic components such as thymoquinone, dithymoquinone and thymohydroquinone (Güllü & Gülcan, 2013; Kaya *et al*., 2003). Thymoquinone, which is one of the most important bioactive components of *N. sativa* exists as a volatile oil in a proportion of 18.4%–24.0% (Ali & Blunden, 2003; Burits & Bucar, 2000; Yüncü *et al*., 2013). However, other analyses have indicated that the concentration of thymoquinone is 52.6 mg/100g (Tüfek *et al*., 2015).

Shan *et al*. (2014) found that cloves have the highest amount of flavonoids (366.5 as mg per 100 g), followed by caraway (171.9), coriander (167.2) and rosemary (37.8). The abundant and most biologically active compound in clove is eugenol and that of caraway are carvone and limonene. Deepa *et al.* (2013) reported that cardamom and coriander were good sources of flavonoid and scavengers of free radicals. Badei *et al*. (2002) reported that the threshold level (in cookies) of the volatile oils of cardamom and cinnamon was 0.05%, while that for clove volatile oil was 0.075%. The bioactive compounds of essential oils found from cinnamon bark are trans-cinnamaldehyde, eugenol and linalool, which are representative of almost 82.5% of total compounds (Asimi *et al*., 2013).

Table 1. Major bioactive compounds in some spices/herbs

S.No	Name of spices/herbs	Major bioactive compounds	References
1	Ginger	Shogaols, paradols and zingerone	Choudhari and Kareppa, 2013; Kim *et al*., 2002; Wohlmuth *et al*., 2005
2	Turmeric	Curcumin, demethoxycurcumin and curcuminoid	Salem *et al*., 2014; Sahne *et al*. 2016; Tajik *et al*., 2008
3	Black pepper	Piperine, Piperidines and pyrrolidines	Dawid *et al*., 2012; Puvaca *et al*., 2014
4	Black cumin	Thymoquinone, dithymoquinone and thymohydroquinone	Güllü & Gülcan, 2013; Kaya *et al*., 2003
5	Caraway	Carvone and limonene	Sedláková *et al*., 2003
6	Clove	Eugenol	Pino *et al*., 2001; Raina *et al*., 2001; Zachariah *et al*., 2005
7	Cinnamon	Trans-cinnamaldehyde, eugenol and linalool	Asimi *et al*., 2013; Tabak *et al*., 1996
8	Cardamom	Limonene, Cineole and α-terpinyl acetates	Agbor *et al.* 2001
9	Rosemary	α-pinene, camphor, cineole and camphene	Derwich, *et al.* 2011

Antioxidant and Antimicrobial Activities of Bioactive Compounds

Antioxidants are substances that prevent oxidation of other compounds or neutralize free radicals. Plants such as fruits, vegetables, spices and herbs are rich sources of antioxidants. Antioxidants from spices are a large group of bioactive compounds which consist of flavonoids, phenolic compounds, sulfur-containing compounds, tannins, alkaloids, phenolic diterpenes, and vitamins (Peter, 2004; Charles, 2013; Yesiloglu *et al*., 2014; Srinivasan *et al*., 2014; Choi and Cha, 2014; McCormick, 2017). Spices such as turmeric (*Curcuma longa*), garlic (*Allium sativum*), ginger (*Zingiber officinalis*), black cumin (*Nigella sativum*), clove (*Syzygium aromaticum*), red pepper (*Capsicum annuum*) and black pepper (*Piper nigrum*) contain several natural antioxidant biomolecules either water-soluble or lipid-soluble.

Antimicrobials derived from plants sources are phytochemicals which are important for the proper functioning of the plant. These antimicrobial compounds are helped the plants as defense mechanism to protect them from plant pathogens and other predators. Phytochemicals in spices are broadly grouped into phenolic compounds, terpenoids and essential oils, alkaloids and polypeptides. It is suggested that the hydrophobicity of the essential oils and their components is an important characteristic that enables the essential oils to accumulate in the lipid bilayer of the bacterial cell membrane and mitochondria, disturbing the cell structures and rendering them more permeable (Benchaar *et al*., 2008; Solorzano-Santos and Miranda-Novales, 2012).

Table 2. Antioxidant activities of bioactive compounds in spices/herbs

Name of spices/herbs	Bioactive compounds	Their function	Comparable with synthetic antioxidant/antimicrobial	References
Ginger	Gingerol	Inhibited hydroxyl radicals	higher antioxidant activity than quercetin	Stoilova *et al.*, 2007
Black cumin	Thymoquinone	As antioxidant activities	Higher than butylated hydroxyanisole and butylated hydroxytoluene	Singh *et al.*, 1998; Kapoor *et al.*, 2010
Cinnamon	Cinnamaldehyde	Scavengers of peroxide radicals	Comparable to synthetic antioxidants	Shahid *et al.*, 2018; Wu *et al.*, 1994;
Clove	Eugenol and eugenyl acetate	Antioxidant activity against hydroxyl radicals and acts as an iron chelator	Greater than BHA, BHT, TBHQ, PG and OG	Ghadermazi *et al.*, 2017; Hossain *et al.*, 2008; Jirovetz *et al.*, 2006
N. sativa	Thymoquinone and dithymoquinone	decreases lipid peroxidation and increases antioxidant enzymes	Greater than synthetic antioxidants	Yakup, 2007; Al-Mahasneh *et al.*, 2008; Abdulazeez *et al.*, 2015

Table 3. Antimicrobial activities of bioactive compounds in spices/herbs

Spices/herbs	Bioactive compounds	Effective against microorganisms	References
Clove	Eugenol and beta caryophyllene	Antibacterial activity against *Escherichia coli, Listeria monocytogenes, Salmonella enterica, Campylobacter jejuni, Staphylococcus aureus, Bacillus subtilis* and *Saccharomyces cerevisiae*	De *et al.*, 1999; Chaieb *et al.*, 2007; Singh, 2018
Clove	Clove oil and eugenol	Antifungal activity against rye bread spoilage fungi, *Rhizoctonia solani Cladosporium herbarum, Penicillium glabrum, P. expansum, Fusarium verticilloides* and *A. niger*	Lee Sang *et al.*, 2003; Martini *et al.*, 1996; Suhr and Nielsen, 2003; Veluti *et al.*, 2004
Cinnamon	Cinnamaldehyde	*Listeria monocytogenes, Staphylococcus aureus* and *Salmonella enterica*	Shan *et al.*, 2009
Coriander leaves and seeds	It's crude extract	*Escherichia coli, Bacillus subtilis and Salmonella typhi*	Elgayyar *et al.*, 2001
Ginger	It's crude extract	Staphylococcus aureus, Streptococcus pyogenes; *E. coli* and strengthening immune system of fish	Awad & Awaad, 2017; Sebiomo *et al.*, 2011; Sikrodia *et al.*, 2018; Snuossi *et al.*, 2016
Garlic	It's crude extract	Proteus mirabilis and Escherichia coli	Petropoulos *et al.*, 2018

Bioactive Compounds in Preventing Food Oxidation

Oxidation is one of the major factors in food deterioration and reduces its nutritional quality during processing and storage time. Moreover, the free radicals produced from oxidation process are dangerous for human health. However, addition of antioxidants is a useful way to prevent the formation of these harmful compounds. In recent years, synthetic antioxidants such as Butylated hydroxyanisole (BHA), Butylated hydroxytoluene (BHT), tertiary butyl hydroquinone (TBHQ) and propyl galates have been widely used in food industry (Stoilova *et al.*, 2007). However, they have been reported to have demonstrated various adverse effects on the human health including allergy, headache, asthma, cancer and dermatitis (Bondi *et al.*, 2017; Lobo *et al.*, 2010; Shasha, 2014). In contrast natural antioxidants do not have harmful effect and also can improve human health compared to synthetic antioxidants (Bober *et al.*, 2018; Gao *et al.*, 2012; Karaman *et al.*, 2014; Pokorny *et al.*, 2001; Segura Campos *et al.*, 2015).

Spices represent a potent tool for the food industry, thanks to their natural properties (Hyldgaard *et al.*, 2012). Indeed spices possess antioxidant capacity, mainly due to the presence of phenolic compounds. They exhibit antioxidant property by scavenging free radicals, chelating transition metals, quenching of singlet oxygen, and enhancing the activities of antioxidant enzymes (Rubió *et al*., 2013).

Alex and Eagappan, (2017) studied on the empirical effect of spices and herbs in the shelf life of dried indian anchovy fish. They concluded that the indigenous spices used, such as black pepper, turmeric and ajwain had chemical preservative and antioxidant properties. Among the three spices, black pepper in combination with ajwain was found to have the most effective preservation potential of sun-dried fish during storage. Essential oils (OEs) of clove used as a natural antioxidant significantly reduced the oxidation of soybean oil and replaced synthetic antioxidants to increase the safety of food systems (Ghadermazi *et al*., 2017). The antioxidant activity of clove bud extract and its major aroma components, eugenol and eugenyl acetate, were the most effective for retarding lipid oxidation and presented the highest antioxidant activity in raw pork (Shan *et al*., 2009).

The addition of rosemary or marjoram EOs at a concentration of 200 mg/kg in beef patties has been shown to reduce lipid oxidation, due to the EOs' antioxidant properties, thus improving the flavour of the patties (Mohamed and Mansour, 2012). It suggested that addition of coriander leaves to food would increase the antioxidant content and may have potential as a natural antioxidant and thus inhibit unwanted oxidation processes (Wangensteen *et al*., 2004). Shahid *et al*. (2018) did on the antioxidant capacity of cinnamon extract for palm oil stability. They concluded that the cinnamon extract proved effective in reducing the lipid oxidation of palm oil and it can be successfully used in place of synthetic antioxidants in food preparations.

Grains of *Black pepper* and the essential oil obtained from them contain compounds that have antimicrobial activity. It is a source of natural antioxidants that stop rancid fats, which is the task of a natural preservative (Abdulazeez *et al*., 2015). It is proposed that the *N. sativa* extract grown in Tunisia can be used as a natural antioxidant in *in vitro* and *ex vitro* environments, and as a food additive to prevent the organoleptic deterioration that occurs due to free radicals (Soumaya *et al*., 2012). Cardamom incorporated yoghurt had the highest anti-oxidant activity as measured by DPPH assay (Vijaylakhshmi *et al.* 2014).

Bioactive Compounds in Preventing Food Spoilage

Microbial pathogens in food may cause spoilage and contribute to food borne disease incidence, and the emergence of multidrug resistant and disinfectant resistant bacteria—such as *Staphylococcus aureus* (*S. aureus*), *Escherichia coli* (*E. coli*), and *Pseudomonas aeruginosa* (*P. aeruginosa*) have increased rapidly, causing the increase of morbidity and mortality (Miladi *et al*., 2016). Weak acids such as benzoic and sorbic acids (Brul and Coote, 1999), which are commonly applied in food industry as chemical preservatives to increase the safety and stability of manufactured food products on its whole shelf-life by controlling pathogenic and spoilage food-related microorganisms (De Souza *et al*, 2005), can result in the development of microbiological resistance (Silva and Domingues, 2017) and are restricted in many countries (Madsen, *et al.* 1995).

The search for cheap, non-toxic and natural food preservatives which could be used safely and effectively is an important factor for future food industry. Spices are natural sources having antioxidant and antimicrobial activity that offer an opportunity to replace synthetic preservatives in food, such as nitrates, which have been claimed to possess negative effect on human health (Anand and Sati, 2013). Combinations of probiotics with spices may provide further therapeutic properties. In-vitro studies that tested spices on the growth of selected probiotics showed that spices significantly enhanced the growth of probiotics while inhibiting pathogens (Be *et al.* 2009). Compounds isolated from different spices shows positive antimicrobial activity against some of the most common microorganisms that affect the food quality and decrease the shelf life of food (Tajkarimi. *et al.* 2010).

The use of spices EOs as natural preservatives in food industries meets the current consumer trends of "green","biological", "natural" and "no chemicals added" labels. The FDA (Food and Drug Administration) treats antimicrobial agents of natural origin as GRAS (Generally Recognized As Safe) type products, including plant products from which essential oils (EOs), oleoresins and natural extracts, as well as their distillates, are obtained (Burt, 2004; Newberne *et al*., 2000; Sauceda, 2011).

Meat and Meat Products

It has been shown that plant extracts are useful for reduction of pathogens associated with meat products. The application of thyme and cinnamon EOs in ham has been shown to significantly decrease the *L. monocytogenes* population (Dussaul *et al*., 2014). The shelf-life of mortadella and bologna sausages has been extended with the use of rosemary/thyme and oregano EOs, respectively (Viuda-Martos *et al*., 2010). García-Díez *et al*. (2016) reported the improved safety of dry-cured sausages through the antibacterial effect of garlic and oregano EOs against *Salmonella* spp., *L. monocytogenes* and *S. aureus*. At concentrations of 0.5% and 1% clove EO restricted the growth of *L. monocytogenes* in meat at both 30°C and 7°C (Vrinda Menon and Garg, 2001). In another study clove, cinnamon, cumin and oregano are effective against inoculated microorganisms on meat, particularly against gram positive and gram negative bacteria (Souza *et al*., 2006; Sema *et al*., 2007; Celikel and Kavas, 2008).

Combined use of EOs and starter cultures in the manufacture of traditional Chinese smoked horsemeat sausages showed that both EOs of spices (cinnamon, cloves, ginger and anise) and starter cultures (*L. sakei* and *S. xylosus*) inhibited the accumulation of biogenic amines, namely tryptamine, putrescine, cadaverine, histamine and tyramine, and the growth of enterobacteria. It is noteworthy that the inhibitory effects of EOs were stronger than those of starter cultures. Additionally, the synergistic effects between EOs and starter cultures against the accumulation of the above mentioned biogenic amines and the growth of enterobacteria were observed (Lu *et al*., 2015).

Krisch *et al*. (2010) conducted comparative study to investigate the antimicrobial effect of commercial herbs, spices and essential oils (fresh and dried garlic, onion, thyme, marjoram, and oregano) in minced pork. While fresh spices showed weak or no inhibition on viable cells of minced pork, some effects of essential oils were observed. Best shelf life values were obtained for pork meat added with garlic and marjoram oil. Antimicrobial activity studies of garlic oil against bacterial isolates from carp showed that, it had the strongest antimicrobial activities, followed by iso-eugenol, eugenol and then citral for increasing the shelf life of carp fillets, respectively (Mahmoud *et al*., 2007). Basil, clove, garlic, horseradish, marjoram, oregano, rosemary, and thyme have been used successfully to implement hurdle technology for protecting seafood from the risk of Vibrio parahaemolyticus contamination (Yano *et al*., 2006). A synergistic effect of treatment with anodicelectrolyzed NaCl solution, combined with eugenol and linalool, has been found to enhance shelf-life extension of coated semi-friedtuna (Abou-taleb and Kawai, 2008).

Hernández-Ochoa *et al*. (2014) studied on use of essential oils and extracts from spices in meat protection. The results showed that the essential oils with functional extracts were used on meat samples at three different concentrations: 750, 1,500 and 2,250 µL. The cumin essential oil produced a reduction of 3.78 log UFC/g with the application of 750 µL, the clove essential oil produced a reduction of 3.78 log UFC/g with the application of 2,250 µL and the cumin and clove functional extracts got a reduction of 3.6 log UFC/g. A relevant preservation effect for fresh chicken breast meat, stored at 4°C, was obtained by dipping meat in oregano oil, prior to packaging under MAP (Chouliara *et al*., 2007). Shelf life of carp fillets was extended fourfold by application of combined carvacrol + thymol with some other additives, compare to sterile 0.2% agar solution as a control (Mahmoud *et al*., 2007).

Dairy Products

Recently, some studies have recorded the efficacy of natural compounds, alone or in combination with other preservation methods, when directly applied to milk (Cava *et al*., 2007) or to cheese by spraying, immersing, or dusting the products. In line of this idea, Cinnamon, cardamom and clove oils inhibit the growth of yoghurt starter cultures more than mint oil; however, in other study mint oil was effective against Salmonella enteritidis in low-fat yoghurt (Burt, 2004).

The antimicrobial efficacy of the different EOs in dairy products can be influenced by several factors, such as the chemical composition of these products, the concentration in which the oils are used and the microorganisms that are intended to be reduced or eliminated. Comparing the anti-microbial effect of clove, cinnamon, bay and thyme EOs in different concentrations (0.1%, 0.5% and 1%) in low-fat and full-fat soft cheese, Smith-Palmer *et al.* (2001) found that 1% was the most effective concentration for all EOs. The anti-*Listeria monocytogenes* effect was more pronounced in the low-fat cheese, but clove EO at 1% was more effective in the two types of cheese. This essential oil, at the same concentration, was more active against *Salmonella* Enteritidis in full-fat cheese than in low-fat cheese. When used at a concentration of 0.5%, the population of *Salmonella* Enteritidis recovered in the low-fat cheese, but not in full-fat cheese.

In another study clove EO (0.5% and 1%) restricted the growth of *L. monocytogenes* in cheese both at 30°C and 7°C (Vrinda *et al*., 2001).

A new dairy product “Karishcum” obtained by adding Curcuma Longa (Curcumin or Turmeric) to classic Karish cheese at a rate of 0.3% (w/v) was realized in a study conducted by Hosny *et al*. (2011). A primary experiment was done to determine the correct percentage of Curcumin addition to cheese milk to get a good taste and a long shelf life. The behavior of pathogenic bacteria in the artificially contaminated product during cold storage for 14 days revealed that addition of the extract (0.3%) determined a reduction of bacterial counts of about 1 log of *S. typhimurium* and two log of *P. aeurogenosa* and *E. coli* 0157:H7.

Fruits and Fruit Products

Different studies have demonstrated the effectiveness of essential oils and their active compounds to control or inhibit the growth of pathogenic and spoilage microorganisms in both fresh-cut fruit and fruit juices. With the support of this idea, Raybaudi-Massilia *et al*. (2009) incorporated active compounds of herbs and spices into an alginate-based edible coating and applied on fresh-cut apples where they found a high effectiveness for reducing populations of inoculated *E. coli* O157:H7 during storage time.

Recently, the idea of using the potential antimicrobial effect of essential oils (Eos) has served as a basis for the development of innovative approaches to increase shelf-life of fresh-cut fruits and vegetables, referred to as minimally processed (MP) products (Patrignani *et al*., 2015), such as the use of EOs in addition to edible films (Maria *et al*., 2012). The more enlightened consumers show great interest in acquiring MP products, "easy to eat", and at the same time seeking to ensure that these products correspond to the concept of clean label, natural and environmentally "friendly".

Raybaudi-Massilia *et al*. (2008) investigated the combined effects of malic acid and essential oils of cinnamon, palmarosa, and lemongrass (0.3 and 0.7%) and their main active compounds on microbiological and physicochemical shelf-life of fresh-cut melon. The active compounds were incorporated into an alginate-based edible coating. Melon pieces were inoculated with a *S. enteritidis* (108 CFU/ml) culture before applying the coating. The incorporation of essential oils or their active compounds into the edible coating prolonged the microbiological shelf-life by more than 21 days. Recently, Campos *et al.* (2016) using thyme and sage EOs, in strawberries, in the head space of the package, observed the decreasing in the amount of fungi existing with these treatments, when compared with the control samples.

Use of Bioactive Compounds in Active Food Packaging

In packaged foods, growth and survival of common spoilage and pathogenic microorganisms are affected by a variety of intrinsic factors, such as pH and presence of oxygen or by extrinsic factors associated with storage conditions, including temperature, time, and relative humidity (Singh *et al*., 2003; Lòpez-Malo *et al*., 2005; Rydlo *et al*., 2006). So, to prevent growth of spoilage and pathogenic microorganisms in packed foods, several chemical preservation techniques have been used in the food industry as these authors reported (Davidson and Taylor, 2007; Farkas, 2007) and not only this, but also different alternatives methods like combination of natural and chemical preservatives have been also utilized.

Nowadays, smart packaging has gained increasing attention, for example, antimicrobial packaging, which can be applied to extend the shelf life of food and products (Appendini and Hotchkiss 2002; Quintavalla and Vicini 2002). Active packaging incorporated with natural extracts is a promising technology to extend shelf life of perishable food. The addition of bioactive compounds with antioxidant/antimicrobial properties directly to food or packaging materials depends primarily on their activity against the targeted microorganisms and oxidative degradation, and their ability to be released at controlled rate during storage and distribution, resulting in extension of food shelf-life (Manzanarez-L´opez *et al*., 2011).

Many active packaging materials have been developed in the last few years with bioactive compounds extracted from spices and herbs. Typically, in antimicrobial and antioxidant packaging systems, additives are incorporated in different ways (G´omez-Estaca *et al*., 2014; Manso *et al*., 2015). The use of spice extracts as active agents in food packaging has been suggested and studied since they provide antioxidant and antimicrobial properties to packaging materials (Sadaka *et al*., 2014) acting as potential alternatives to food synthetic preservatives (G´omez-Estaca *et al*., 2014).

The extraction method selected to obtain EOs from spices plays a key role in their composition and final quality, modifying their antimicrobial activity. Nevertheless, the current use of EOs extracted from spices in food packaging is still limited by their volatility and low stability against oxygen and light during processing and storage. Microencapsulation technologies have emerged as a promising alternative to control the release of EOs onto food surfaces and to increase stability against environmental factors.

Pires *et al*. (2009) developed a microbial sachet incorporated with allyl isothiocyanate. Its efficiency was tested against yeasts, molds, Staphylococcus sp. and psychrotrophic bacteria in sliced mozzarella cheese stored at 12°C ± 2°C. A reduction of 3.6 log cycles was observed in yeasts and molds counts in the mozzarella packed with antimicrobial sachet over 15 days of storage time. Ramos *et al*. (2012) reported the development of antimicrobial active films based on polypropylene by incorporating thymol and carvacrol at three different concentrations (4, 6 and 8 wt%) demonstrating their potential to be used as active additives.

Ojagh *et al*. (2010) reported that the use of a coating with chitosan and cinnamon essential oil improved trout fillet shelf life (16 days vs 10 days of the control) and in particular it enhanced texture, odor, and color. Similar results were also obtained for trout fresh fillets coated with gelatin enriched with cinnamon oil (1%, 1.5%, and 2%). In particular, experimental data indicated that the active coating can be suitable for preserving the fillets and maintain quality to an acceptable level (Andevari and Rezaei, 2011).

New active packaging materials consisting of self-adhesive PP labels with cinnamon EOs inside PET trays were used to extend the shelf-life in late maturing peach fruits. Authors reported the high decrease in the number of infected fruits after 12 days at room temperature when the active label was used (13%), in comparison with the non-active packaged peaches (86%). An active packaging with cinnamon essential oil combined with MAP was also tested to increase the shelf life of gluten-free sliced bread. Results showed that the active packaging is better than MAP to increase product shelf life because it inhibited microbial growth while maintaining the sensory properties of the gluten-free bread (Gutiérrez *et al*., 2011).

Victor *et al*. (2018) studied on shelf life assessment of fresh poultry meat packaged in novel bionanocomposite of chitosan/montmorillonite incorporated with ginger essential oil. The results showed that when compared to unwrapped poultry meat, samples wrapped in the bionanocomposites showed a reduction in microorganisms count of 1.2–2.6 log CFU/g, maintained color and pH values and thiobarbituric acid reactive substances (TBARS) index increased at a lower rate, extending fresh poultry meat shelf life. The incorporation of ginger EO enhanced the biopolymer activity, by reducing lipid oxidation and microbiological growth of the poultry meat.

A mixture of cinnamon and clove EOs was found to have a good potential to inhibit growth of spoilage fungi, yeasts and bacteria usually found at intermediate moisture foods. EOs extracted from them were studied with successful incorporation into natural and synthetic polymers, providing bioactive properties to films (Sadaka *et al*., 2014). Some increase in the antimicrobial stability with the decrease in cinnamon EOs release rate was observed for gelatin films incorporated with cinnamon EO nanoliposomes (Wu *et al*., 2015). In other study, Kechichian *et al*. (2010) evaluated the antimicrobial effect of cassava starch films with clove and cinnamon powders in contact with bread slices. They concluded that the antimicrobial effect of this combination of spices could not be clearly assessed since water activity of the bread slices increased considerably during storage, resulting in good conditions for microorganisms' proliferation.

Different authors tested a new package, with grapes wrapped with two distinct films, with the addition of a mixture of eugenol, thymol and carvacrol, and observed that microbial counts were drastically decreased as well as lower occurrence of berry decay (Valero *et al.,* 2006; Guillén *et al*., 2007). Also other works on 'Crimson Seedless' table grapes, using MAP and eugenol, thymol or menthol inside the packages, showed that counts for yeasts and moulds were significantly reduced in the grapes' packages with natural antimicrobial compounds. Valero *et al.* (2006) tested table grapes on MAP conditions and active packaging by adding eugenol or thymol and obtained reduced losses of quality, considering sensory, nutritional and functional properties, and also lower spoilage counts, in active packaging with added EO.

Munhuweyi *et al.* (2017) investigated the *in vitro* and *in vivo* inhibitory effects of chitosan EOs, with different concentrations of lemongrass, cinnamon, and oregano oils, using vapour emission and direct coating against *Botrytis s*p., *Penicillium* sp. and *Pilidiella granati* pathogens of pomegranate fruit. Chitosan film incorporated with oregano EO had the highest antifungal activity, followed by cinnamon and lemongrass EOs. The inhibitory effect was higher for fruit directly dipped into the chitosan-EO emulsions than those exposed to vapour.

Other strategies to incorporate EOs into water-soluble polymers to form antimicrobial films have been reported. Otoni *et al*. (2014) prepared coarse emulsions (1.3–1.9 mm diameter) and nanoemulsions (180–250 nm diameter) of clove bud EOs through low-speed mixing and ultrasonication, respectively, to be incorporated into methylcellulose matrices. They observed that droplet size reduction provided further improvement in antimicrobial properties against yeasts and moulds in sliced bread. In addition, low EOs contents might be used if encapsulated in smaller particles to keep antimicrobial efficiency.

Insecticide Activities of Bioactive Compounds

In developing countries food grains are losses through insect infestation, especially during storage time (Dubey *et al*., 2008; Talukder *et al*., 2004). Losses caused by insects include not only the direct consumption of kernels, but also accumulation of by-products. High levels of the insects detritus may result in grain that is unfit for human consumption and loss of the food commodities, both, in terms of quality and quantity. Insect infestation-induced changes in the storage environment may cause warm moist "hotspots" that provide suitable conditions for storage fungi that cause further losses.

The increasing serious problems of resistance and residue to pesticides and contamination of the biosphere associated with large-scale use of broad spectrum synthetic pesticides have led to the need for effective biodegradable pesticides with greater selectivity. This awareness has created a worldwide interest in the development of alternative strategies, including the discovery of newer insecticides (Dayan *et al*., 2009).

Natural pesticides are active substances derived from plants and are often used for pest management. Many plant extracts show a broad spectrum of activity against several pests and pose little threat to human health and the environment. Therefore, they have long been touted as attractive alternatives to synthetic pesticides for pest control. Moreover, plant essential oils or their constituents have a broad spectrum of activity against insect pests, plant pathogenic or other fungi, weeds, and nematodes (Dudai *et al*., 1999; Isman, 2000). Natural products showing activity against pests have been and are still being explored for possible production of commercially available natural products that can be effective on certain pests, selective in crops, non-toxic for the user, easily biodegradable, and that can be locally and easily produced, especially by farmers who usually cannot afford expensive synthetic pesticides.

The characteristic flavours and odours emanating from the volatile oils of spices are known to have various effects on insect pests, including stored insects (Shayya *et al*., 1991). The uses of these spices as insecticides provide an opportunity to replace the synthetic compounds from insecticides by natural alternatives which creates a sustainable market for this kind of products. Therefore with the use of spices as insecticidal natural products, the problem of synthetic pesticides can be solved by the substitution of the synthetic compounds that have been related to harmful health effects with the main active compound of spices which are safe (Eddleston *et al*., 2006).

Pascual Villalobos (2003) found the potential of plant essential oils against stored-product beetle pests. He reported that coriander oil (10 µl) showed activity against the bruchid *Callosobruchus maculates*, the cereal storage pest. Eugenol, isoeugenol and methyl eugenol cause contact toxicity to the storage pathogens, *Sitophilus zeamis* and *Tribolium costaneum*. These compounds have similar toxicity to *S. zeamis* at LD50 30 µg/mg insect, while for *T. costaneum* the order of potency is isoeugenol > eugenol > methyl eugenol (Ho *et al*., 1994; Huang *et al*., 2002). The volatile oil from cardamom acts as a potential grain protectant by killing various life stages of the stored product insects attacking wheat, e.g. *Tribolium castaneum* and *Sitophilus zeamais*, via contact and fumigant action (Huang *et al*., 2000; Singh *et al*., 2018). Cinnamon essential oil has also been used as insecticidal (Cheng *et al*., 2009).

Turmeric has been found effective in controlling certain agricultural and animal pests due to the presence of a variety of bioactive constituents that interfere with insect behavior and growth. The bioactive compounds with insecticidal or pesticidal activity are present in the form of essential oil, those are alpha-Penene, beta-Pinene, Caryophyllene, Eugenol, Limonene turmerones and Ar-turmerone (Duke, 1999; Tripathi *et al*., 2002). O-Coumaric acid and protocatechuic acid are extracted from leaf of *C. longa* (Duke, 1999). Curcumin (diferuloylmethane) (34% is responsible for the yellow colour, and comprises curcumin I (94%), curcumin II (6%) and curcumin III (0.3%) and it is the most active chemical which acts as natural pesticides (Bhardwaj *et al*., 2011).

Essential oil extracted from the leaves of turmeric and *C. longa* showed toxic and growth inhibitory activity, fumigant toxicity, anti-feedent and affects the progeny against stored grain insects. It reduced ovi-position and eggs hatching in cinnamaldehyde and cinnamyl acetate have shown stored grain insects (Sharma *et al*., 2005). Moreover, turmeric powder in combinations with mustard oil has been reported to protect milled rice against *S. oryzae* (Chander *et al*., 1991). A combination of 4 ml/kg of mustard oil and turmeric powder at 20 g/kg provided the best protection of milled rice by completely suppressing progeny emergence of *S. oryzae*. In another study, turmeric powder (or grit) provided 63.2% suppression of progeny of the test insect at 0.5% level (Chander *et al*., 2003).

The major constituents of the essential oil of garlic; *Allium sativum*, methyl allyl disulfide and diallyl trisulfide were to be potent toxicant and fumigants against *Sitophilus zeamais* and *Tribolium castaneum* (Huang *et al*., 2000). The study on other spices reported that the essential oil vapours distilled from anise, cumin, eucalyptus, oregano, and rosemary were also fumigantants and caused 100% mortality of the eggs of *Tribolium confusum* and *Ephestia kuehniella* (Tunc *et al*., 2000).

Kim *et al*. (2014) developed laminated films based on PP and LDPE coated with a printing ink containing microencapsulated cinnamon EO to protect food from the Indian meal moth (Plodia interpunctella). Authors reported that these films effectively inhibited the invasion of moth larvae in cookies, milk, chocolate and caramel, acting as insect-resistant films. They observed that microencapsulation decreased the release rate of cinnamaldehyde EO and increased their thermal stability, with no effect on the tensile and moisture barrier properties of the active film.

Conclusion

The bioactive compounds extracted from spices have high antioxidants and antimicrobial activities. The antimicrobial activities which are extracted from spices are either killing or retarding the growth of spoilage and pathogenic microorganisms. Some of these bioactive compounds also have the ability to destroy the antibiotic resistant microorganisms. Also, the antioxidants which are extracted from spices are comparable to synthetic antioxidants and others are greater than that of synthetic antioxidants. Generally, because of their ability to preventing oxidation, retarding the growth of microorganisms and killing grain store pests; bioactive compounds found in spices are used in food industries and grains storage.

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