Plant antimicrobials in food applications: Minireview

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Plant antimicrobials fulfill the needs of today’s consumer looking for wholesome food without chemical preservatives. These can be classified as novel compounds obtained from plants that delay microbial growth of pathogens and spoilage organisms in food. The antimicrobial activity of plant extracts that is observed in in-vitro conditions is quite different to its effect in complex food systems. In most cases antimicrobial activity is decreased due to interactions with food components. This could be a challenge in utilizing plant antimicrobials, as a higher concentration could result in unfavourable changes to the taste and aroma of food. There is growing scientific evidence of the potential use of plant antimicrobials for the extension of shelf life in food. This review covers recent trends in using plant antimicrobials in food, their combination with other technologies, their role in controlling food pathogens and mechanisms of action.

Keywords: Natural antimicrobials, phytochemicals, plant extracts, food pathogens, food safety

1. Introduction

Consumption of fresh foods like seafood, meat and horticultural products have increased due to the need of consumers for convenient ready to eat or ready to cook foods and the desire to lead a healthy lifestyle. The challenge of these fresh foods is their limited storage life, their association with foodborne disease outbreaks, resulting in continuing commercial pressures to use synthetic chemicals as preservatives. At present a wide variety of chemical preservatives are permitted and used in foods to prevent the growth of food spoilage and disease causing bacteria. The type of preservative, amount allowed to be used and in which foods vary between countries but use of preservatives is increasingly being negatively perceived by consumers. Foodborne disease outbreaks are on the rise even in developed countries, with a shift from challenges posed by foods from animal origin to fresh foods such as produce, shellfish and dry products and ingredients. New risks are being encountered because of changes to food production practices, environment, increase in global trade of food and changes to the genetic characteristics of the relevant pathogenic microorganisms [1]. An increase in the fresh-cut convenient salad market has coincided with an increase in foodborne diseases; pre-cutting of the salad leaves releases nutrients which support microbial growth. The modified atmosphere within the package reduces spoilage by aerobes but enhances the virulence of pathogens like *E.coli* 0157:H7 [2, 3]. Traditional food preservation methods are less effective in preventing the growth of these food pathogens in fresh food. New and innovative techniques are needed by the food industry to overcome these challenges. Use of Plant antimicrobials is an emerging technology that could be used by the industry to extend the storage life of food and overcome these food safety issues.

1.1 Application of plant antimicrobials in shelf-life extension of food

Plant antimicrobials are phytochemicals which are important for the proper functioning of the plant. In most cases these substances act as plant defence agents against microorganisms and other predators. They also regulate growth, pollination and fertilization [4, 5]. Phytochemicals in plants are broadly grouped into phenolic compounds, terpenoids and essential oils, alkaloids, lectins and polypeptides. The phenolic compounds also include simple phenols and phenolic acids, quinones, flavonoids and tannins [5, 6]. Phenolic compounds are secondary metabolites and one of the most widely occurring phytochemicals in plants. They contribute to the sensory properties when added to food and have antioxidant and antimicrobial properties [6], characteristics that are useful in extending the shelf-life of food. The antioxidant and other biological properties in phenolic compounds has been attributed to beneficial health effects when consuming foods rich in polyphenols [7]. Other classes of compounds such as polyamines, glucosinolates and glucosides have revealed potential as natural antimicrobials and glucosinolates in particular have been identified for antifungal, antibacterial and antioxidant properties, in addition to other functional properties. Allyl isothiocyanate, a hydrolysis product of glucosinolates is a potent antibacterial compound and is used as a preservative in the food industry [8]. In summary antimicrobials are chemical compounds or substances that may delay microbial growth or cause microbial death on entering a food matrix. Antimicrobials can be classified as traditional and novel substances called “naturals”. Antimicrobials are called traditional when they are the permitted chemical preservatives. Natural antimicrobials are obtained from raw materials of vegetable, fruit, herbs/spices or microbiological origin. An example would be plant extracts which can provide properties such as antioxidants, shelf-life extension (natural antimicrobials), as well as exciting new flavours.
1.2 New strategies to study antimicrobial inhibition

The most recent food borne disease outbreak in 2011 was reported from Germany, attributed to the consumption of raw sprouts where Shiga toxin-producing E. coli or STEC infections caused hemolytic uremic syndrome (HUS) in 784 patients and 23 deaths [9]. Such outbreaks are a challenging issue for the food industry and underpin the need for a paradigm shift in the methods used to prevent or minimize such occurrences. Use of antimicrobials to control the growth of food borne pathogens is one strategy that has been adopted. However, the screening of antimicrobial compounds has been based on planktonic bacterial cells and is not the case in real food systems where bacteria live as part of the population of native or indigenous microbiota. Food preservation methods aim at reducing the microbial load by extending the lag phase and limiting the rate of growth in the exponential phase [10]. This does not take into consideration the intra and inter species communication within a microbial population that is present in a food matrix.

In the antimicrobial screening assays currently used [11, 12] antimicrobial compounds are either evaluated as having bacteriostatic effects where the cell growth is inhibited or having bactericidal effects where cell death occurs. Methods of detection where antimicrobial treatments are based on the reduction of selective pressure such as quorum sensing signaling pathways are gaining interest [13]. Quorum sensing is the term used to describe the mechanism of cell-cell communication of bacteria that live in a population. Such populations produce, release, detect and respond to small signaling molecules called autoinducers. Quorum sensing in a bacterial population can cause biofilm formation, competence development and sporulation, antibiotic synthesis and enhance bacterial virulence factor [14]. The autoinducer AI-2 has been identified as a universal signaling molecule due to its ability to modulate the gene expression of a number of different bacterial species and genera. [15 - 15]. A recent study has reported that E. coli O157:H7 produced maximum levels of AI-2 signals in 12 h of incubation in meat, poultry and produce broths and subsequently formed a strong biofilm in 24 h of incubation [16]. Another study reported the growth of Campylobacter jejuni in chicken meat juice at chilled temperature upregulated the LuxS gene which catalyses the formation of AI-2 [17]. Understanding the native microbial interactions on food surfaces is critical as they are the microbial populations that govern the shelf-life and safety of food products. Food spoilage and food poisoning could be regulated by the communication of this native microbiota [18, 19]. Epiphytic microbiota of spinach leaves were altered during storage at low temperatures with the selection of psychotropic microorganisms. The presence of E. coli O157:H7 on spinach leaves and the change of the spinach leaf microbiota combined with abused storage temperature at 10°C influenced this pathogen to grow and establish on the spinach leaf surface. This illustrates the importance of the native microbiota in the growth of food borne pathogens [20]. Cell-free culture supernatants of food spoilage and pathogenic bacteria of Pseudomonas aeruginosa, Yersinia enterocolitica and Serratia proteamaculans affected the growth of Salmonella enteritidis and S. typhimurium strains, indicating the influence quorum sensing signalling compounds have on interspecies bacterial communications [18].

Information in Table 1 suggests that plant antimicrobials could serve as a source to develop bacterial intervention strategies targeting microbial cell signalling processes.

<table>
<thead>
<tr>
<th>Inhibitor</th>
<th>Mode of action</th>
<th>Biological effect</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Citrus Limonoids - Obacunone, nomilin, deacetyl nomilin (DAN), Limonin 17-β-D-glucopyranoside</td>
<td>Inhibition of autoinducer AI-2 mediated cell-cell signaling</td>
<td>Citrus limonoids possess anti-quorum sensing activity and are antagonistic to biofilm of Escherichia coli O157:H7</td>
<td>[21]</td>
</tr>
<tr>
<td>Furanone 2(5H)-furanone and bromofuranone</td>
<td>Inhibition of autoinducer AI reducing the release of N-acyl homoserine lactones (AHL) as signal molecules</td>
<td>Effective in inhibiting AHL production in Pseudomonas sp. and in reducing its virulence expression and shelf life extension in fermented milk</td>
<td>[22]</td>
</tr>
<tr>
<td>Grapefruit juice and furocoumarins</td>
<td>Inhibition of autoinducers AI and AI-2</td>
<td>Inhibition of biofilm formation by Escherichia coli O157:H7, Salmonella typhimurium and Pseudomonas aeruginosa</td>
<td>[23]</td>
</tr>
</tbody>
</table>
### 1.3 Food composition and interaction of plant extracts and effects on antimicrobial activity

Antimicrobial properties of plant extracts against food spoilage and pathogenic bacteria have been reviewed extensively in the literature [11, 12, 27-30]. Most of these reported studies have looked at the efficacy of plant extracts against planktonic cultures of food related bacteria. Screening for antimicrobial activity against the native microbiota of the food or microflora at different times of the storage period, changes during processing and packaging would be a more accurate representation of the bacteria that could be in the food. An example of such a product is lightly preserved fish products where certain ingredients such as salt or sugar are added and mildly processed using cold smoke. This type of processing lowers the water activity thereby inhibiting the growth of spoilage organisms and enhancing the growth of lactic acid bacteria (LAB) [31]. Vacuum packing of meat inhibits the aerobic *Pseudomonas* sp. causing a change in the microbiota to LAB and *Enterobacteriaceae* [32].

A greater concentration of natural extracts from plants is generally needed to achieve the same effect in food in comparison to in vitro assays [12]. The intrinsic (pH, salt, antioxidants and other additives) and extrinsic properties (temperature, vacuum and modified atmosphere packaging, characteristic of microorganisms) of the food can influence the antimicrobial efficacy of the plant antimicrobials [33]. Studies have been done on fruit and vegetable model media to evaluate plant extract efficacy. Carrot broth was made by washing, peeling and mashing with water and fractional heat treatment which provided sufficient decontamination in addition to the background microflora remaining in the carrot broth. This broth was inoculated with *Bacillus cereus* and the antibacterial activities of 11 essential oils studied. Cinnamon essential oil was the most effective under refrigerated temperature, inhibiting the growth of *B. cereus* for at least 60 days in a model refrigerated minimally processed food product made with carrots and fractional heating [34]. Lettuce leaf, beef and milk model media were used to study the efficacy of essential oils against *Listeria* sp. and spoilage bacteria and compared to the lab control media Tryptic Soy Broth (TSB). The efficacy of essential oils in the lettuce model media was 10 fold higher than in TSB, possibly due to the low fat content of vegetables. The essential oils were more effective in beef extract than in TSB, high protein concentrations in beef extract promoted the growth of *Listeria* sp. but the efficacy of oregano and thyme essential oils was also higher. This could be due to the high binding capacity of proteins to volatile compounds. Oregano and thyme were the most effective for inhibition of *Listeria* sp. and spoilage organisms for the above food model media tested [35, 36].

#### 1.3.1. Antimicrobial efficacy of Glucosinolates

Special reference to glucosinolates is made due its interest as a natural preservative for the food industry. Glucosinolates, the precursors of isothiocyanates, are present in sixteen families of dicotyledonous angiosperms including a large number of edible species [37]. Examples of edible species that have glucosinolates are horseradish, mustard, Brussels sprouts, broccoli and turnip. Some of the studies reported on isothiocyanates in different foods include the following. When Allyl isothiocyanate extracted from Horseradish (*Armoracia rusticana*), from the Brassicaceae family was injected into tofu, the growth of microflora in the control was 8 log CFU/g in comparison to tofu containing allyl isothiocyanate at 200 ppm showing a significant inhibition to 4 log CFU/g [38].

Commercial allyl isothiocyanate was tested for efficacy against *E. coli O157:H7* in fresh ground beef packaged under nitrogen and stored at chilled and frozen storage temperatures. The mesophilic bacteria were unaffected due to

<table>
<thead>
<tr>
<th>Plant Extract</th>
<th>Inhibition of Autoinducers</th>
<th>Inhibition of Biofilm Formation by <em>Escherichia coli</em> O157:H7</th>
<th>Potential to Affect Bacterial QS Regulated Processes</th>
<th>Attenuates the Virulence of <em>P. aeruginosa</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Citrus flavonoids</td>
<td>Inhibition of AI-2</td>
<td>[24]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cinnamaldehyde</td>
<td>Inhibition of N-3-oxohexanoyl-L-homoserine lactone (3-oxo-C6-HSL) and AI-2</td>
<td>[25]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Garlic extract</td>
<td>Blocks production of quorum-sensing signal molecules and extracellular virulence factors.</td>
<td>[26]</td>
<td></td>
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</tbody>
</table>
the addition of allyl isothiocyanate, however 3 log CFU/g E. coli O157:H7 was reduced to undetectable levels after 18 days at 4°C or 10 days at -18°C. Samples inoculated with 6 log CFU/g revealed >3 log CFU/g reduction after 21 days storage at 4°C while a 1 log CFU/g reduction was observed after 8 and 35 days at 10 and -18°C [39].

Another study on allyl and other isothiocyanates was done with mustard flour, to evaluate if naturally present glucosinolates could have an effect on E.coli O157:H7 inoculated in ground beef at 5, 10 and 20% levels. At these levels 3 log CFU/g E.coli O157:H7 were reduced to undetectable levels within 3-18 days and an inhibitory effect at 10% and 20% on the natural microbiota present in the meat was reported [40].

This clearly demonstrated the potential of using isothiocyanates as plant antimicrobials which extend the storage life and improve the quality and safety of food products.

### 1.4 Synergies within plant extracts

Plant extracts also have unique flavours and have historically been used as a seasoning in food as they have been known for their preservative effect. However due to the strong aroma in some of these extracts, their application in high concentrations is limited due to unfavourable organoleptic properties. Therefore optimisation of levels of these plant extracts in food is important to further their application as natural antimicrobials. Study of combinations of plant extracts and their effects on antimicrobial efficacy in low concentrations is important for its application in food. It has been reported that whole plant extracts have a higher antimicrobial efficacy than when individual major components are mixed, indicating that minor components of plant essential oils may be contributing synergistically [12]. Synergism between carvacrol and p-cymene in brain heart infusion broth has been reported [41], suggesting that a combination of weaker activity components can achieve a synergistic effect. An additive effect is observed when the combined effect is equal to the sum of the individual effects. Antagonism is observed when the effect of one or both compounds is less when they are applied together than when individually applied. Synergism is observed when the effect of the combined substances is greater than the sum of the individual effects[42].

Combinations of seven plant essential oils basil, lemon balm, marjoram, oregano, sage and thyme were studied for synergism, additive, indifference and antagonistic effect. None of these combinations had a synergistic activity against the bacteria used, however oregano combined with all other essential oils had an additive effects against B. cereus but no additive effect was recorded for oregano based combinations against L. monocytogenes [36]. Binary mixtures of carvacrol and thymol and ternary mixtures of carvacrol-thymol-eugenol had synergistic activity against L. innocua in comparison to antimicrobial efficacy of the individual components [43]. A Central Composite Design was used to study the synergistic effect of thymol, grapefruit seed extract and lemon extract in fish hamburgher inoculated with fish spoilage microorganisms. The results revealed that the optimal antimicrobial compound composition which corresponds to the longest time that it takes for the viable cell concentration to reach its potency limit was 110 ppm thymol, 100 ppm grapefruit seed extract and 120 ppm of lemon extract [44]. Green tea extracts alone (20 or 40 mg/ml) or in combination with tartaric acid (37.5 mM) reduced Salmonella, Listeria and E.coli by 2.5 log CFU/ml in broth culture studies [45]. The antimicrobial activity of grape seed extract when combined with bacteriocins like nisin has demonstrated more effectiveness than when used alone against L. monocytogenes. This may be due to the synergistic mechanism of action of nisin and polyphenols present in grape seed extract [46].

### 1.5 Antimicrobial efficacy of plant antimicrobials in different delivery models or systems

There are many methods that a plant antimicrobial can be incorporated in to foods. The simplest method would be the addition of the compound to the food directly and mixing. In foods where surface sanitisation is targeted the food product can be dipped in the plant extract or applied as a spray. These simple delivery modes have become more sophisticated with the advance in packaging, encapsulating and nanotechnologies. Some of the modes of application that are available for plant antimicrobials and the potential of these technologies in different food are discussed below.

#### 1.5.1. Bioactive packaging

Incorporating antimicrobial compounds in films rather than directly mixing it with the food allows for the functional effect at the food surface, where most of the microbial growth is localized. Antimicrobial packaging would include systems such as adding a sachet into the package, dispersing bioactive agents in the packaging, coating bioactive agents on the surface of the packaging material, or using antimicrobial macromolecules with film forming properties as edible packaging material [47]. Incorporation of garlic oil at a level of 100 µl/g in chitosan and forming a film was found to have antimicrobial activity against Staphylococcus aureus, Listeria monocytogenes and B. cereus [48]. Kakadu plum (Terminalia ferdinandiana) is one of the Australian native fruits indentified for its antimicrobial properties, having gallic acid as one of the components with antimicrobial efficacy. Films made from 3% kakadu plum powder were found to have antimicrobial activity against Staphylococcus aureus, methicillin-resistant Staphylococcus aureus (MRSA), Listeria monocytogenes, Bacillus cereus, Bacillus subtilis, Escherichia coli, Pseudomonas aeruginosa and Acinetobacter baumannii [49]. Edible films made from ‘Golden Delicious’ apple puree with apple skin polyphenols at
1.5% (w/w) was very effective against *L. monocytogenes* [50]. In Kiam wood (*Cotyleobium lanceotatum*), traditionally used in Thailand to prevent or retard microbial fermentation by submerging in sugar palm sap, tannic acid was the main component for antimicrobial efficacy. The edible films made with hydroxypropyl methylcellulose containing kiam wood extract inhibited growth of *L. monocytogenes* more than *E. coli* and *S. aureus* [51]. Examples of demonstrated application of antimicrobial packaging films in food systems are given in Table 2.

### 1.5.2. Encapsulation

Application of phytochemicals as preserving agents in food depends on maintaining the stability and bioactivity of the plant antimicrobial. As discussed some phytochemicals have strong aroma and taste and these drawbacks can be overcome by encapsulating the active compounds instead of applying it as free compounds directly to the food. The technologies of encapsulation of polyphenols include spray drying, coacervation, liposome entrapment, inclusion complexation, cocrystallization, nanoeencapsulation, freeze drying, yeast encapsulation and emulsions [52]. Nanoencapsulation of bioactive compounds represents an efficient approach to increasing the physical stability of the active substances, protecting them from the interactions with the food ingredients and, because of the sub cellular size, increasing their bioactivity. A mixture of terpenes and D-limonene was encapsulated into nanoemulsions based on food-grade ingredients, prepared by high pressure homogenization. The minimum inhibitory concentration (MIC) and the minimum bactericidal concentration (MBC) of the nanoeencapsulated terpenes against *E. coli*, *L. delbrueckii* and *Saccharomyces cerevisiae* were lower or equal to the values of the unencapsulated mixture. The D-limonene nanoencapsulation was able to reduce the MIC but there was no significant difference in the variation of the MBC values in comparison to the unencapsulated mixture [53]. When Mexican oregano essential oils were microencapsulated by spray drying and the antimicrobial efficacy was tested against *Pseudomonas aeruginosa*, *S. aureus* and *E. coli* the antimicrobial activity was preserved and the encapsulated oil was water soluble, which makes it an advantage for food applications [54].

### Table 2 – Effect of novel delivery systems and plant antimicrobials on antimicrobial efficacy in food

<table>
<thead>
<tr>
<th>Type of Food</th>
<th>Plant antimicrobials and other blends</th>
<th>Delivery model</th>
<th>Inhibitory effect</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beef sausages</td>
<td>Carvacrol</td>
<td>Nanocomposite film with methyl cellulose and montmorillonite clay</td>
<td>Reduction in <em>E. coli</em> and <em>S. aureus</em> counts by 0.9 and 0.7 log CFU/ml</td>
<td>[55]</td>
</tr>
<tr>
<td>Cod (<em>Gadus morhua</em>) fillets</td>
<td>Clove essential oil</td>
<td>Gelatine-chitosan film</td>
<td>Significantly reduced gram-negative bacteria, especially enterobacteria</td>
<td>[56]</td>
</tr>
<tr>
<td>Fresh ground beef patties</td>
<td>Thyme and oregano essential oils</td>
<td>Soy protein edible films</td>
<td>Significant reduction in coliform and <em>Pseudomonas</em> sp. counts</td>
<td>[57]</td>
</tr>
<tr>
<td>Fruit-based salads, romaine hearts and pork slices</td>
<td>Green tea extracts (GTE)</td>
<td>Tapioca starch/decolorized hsian-tao leaf (dHG) gum matrix sprayed on food surface and air dried</td>
<td>GTEs reduced the total bacteria and growth of yeasts/molds by 1 to 2 log cycles in fruit-based salads, refrigerated storage of Romaine hearts and pork slices for 48 h, tapioca starch/dHG coatings with GTEs revealed pronounced antimicrobial activity against Gram positive bacteria (4–6 log cycles reduction)</td>
<td>[58]</td>
</tr>
<tr>
<td>Fresh beef cuts</td>
<td>Oregano essential oil</td>
<td>Whey protein isolate films</td>
<td>Significant reduction in total bacteria and Pseudomonads and the growth of lactic acid bacteria was completely inhibited.</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Cheddar cheese</td>
<td>Linalool and methylchavicol from basil</td>
<td>Low density polyethylene</td>
<td>Significant reduction in <em>E. coli</em> and <em>L. innocua</em></td>
<td></td>
</tr>
<tr>
<td>Sausages</td>
<td>Cinnamaldehyde and catechin</td>
<td><em>Gelidium corneum</em> (GC) is a type of red algae, powder is used for film formation</td>
<td>Reduction in <em>E. coli</em> O157:H7 and <em>L. monocytogenes</em> by 1.81 and 1.44 log CFU/g after 5 days of storage</td>
<td></td>
</tr>
<tr>
<td>Orange and pear juices</td>
<td>Terpenes</td>
<td>Encapsulation into Lecithin-based nanoemulsion</td>
<td>The addition of low concentrations of the nanoencapsulated terpenes was able to delay the microbial growth of <em>Lactobacillus delbrueckii</em> (1.0 g/l terpenes) or completely inactivate the microorganisms (5.0 g/l terpenes)</td>
<td></td>
</tr>
<tr>
<td>Fresh beef pieces</td>
<td>Allyl isothiocyanate</td>
<td>Microencapsulate in gum acacia</td>
<td>Allyl isothiocyanate at 4980 ppm eliminated <em>E. coli</em> O157:H7 after 15 and 18 days of storage</td>
<td></td>
</tr>
</tbody>
</table>

1.6 Combined technologies for food preservation

The ability to produce a safe food product with extended storage life which is acceptable to the consumer according to the relevant food standard guidelines is the objective of food preservation. This is achieved through designing processing steps specific to different products. The goal is to combine a range of processes, for example mild heat stress and a low concentration of preservatives to give a safe and quality food product. There is renewed interest in using minimal/ non thermal processing technologies such as High Pressure Processing (HHP) and Pulsed Electric Field (PEF), active and modified atmosphere packaging [63-66]. Examples of combined technologies with different antimicrobial plant extracts is given in Table 3.
### Table 3 – Combined technologies and shelf-extension of fresh food

<table>
<thead>
<tr>
<th>Type of food</th>
<th>Plant antimicrobial</th>
<th>Combined technologies</th>
<th>Shelf-life extension</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh chicken breast meat</td>
<td>Oregano essential oil</td>
<td>Modified atmosphere packaging (MAP), chilled storage</td>
<td>Shelf-life in excess of 5-6 days in comparison to the control</td>
<td>[67]</td>
</tr>
<tr>
<td>Cold smoke sardine</td>
<td>Oregano, rosemary essential oil</td>
<td>High Pressure Processing, smoking and gelatine based edible films, chilled storage</td>
<td>At the end of 20 days storage the control had a total bacteria of 9 log CFU/g and the combined treatment 4 log CFU/g</td>
<td>[68]</td>
</tr>
<tr>
<td>Fresh Spinach leaves</td>
<td>Grape seed extracts</td>
<td>Organic acids, electrostatic spraying and chilled storage</td>
<td>Malic acid (2%) in combination with GSE (3%) or lactic acid (3%) sprayed electrostatically showed reductions of 2.6 to 3.3 log CFU/g compared to lower log reductions (0.0 to 0.3 log CFU/g) by day 14 if sprayed conventionally.</td>
<td>[69]</td>
</tr>
<tr>
<td>Fish burgers with hake and mackerel</td>
<td>Essential oils: thymol, lemon extract and grapefruit seed extract</td>
<td>MAP and chilled storage</td>
<td>Shelf-life extension 23 days</td>
<td>[70]</td>
</tr>
<tr>
<td>Fresh Sea bream fish fillets</td>
<td>Oregano essential oil</td>
<td>Salting, MAP and chilled storage</td>
<td>Control shelf-life of 16 days, combined treatment shelf-life extended to 33 days</td>
<td>[71]</td>
</tr>
<tr>
<td>Fresh carp fillets</td>
<td>Carvacrol and thymol</td>
<td>Electrolyzed water and chilled storage</td>
<td>Control shelf-life of 4 days, combined treatment 16 days</td>
<td>[72]</td>
</tr>
<tr>
<td>Semi-cooked coated chicken fillets</td>
<td>Rosemary and oregano essential oils (EDTA), lysozyme, vacuum packaging and chilled storage</td>
<td>Shelf-life in excess of 7-8 days in comparison to the control</td>
<td></td>
<td>[73]</td>
</tr>
</tbody>
</table>

#### 1.7 Challenges of using plant extracts in food systems and future prospects

It is clear from the literature that a range of plant extracts are needed to inhibit the natural microbiota that is found in different types of food. This is quite different to the traditional preservatives where the same preservatives such as metabisulphites, sodium benzoates, sorbates etc are used in different food systems. The challenges of using plant antimicrobials are:

- Some plant extracts have flavours associated with them that may be a problem, therefore it is important to match the food and the plant extract flavour or understand the synergies to decide on the concentration used.

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- Type of microorganisms present in the food that can cause spoilage and disease is critical to understand the antimicrobial effect of plant extracts as it is not the same for all microorganisms.
- Incorporation of plant antimicrobials in food can give rise to the growth and virulence of certain pathogens due to the changes in microbial ecology. It is critical to understand the effect of plant extracts on the behaviour of these microbial population in complex food systems.
- The growing environment of the source plants influences the levels of antimicrobial compounds in them. In addition, the period of harvest, storage and extraction procedures used will have an effect on the levels of active components responsible for antimicrobial activity and this would be a challenge in using it as a functional food ingredient.

References


