Recent Advances in the Application of Antibacterial Complexes Using Essential Oils

Tae Jin Cho 1, Sun Min Park 2, Hary Yu 2, Go Hun Seo 2, Hye Won Kim 2, Sun Ae Kim 3 and Min Suk Rhee 2,*

1 Department of Food and Biotechnology, College of Science and Technology, Korea University, 2511, Sejong-ro, Sejong 30019, Korea; microcho@korea.ac.kr
2 Department of Biotechnology, College of Life Sciences and Biotechnology, Korea University, 145, Anam-ro, Seongbuk-gu, Seoul 02841, Korea; ash101@korea.ac.kr (S.M.P.); bluet219@korea.ac.kr (H.Y.); gomi960625@korea.ac.kr (G.H.S.); kgpdnjs@korea.ac.kr (H.W.K.)
3 Department of Food Science and Engineering, Ewha Womans University, Seoul 03760, Korea; suanaekim@ewha.ac.kr
* Correspondence: rheems@korea.ac.kr; Tel.: +82-2-3290-3058

Academic Editor: Daniela Rigano
Received: 15 March 2020; Accepted: 7 April 2020; Published: 10 April 2020

Abstract: Although antibacterial spectrum of essential oils (EOs) has been analyzed along with consumers’ needs on natural biocides, singular treatments generally require high concentration of EOs and long-term exposures to eliminate target bacteria. To overcome these limitations, antibacterial complex has been developed and this review analyzed previous reports regarding the combined antibacterial effects of EOs. Since unpredictable combined effects (synergism or antagonism) can be derived from the treatment of antibacterial complex, synergistic and antagonistic combinations have been identified to improve the treatment efficiency and to avoid the overestimation of bactericidal efficacy, respectively. Although antibacterial mechanism of EOs is not yet clearly revealed, mode of action regarding synergistic effects especially for the elimination of pathogens by using low quantity of EOs with short-term exposure was reported. Whereas comprehensive analysis on previous literatures for EO-based disinfectant products implies that the composition of constituents in antibacterial complexes is variable and thus analyzing the impact of constituting substances (e.g., surfactant, emulsifier) on antibacterial effects is further needed. This review provides practical information regarding advances in the EO-based combined treatment technologies and highlights the importance of following researches on the interaction of constituents in antibacterial complex to clarify the mechanisms of antibacterial synergism and/or antagonism.

Keywords: natural antimicrobial agent; antimicrobial effect; anti-infectious effect; combined treatment; antibacterial complex; antibacterial mode-of-action; disinfectant; emulsion; antibacterial synergism; antibacterial antagonism

1. Introduction

Essential oils (EOs) and EO components are mainly secondary metabolites that are volatile aromatic products extracted from plants (e.g., herbs, spices) [1,2]. EOs have been reported to have numerous bioactivities including antioxidation effects [3] and anti-inflammatory effects [4]. This has led to their use in embalming, in pharmaceutical formulas, or as food additives. In particular, EOs have been regarded as considerably effective antibacterials and anti-infectious agents from natural sources in various fields including the food, medical, pharmaceutical, public health, and environmental fields [5].

In addition, EOs have been shown to have antibacterial [6,7], antifungal [8,9], antiviral [10], antimycotic [11], antiparasitic [12], and insecticidal activities [13]. Along with the drastically increased interests from consumers in the use of natural agents for the development of antimicrobial products
(e.g., disinfectants, preservatives, and food additives), natural compounds including EOs are preferred and the role of EOs as alternatives to synthetic chemical agents has been emphasized [14–16]. The majority of EOs are listed as generally recognized as safe (GRAS) substances [17].

Previous studies have focused on the discovery of novel EOs with high antibacterial effects [18–20]. Since the antimicrobial efficacy (i.e., microbicidal/microbiostatic activity and spectrum) of EOs varies based on the treatment conditions (e.g., the extraction methods of the EO from natural sources, temperature, treatment concentration, and surrounding compounds), studies on the development of decontamination technologies and/or the optimization of treatment conditions are ongoing [21–23]. However, the application of EOs can be limited by the following factors: (1) The higher costs compared with using synthetic agents, (2) the need for high concentrations to achieve bacteriostatic effect (the inhibition of bacterial growth without killing cells) or bactericidal effects (the destruction of bacterial cells) [24], and (3) the adverse effects after the EO treatment (e.g., changes in the physicochemical and sensory characteristics of the subject of application) [18,25]. Thus, the major hurdle in broadening the applicability of EOs is the development of technologies to improve their antibacterial effects.

The development and subsequent application of antibacterial complexes is one of the most representative strategies for improving the decontamination efficacy of EOs [26]. Examining the efficacy of EO-based antibacterial complexes is a prerequisite for the evaluation of the efficiency of their combinations because combined treatments can either increase or decrease their actual effects. Comprehensive analysis of the accumulated findings that highlights these unexpected shifts in antibacterial effects is needed to apply combined treatment technologies in practice and prevent the overestimation of the antibacterial effects by avoiding treatment conditions that result in antagonism.

Previous studies reported that the formulation of EOs as antibacterial complexes showed unexpected improvements in effectiveness and/or efficiency (i.e., antibacterial synergism), and the development of technologies specific to the formulation of antibacterial complexes has been regarded as a novel direction for advancing this field. Although literature reviews regarding the antibacterial effects of EOs are available [18,27,28], reviews focusing on synergism validated by quantitative microbiological analysis from short-term treatment are rarely reported [23,29]. This review covers the current issues regarding antibacterial complexes of EOs, which can be divided into the following sections: (1) Background information on the decontamination effects when EOs are used as constituents of antibacterial complexes; (2) combined treatments of EO-based antibacterial complexes with additive, synergistic, or antagonistic effects; (3) bactericidal mechanisms of combined treatments using EOs inducing synergistic effects; and (4) practical applications of EO-based antibacterial complexes.

2. EOs as Antimicrobial Agents

EOs are among the most representative natural antimicrobial agents, and they are widely used as decontaminants in addition to being used as additives and preservatives. Topics of previous reports regarding EOs as antimicrobial agents are diverse according to the purpose of use (e.g., decontamination, elimination of pathogens, delay of use-by-date, and preservation). EOs extracted from plant parts (e.g., seeds, flowers, buds, herbs, and roots) have been used as antimicrobial agents [30]. Among the numerous kinds of EOs, marked bactericidal activity against pathogens has mainly been shown for crude oils extracted from plants, β-resorcylic acid (RA), carvacrol (CAR), cinnamaldehyde (CA), eugenol (EUG), trans-cinnamaldehyde (TC), thymol (TM), and vanillin (VNL) [18,31]. The biocidal properties of EOs have also been reported, especially their broad spectrum activities against various bacterial species (e.g., Acinetobacter baumannii, Aeromonas sobria, Bacillus cereus, Clostridium perfringens, Cronobacter sakazakii, Enterococcus faecalis, Escherichia coli, Klebsiella pneumoniae, Listeria innocua, Listeria monocytogenes, Paenibacillus larvae, Proteus spp., Pseudomonas aeruginosa, Salmonella Enteritidis, Salmonella Typhimurium, Serratia marcescens, Staphylococcus aureus, and Vibrio parahaemolyticus) [18,32–39]. To evaluate the antibacterial performance of EOs, several researchers have primarily investigated the minimum inhibitory concentration (MIC; i.e., the lowest concentration of a chemical that prevents visible growth of bacteria) and/or minimum bactericidal concentration (MBC; i.e., the lowest concentration
of an antibacterial agent required to kill bacteria) of the EO against pathogens [32–35,40,41]. Table 1 summarizes the antimicrobial effects of EOs as a singular treatment (i.e., not in combination with other substances). Since the definitions of MIC and MBC differ between researchers, it might not be possible to directly compare the results from those studies. Moreover, since both the MIC and MBC are determined by exposing the target pathogen to the EO for a sufficient time to ensure bacterial growth in the control group (i.e., without any EO treatment) [42,43], a time-dependent quantitative microbiological analysis to identify an actual active concentration is unavailable.

Table 1. Minimum inhibitory concentration of representative essential oils.

| Essential Oils | Target Microorganisms | Antimicrobial Effects (Minimum Inhibitory Concentration; MIC; µL/mL) | References |
|---------------|-----------------------|---------------------------------------------------------------|------------|
| Carvacrol     | *Escherichia coli*    | 0.225–0.4                                                     | [32,36,37] |
|               | *Escherichia coli O157:H7* | 3                                                             |            |
|               | *Salmonella Typhimurium* | 0.225–0.25                                                   |            |
|               | *Listeria monocytogenes* | 0.375–5                                                       | [33]       |
|               | *Staphylococcus aureus*  | 0.175–0.45                                                   | [41]       |
|               | *Bacillus cereus*      | 0.1875–0.9                                                    | [38]       |
|               | *Escherichia coli*     | 0.225–0.4                                                     | [32,36]    |
| Thymol        | *Listeria monocytogenes* | 0.45                                                        | [33]       |
|               | *Staphylococcus aureus* | 0.14–0.225                                                   | [41]       |
|               | *Bacillus cereus*      | 0.45                                                         | [40]       |
|               | *Escherichia coli*     | 1.0–1.6                                                      |            |
| Eugenol       | *Escherichia coli O157:H7* | 1.7                                                          | [18,33,36] |
|               | *Salmonella Typhimurium* | 0.5                                                          |            |
|               | *Listeria monocytogenes* | >1.0                                                        | [34]       |
|               | *Escherichia coli*     | 0.382–1                                                      |            |
| Trans-        | *Escherichia coli O157:H7* | 0.52                                                          | [32,36,37,39] |
| cinnamaldehyde| *Salmonella Typhimurium* | 0.382–1                                                      |            |
|               | *Listeria monocytogenes* | 3.82                                                        | [34]       |
| Vanillin      | *Escherichia coli*     | 2.183                                                        | [32]       |
|               | *Listeria innocua*     | 5.093                                                        | [35]       |

Evaluations of antimicrobial effects from the perspective of the practical application of EOs have been conducted based on the quantitative analysis of the reduction of a microbial population (i.e., log reduction) after EO treatment (Table 3). However, the limitation of a singular EO treatment in the efficiency has been highlighted, as reported by previous studies, mainly because of: (1) The negligible antibacterial effects (ca. <1 log reduction) [25,44,45], (2) the requirement of a high EO concentration to achieve a desirable effect from short-term exposure [46,47], or (3) the requirement of a long-term exposure [48–59].

In addition, food matrix is a representative case for emphasizing these limitations in the practical application of EOs because higher amounts of EOs and/or long-term exposure are generally required to achieve sufficient bactericidal effects (Table 2), as found from in vitro experiments conducted by using bacterial suspensions (Table 3) [18,60]. This phenomenon can likely be attributed to the complexity of food matrices and/or the presence of available nutrients that support the recovery of injured bacteria [61]. Previous studies on the occurrence of synergistic effects in EO-based antibacterial complex revealed that the antibacterial effect of singular treatment with an EO at a concentration that achieved synergism in a combined treatment is negligible (ca. <1 log reduction) [30,62]. Even previous studies that achieved desirable antibacterial effects (e.g., the delay of food spoilage by reducing natural flora) noted that concerns remain about the adverse changes in the quality of the target foods [63]. While the elevation of treatment temperature (e.g., 50–60 °C) was considered to complement the low antimicrobial effect by the addition [64] or the vaporization of EOs [65]. Since using high amount of EOs may accompany with unpleasant odor and a burden of cost (i.e., high price), novel treatment methods without any quality change are needed and the combined treatment can be a representative countermeasure.
Table 2. Antimicrobial efficacy of singular treatment of essential oils in foods.

| Matrix               | Treatment Condition | Target Microorganisms                          | Singular Treatment | Antibacterial Effects (Log Reduction; Log CFU/g or mL) | Reference |
|----------------------|--------------------|------------------------------------------------|-------------------|------------------------------------------------------|-----------|
| Soy sauce            | 22 °C, 10 min      | *Escherichia coli* O157:H7, *Salmonella* Typhimurium, *Listeria monocytogenes* | CAR/TM 1 mM       | negligible (ca. <1)                                   | [30]      |
| Infant formula       | 45 °C, 30 min      | *Cronobacter sakazakii* *Salmonella* Typhimurium | VNL < 30 mM       | negligible (ca. <1)                                   | [62]      |
| Ground beef          | Heat (60 °C, 1 h), vacuum package | *Clostridium perfringens* | CAR/TM/CA/oregano oil 0.1–2.0% | 3.2–5.0                                              | [64]      |
| Ground beef          | Marination with wine, storage (5 °C, 10 d) | *Salmonella enterica* *Listeria monocytogenes* | oregano oil 0.5%  | 1.0–3.1                                               | [68]      |
| Catfish fillet       | Storage (4 °C, 14 d) | *Listeria monocytogenes* | CAR/thyme oil/oregano oil 1–5% | <4                                                   | [69]      |
| Taramosalata         | Storage (4, 10 °C, 9 d) | *Salmonella Enteritidis* *Listeria monocytogenes* | mint oil 0.5–2.0% | 1.1–1.9                                               | [70]      |
| Mozzarella cheese    | 60 °C (1, 3, 7 h)  | *Salmonella spp.* | TM/CA 200–600 μg/mL of air | >3                                                   | [65]      |
| Honeydew             | Storage (4 °C, 21 d) | Natural flora | CA 5–15 mM | <5.1                                                 | [63]      |
| Lettuce/baby carrot  | 1–15 min           | *Escherichia coli* O157:H7 | thyme oil 0.1–10.0 μg/mL | 1.5–2.0                                              | [72]      |
| Boiled rice          |                    | *Bacillus cereus* | CAR 0.15–0.75 μg/mg | 1.0–3.8                                              | [73]      |

1 Abbreviation of essential oils: carvacrol (CAR), thymol (TM), cinnamaldehyde (CA), eugenol (EUG), and vanillin (VNL).
Table 3. Antimicrobial efficacy of singular treatment of essential oils in microbial suspension.

| Medium                              | Treatment Conditions | Target Microorganisms                  | Singular Treatment ¹ | Antibacterial Effects (Log Reduction; Log CFU/g or mL) | References |
|-------------------------------------|----------------------|----------------------------------------|----------------------|--------------------------------------------------------|------------|
| 0.85% saline                        | 37 °C, 10 min        | *Escherichia coli* O157:H7             | CAR/EUG/RA/TC/TM/VNL 1 mM | negligible (ca. <1)                                     | [25]       |
|                                     | 22 °C, 5 min         | *Escherichia coli*                     | CAR/TM 2 mM          | negligible (ca. <1)                                     | [45]       |
| Deionized water                     | 22 °C, 10 min        | *Listeria monocytogenes*               | TM 2 mM              | negligible (ca. <1)                                     | [44]       |
|                                     | 22 °C, 10 min        | *Escherichia coli* O157:H7             | CAR 2 mM             | 1–2                                                    |            |
| Deionized water (with 10 µg/µL Tween 80) | 1 min ²             | *Escherichia coli* O157:H7             | CAR 0.875 µg/mL      | >4                                                     | [46]       |
| 0.1% peptone water                  | 37 °C, 30 min        | *Escherichia coli* O157:H7             | cinnamon bark oil 0.0625% | ³                         |            |
|                                     |                      | *Salmonella Typhimurium*               | cinnamon leaf oil 0.0625% | ³                         |            |
|                                     |                      | *Escherichia coli*                     | cinnamon bark oil 0.0625% | ³                         |            |
|                                     |                      |                                           | cinnamon leaf oil 0.0625% | ³                         |            |
|                                     |                      |                                           | *Mentha arvensis* L. 0.625 | >5                         | [49]       |
| Brain heart infusion broth          | 4 °C, 8 h            | *Escherichia coli*                     | Mentha *piperita* oil 5 µL/mL | >5                         | [49]       |
|                                     | 37 °C, 8 h           | *Salmonella Enteritidis*               | *Mentha arvensis* L. 0.625 | >5                         | [50]       |
|                                     |                      | *Escherichia coli*                     | armoise oil 0.10% | >8.0                              |            |
|                                     |                      |                                           | clove oil 0.10%    | >7.5                              |            |
|                                     |                      | *Escherichia coli*                     | orange oil 10% | 7                                  | [47]       |
| Butterfield’s phosphate buffer      | 2 min ²              | *Salmonella Typhimurium*               | *Bunium persicum* (Black zira) oil 0.20% | ³                         | [52]       |
| Fish peptone broth                  | 4 °C, 12 d           | *Listeria monocytogenes*               | *Bunium persicum* (Black zira) oil 0.20% | ³                         | [52]       |
| Medium                      | Treatment Conditions | Target Microorganisms                      | Singular Treatment 1 | Antibacterial Effects (Log Reduction; Log CFU/g or mL) | References |
|-----------------------------|----------------------|--------------------------------------------|----------------------|--------------------------------------------------------|------------|
| Luria-Bertani broth         | 22 °C, 3 h           | *Escherichia coli* O157:H7                 | TM 150 µg/mL         | 1                                                      | [59]       |
|                             |                      | *Cronobacter sakazakii*                    | CAR 300 µg/mL        | 1                                                      |            |
|                             |                      |                                             | TC 350 µg/mL         | 1                                                      |            |
| Mueller-Hinton broth        | 4 °C, 24 h           | *Campylobacter jejuni*                     | rosemary extract 310 µg/mL | 7                                                      | [51]       |
|                             | 37 °C, 0.17 h        | *Escherichia coli*                         | oregano oil 0.596 µg/mL | 5                                                      |            |
|                             |                      | *Staphylococcus aureus*                    |                     |                                                        |            |
| Phosphate-buffered saline   | 37 °C, 72 h          | *Salmonella Typhimurium*                   | bark cinnamon oil 0.5% | >9                                                     | [48]       |
|                             | 37 °C, 8 h           | *Listeria monocytogenes*                   | leaf cinnamon oil 0.5% | >9                                                     |            |
|                             | 2 min                | *Vibrio parahaemolyticus*                  | orange oil 10%       | 7                                                      | [47]       |
|                             |                      |                                             |                     |                                                        |            |
|                             | 32 °C, 24 h          | *Listeria monocytogenes*                   | bark cinnamon oil 313 ppm | 2.0                                                   | [49]       |
|                             |                      |                                             | TM 625 ppm           | 5.3                                                    |            |
|                             | 37 °C, 16 h          | *Escherichia coli* O157:H7                 | noni oil 4 µL/mL     | >8                                                     | [54]       |
|                             |                      | *Salmonella enterica*                      | noni oil 4 µL/mL     | >8                                                     |            |
|                             | 32 °C, 24 h          | *Salmonella Typhimurium*                   | clove oil 600 µg/mL  | >5                                                     | [55]       |
|                             |                      |                                             | garlic/cinnamon oil 600 µg/mL | 3                                                      |            |
| Tryptic soy broth           | 37 °C, 24 h          | *Listeria monocytogenes*                   | garlic/clove oil 400 µg/mL | >5                                                     | [56]       |
|                             |                      | *Escherichia coli*                         | Eucalyptus globulus oil 5 µL/mL | 8.7                                                   |            |
|                             |                      | *Salmonella Enteritidis*                   | Eucalyptus globulus oil 7.5 µL/mL | 8.1                                                   |            |
|                             | 37 °C, 24 h          | *Bacillus cereus*                          | Eucalyptus globulus oil 5 µL/mL | 9.0                                                   | [56]       |
|                             |                      | *Staphylococcus aureus*                    | Eucalyptus globulus oil 5 µL/mL | 9.0                                                   |            |
|                             |                      | *Escherichia coli*                         | Eucalyptus globulus oil 5 µL/mL | 9.0                                                   |            |
|                             | 35 °C, 3 h           | *Listeria monocytogenes*                   | TM 300 ppm           | 4–5                                                    | [57]       |
|                             |                      | *Salmonella Typhimurium*                   | TM 500 ppm           | 4–5                                                    |            |
|                             | 37 °C, 24 h          | *Escherichia coli*                         | EUG/VNL 125 µg/mL    | 7                                                      | [58]       |

1 Abbreviation of essential oils: carvacrol (CAR), eugenol (EUG), β-resorcylic acid (RA), trans-cinnamaldehyde (TC), thymol (TM), and vanillin (VNL). 2 Treatment temperature was not indicated in the previous reports.
3. Antibacterial Complex Using EOs

The development and the application of a technological basis for combined treatments using EOs have focused on the unexpected effects of the formulation of antibacterial complexes. The use of combinations of multiple antimicrobial agents can result in various combined effects according to the composition and concentration of the components [74–76] (Figure 1): (1) Synergistic effects: antimicrobial activity of the blend of antimicrobial that is greater than the sum of the effects of the individual components, (2) additive effects: the antimicrobial activity is equal to the sum of the effects of the individual components, (3) antagonistic effects: the antimicrobial activity is less than the sum of the effects of the individual components.

![Figure 1. Combined effects of antibacterial complex composed with multiple antimicrobial agents: synergistic effect (a); additive effect (b); antagonistic effect (c).](image)

As shown in Table 4, recent studies on antibacterial complexes have mainly reported synergistic or antagonistic effects rather than additive effects. The aims of developing combined treatment technologies inducing antibacterial synergism are mainly broadening the applicability of EOs: 1) The maximization of the antimicrobial effects and 2) the optimization of treatment conditions especially for major factors influencing treatment efficiency (e.g., shortening treatment time, manipulating the composition of antibacterial complex specialized for stress-adapted and/or stress-tolerant pathogens). Since EOs are representative compounds obtained from natural sources (e.g., plants), the combination of natural agents was considered a primary technological hurdle, and antibacterial complexes formulated from several EOs were developed [36,37]. Pei et al. [36] reported the antibacterial synergism between EUG and three other EOs (CA, CAR, TM) against *E. coli*; antibacterial mechanisms of the combinations could be hypothesized that CAR and TM may have disintegrated the outer membrane of the target pathogen [17,32], helping EUG to easily enter the cytoplasm and combine with proteins [77]. It was also suggested that the synergism from EUG + CA was based on their action on diverse proteins or enzymes in bacterial cells.

Formulations consisting of EOs with other natural antimicrobials were also suggested including medium chain fatty acids (MCFAs) [25,62], organic acids (OAs) [37], MCFAs + OAs (caprylic acid + citric acid) [78], citrus fruit extracts [45], nisin [79–82], and foodstuffs [e.g., sodium chloride (NaCl), soy sauce, and teriyaki sauce] [50,44,83]. Enhancing the antibacterial effects of EOs by inducing synergism was also achieved with chelating agents (e.g., EDTA) [37] and nanomaterials [e.g., biological silver nanoparticles (bio-AgNPs)] [67]. In the case of antagonistic effects, researchers have focused on the occurrence of undesirable decreases in the antibacterial effects of combined treatments to facilitate 1) the prevention of overestimating the EOs’ efficacy, and 2) the establishment of countermeasures against these unexpected combined effects prior to practical application [29,74,76]. Combined effects can vary based on the target bacterial species, highlighting the importance of the evaluation of antibacterial complexes for each target bacterial species; as shown by research on the complex formulated from lauric alginate with EO, which showed synergistic effects against *L. monocytogenes* but antagonistic effects against *E. coli* O157:H7 and *S. Enteritidis* [84].
Table 4. Efficacy of combined treatment of essential oils as antibacterial complex.

| Components of the EO-Based Antibacterial Complex | Treatment Conditions | Target Microorganisms | Combined Treatment 1 | Antibacterial Effects (Log Reduction; Log CFU/g or mL) [combined effect] | Reference |
|--------------------------------------------------|----------------------|-----------------------|----------------------|--------------------------------------------------------------------------------|-----------|
| Combination of EOs                                | 37 °C, 24 h          | *Escherichia coli*    | CA 100 mg/L + TM 100 mg/L                                  | 2.2 [Synergism] | [36,37] |
|                                                  |                      |                      | CA 100 mg/L + CAR 100 mg/L                               | 2.1 [Synergism] |          |
|                                                  |                      |                      | TM 100 mg/L + CAR 100 mg/L                               | 2.4 [Synergism] |          |
|                                                  |                      |                      | CA 50 mg/L + TM 100 mg/L                                 | 0.44 [Synergism] |          |
|                                                  |                      | *Salmonella Typhimurium* | CA 50 mg/L + CAR 100 mg/L                               | 0.42 [Synergism] | [37]     |
|                                                  |                      |                      | TM 100 mg/L + CAR 100 mg/L                               | 0.27 [Synergism] |          |
| Medium chain fatty acid                          | 37 °C, 24 h          | *Escherichia coli* O157:H7 | Caprylic acid 0.4 mM + capric acid 0.4 mM + RA/CAR/EUG/TC 0.4 mM | >7 [Synergism] | [25]     |
|                                                  |                      |                      | caprylic acid 1.0 mM + RA/CAR/EUG/TC 1.0 mM lauric acid 0.5 mM + RA/CAR/TM 1.0 mM |          |          |
|                                                  |                      |                      | caprylic acid 20 mM + VNL 30 mM lactic acid 0.10% + CAR 200 µL/L | >7 [Synergism] | [62]     |
| Organic acid                                     | 40 °C, 10 min        | *Cronobacter sakazakii* | caprylic acid 20 mM + VNL 30 mM lactic acid 0.10% + CAR 200 µL/L | 0.37 [Synergism] |          |
|                                                  | 40 °C, 5 min         | *Salmonella Typhimurium* | lactic acid 0.10% + CAR 200 µL/L acetic acid 0.05% + TM 100 mg/L | 0.57 [Synergism] | [37]     |
|                                                  |                      |                      | acetic acid 0.05% + CAR 100 µL/L                         | 0.15 [Synergism] |          |
| Caprylic acid + citric acid                      | 3 °C, 10 d           | *Listeria monocytogenes* | 0.5% caprylic acid + 0.1% citric acid + 0.2% oregano oil | <5 [Synergism] | [78]     |
| Citrus fruit extracts                            | 22 °C, 5 min         | *Escherichia coli* O157:H7 (Acid-adapted) | calamansi 10% + CAR/TM 2.0 mM | >6.9 [Synergism] | [45]     |
|                                                  |                      | *Salmonella Typhimurium* (Acid-adapted) | calamansi/lemon 10% + CAR/TM 2.0 mM |          |          |
|                                                  |                      | *Listeria monocytogenes* (Acid-adapted) | calamansi/lemon/lime 10% + CAR/TM 2.0 mM |          |          |
|                                                  |                      | *Listeria monocytogenes* | LAE 375 ppm + cinnamon leaf oil/EUG/TM 3,000 ppm | >4 [Synergism] | [84]     |
| Lauric arginate (LAE)                            | 21 °C, 48 h          | *Escherichia coli* O157:H7 | LAE 375 ppm + cinnamon leaf oil/EUG 2,500 ppm | >2 log growth 2 [Antagonism] |          |
|                                                  |                      |                      | LAE 375 ppm + TM 2,000 ppm                               | >2 log growth 2 [Antagonism] |          |
### Table 4. Cont.

| Components of the EO-Based Antibacterial Complex | Treatment Conditions | Target Microorganisms | Combined Treatment ¹ | Antibacterial Effects (Log Reduction; Log CFU/g or mL) [combined effect] | Reference |
|-------------------------------------------------|----------------------|-----------------------|-----------------------|-------------------------------------------------------------------------|-----------|
| 8 °C, 20 min | **Salmonella Enteritidis** | LAE 375 ppm + cinnamon leaf oil/EUG 2,500 ppm | 1 log growth ² [Antagonism] | [79] |
| 8 °C, 30 min | **Listeria monocytogenes** | nisin 5.3 µg/mL + CAR 1.3 mmol/L | >1 log growth ² [Antagonism] | [79] |
| 4 °C, 12 d | **Staphylococcus aureus** | nisin 1000 IU/g + thyme essential oil 0.6% | 4.0 log reduction [Synergism] | [80] |
| 4 °C, 12 d | **Salmonella Enteritidis** | nisin 500 IU/g + oregano essential oil 0.9% | ca. 3 log reduction [Synergism] | [81] |
| 37 °C, 32 h | **Escherichia coli O157:H7** | nisin 500 IU/g + thyme essential oil 0.6% | ca. 1 log reduction [Synergism] | [81] |
| 37 °C, 24 h | **Salmonella Typhimurium** | EDTA 75 mg/L + TM 100 mg/L | 0.7 log reduction [Synergism] | [37] |
| 22 °C, 1 min | **Listeria monocytogenes** | sodium chloride 5% + CAR 2.0 mM | 7 log reduction [Synergism] | [44] |
| 22 °C, 1 min | **Staphylococcus aureus** | sodium chloride 10% + CAR 2.0 mM | 7 log reduction [Synergism] | [44] |
| 4 °C, 5 min | **Escherichia coli O157:H7** | soy sauce + TM 0.5 mM | 7 log reduction [Synergism] | [30] |
| 4 °C, 5 min | **Listeria monocytogenes** | soy sauce + TM 0.5 mM | 7 log reduction [Synergism] | [30] |
| 4 °C, 10 min | **Salmonella Typhimurium** | soy sauce + TM 0.5 mM | 7 log reduction [Synergism] | [30] |
| 4 °C, 7 d | **Escherichia coli O157:H7** | teriyaki sauce + TM/CAR 0.5% | 3.0–3.4 log reduction [Synergism] | [83] |
| 37 °C, 24 h | **Salmonella Typhimurium** | bio-AgNP 125 µM + *Origanum vulgare* oil 0.298 mg/mL | >5 log reduction [Synergism] | [67] |
| 37 °C, 24 h | **Methicillin resistant Staphylococcus aureus** | bio-AgNP 31.25 µM + *Origanum vulgare* oil 0.075 mg/mL | >5 log reduction [Synergism] | [67] |

¹ Abbreviation of essential oils: cinnamaldehyde (CA), thymol (TM), carvacrol (CAR), β-resorcylic acid (RA), eugenol (EUG), and trans-cinnamaldehyde (TC).
4. Antimicrobial Mechanisms of EO Complex against Pathogens

The modes of action (MOAs) of the antimicrobial effects of EOs have been investigated from the perspective of the interactions between EOs and the target microorganisms. Although the mechanisms are not yet fully understood and remain controversial, key principles have been reported for representative EOs (e.g., CAR, TM, EUG, and TC). These principles include: (1) Disrupting the outer membrane; (2) causing cell lysis or the release of lipopolysaccharides; (3) changing the fatty acid composition of the membrane; (4) dissolving, aligning, or forming channels in the phospholipid bilayer; (5) interfering with or inhibiting glucose uptake; and (6) inhibiting enzyme activity [18,85]. Previous studies regarding the MOA of the antibacterial effects of EOs have suggested that those mechanisms involve changing the characteristics of the membrane [17,31,32,86,87]. The specific membrane changes by EOs have mainly been attributed to the destruction of the membrane based on the damage to the cytoplasmic membrane (e.g., CAR and TM) [17] or the alteration of the membrane fatty acid composition (e.g., EUG and TC) [88].

In the case of MOAs regarding the EO-based antibacterial complexes, most previous relevant studies have focused on the mechanisms of the combined effect derived from the growth inhibition caused by long-term exposure (e.g., using the MIC test, and checkerboard assay) [18,23,26,29,42,89,90]. Since the general aim of combined treatments is to achieve synergistic activity by using the smallest quantity of EOs with short-term exposure [14], the investigation of the MOA of synergistic bactericidal effects validated by quantitative microbiological analysis is regarded as primary information in the research fields of antibacterial complexes. Direct comparison of the characteristics for target bacterial cells subjected to singular treatments that showed negligible bactericidal effects and combined treatment showing dramatic synergism is expected to provide key evidence for the antibacterial synergism.

Since the cell membrane disruption is a major antibacterial mechanism of EOs, researches on the MOA of EO-based complexes have also focused on membrane integrity of bacteria after the singular or combined treatment [44,62]. According to the research by Choi et al. [62], time-dependent changes in membrane integrity analyzed by flow cytometry showed gradual increases in the population of permeabilized cells (i.e., membrane-disrupted cells) for both C. sakazakii and S. Typhimurium following combined treatment with caprylic acid + VNL (Figure 2). Because flow cytometry can be used to demonstrate the MOA of EOs, comprehensive analysis of the results of flow cytometry in conjunction with TEM was adopted for elucidating the mechanisms of combined effects relative to those of singular treatments; this strategy was used to study S. aureus treated with CAR + NaCl [44]. As shown in Figure 3, comprehensive analysis of flow cytometry plots and TEM images indicates that the target cells treated by antibacterial complexes have characteristics distinct from cells treated with the components of these complexes. TEM images following singular treatments with CAR and NaCl showed disrupted membranes with damage to the cytoplasm and a decrease in the density of the cytoplasm, respectively. However, most of those cells maintained their morphological characteristics despite the slight increases in damaged cells observed by flow cytometry, highlighting that membrane damage caused by singular treatments using low quantity of EOs with short-term exposure was reversible and insufficient for affecting viability [9]. The combined treatments showed evidence of irreversible damage or cell death by both analytical methods (flow cytometry and TEM) based on the increases in the population of damaged/dead cells and highly deformed membranes allowing the leakage of cellular material from the cells, respectively.
Figure 2. Time-dependent flow cytometry plots for the demonstration of the cell membrane destruction by the EO-based antibacterial complex against *Cronobacter sakazakii* and *Salmonella Typhimurium* treated with caprylic acid + vanillin. This figure was adopted from Choi et al. [62].
5. Practical Application of EO-Based Antibacterial Complex

The development of disinfectants in the form of emulsions or antibacterial films are representative applications of antibacterial complexes. Commercial disinfectant products are generally formulated with various materials other than EOs, and their antibacterial effects are likely to vary based on the amounts and identities of those components [29,91,92]. However, as shown in Table 5, most previous studies regarding the evaluation of the antimicrobial efficacies of the disinfectants have focused on the direct evaluation of the end-product of the formulation rather than the contribution of each component from antibacterial complex. Since EOs incorporated into antibacterial complexes are typically crude extracts rather than EO components (e.g., CA, CAR, and EUG) [93,94], unfortunately, the comparative analysis of the findings from those studies and the identification of the impact from incorporating each ingredient other than EO (e.g., the bonding agent, surfactant, thickener, emulsion stabilizer, emulsifier, ointment base, preservative, film former, plasticizer, detergent, cation, and organic substances) are unavailable.
Table 5. Major ingredients and antibacterial efficacy of EO-based disinfectant composites.

| Species                  | Product Type                      | No. of Components Other than EO \(^1\) | EO with Antibacterial Activity \(^2\) | Test Method              | Reference |
|--------------------------|-----------------------------------|---------------------------------------|-----------------------------------|--------------------------|-----------|
| *Acinetobacter baumanii* | EO + Interfering substance        | 1                                     | tea tree oil                      | Agar diffusion, broth dilution | [95]      |
| *Aeromonas sobria*       | EO + Interfering substance        | 1                                     | tea tree oil                      | Agar diffusion, broth dilution | [95]      |
| *Bacillus cereus*        | Carboxymethyl cellulose film      | 2                                     | *Zataria multiflora Boiss* oil    | Agar diffusion            | [96]      |
|                          | Emulsion                          | 8                                     | *Thymus vulgaris, Origanum onites*| Agar diffusion            | [97]      |
|                          | Corn and wheat starch film        | 7                                     | cinnamon, lavender, lemongrass, lemon oil, peppermint, tea tree | Agar diffusion            | [98]      |
| *Escherichia coli*       | Wound dressing films              | 3                                     | lemon oil                         | Agar diffusion            | [99]      |
|                          | Carboxymethyl cellulose film      | 2                                     | *Zataria multiflora Boiss* oil    | Agar diffusion            | [96]      |
|                          | Water-based emulsion              | 2                                     | garlic oil                        | Agar diffusion            | [100]     |
|                          | Cream formulation                 | 7                                     | *Lavandula officinalis, Melaleuca alternifolia, Cinnamomum zeylanicu* oils | Time-kill assay           | [101]     |
|                          | Chitosan film                     | 3                                     | *Eucalyptus globulus* oil         | Agar diffusion            | [102]     |
|                          | Emulsion                          | 2                                     | lemongrass, majoram, clove, palmarosa, tea tree, rosewood, thyme, sage, geranium, mint | Time-kill assay           | [103]     |
|                          | Gelatin film                      | 2                                     | oregano, lavender oil             | Agar diffusion            | [104]     |
|                          | Cellulose film                    | 2                                     | CA, EUG                           | Vapor diffusion           | [93]      |
|                          | Surfactant micelles               | 1                                     | CAR, EUG                          | Broth dilution            | [94]      |
| *Escherichia coli O157:H7*| Emulsion                          | 1                                     | thyme oil                         | Broth dilution            | [105]     |
|                          | Chitosan film                     | 3                                     | oregano oil                       | Agar diffusion            | [106]     |
|                          | Emulsion                          | 8                                     | *Origanum onites*                 | Agar diffusion            | [97]      |
| *Enterococcus faecalis*  | EO + Interfering substance        | 1                                     | tea tree oil                      | Agar diffusion, broth dilution | [95]      |
| *Klebsiella pneumoniae*  | EO + Interfering substance        | 1                                     | tea tree oil                      | Agar diffusion, broth dilution | [95]      |
| Species                        | Product Type                  | No. of Components Other than EO | EO with Antibacterial Activity | Test Method           | Reference |
|-------------------------------|-------------------------------|---------------------------------|--------------------------------|-----------------------|-----------|
| *Listeria monocytogenes*      | Surfactant micelles           | 1                               | CAR, EUG                       | Broth dilution        | [94]      |
|                               | Water-based emulsion          | 2                               | garlic oil                     | Agar diffusion        | [100]     |
|                               | Edible coating                | 2                               | ginger oil                     | Agar diffusion        | [107]     |
|                               | Emulsion                      | 1                               | thyme oil                      | Broth dilution        | [105]     |
|                               | Cellulose film                | 2                               | CA, EUG                        | Vapor diffusion       | [93]      |
|                               | Chitosan film                 | 3                               | oregano oil                    | Agar diffusion        | [106]     |
| *Paenibacillus larvae*        | EO + Emulsifier               | 1                               | wild chamomile, Andean thyme   | Broth dilution        | [108]     |
|                               | Carboxymethyl cellulose film  | 2                               | *Zataria multiflora Boiss* oil | Agar diffusion        | [96]      |
|                               |                               |                                 | *Lavandula officinalis,*       |                      |           |
|                               |                               |                                 | *Melaleuca alternifolia,*      |                      |           |
|                               |                               |                                 | *Cinnamomum zeylanicum* oils   |                      |           |
| *Pseudomonas aeruginosa*      | Cream formulation             | 7                               |                               | Time-kill assay       | [101]     |
|                               | Chitosan film                 | 3                               | *Eucalyptus globulus* oil      | Agar diffusion        | [102]     |
|                               |                               |                                 | tea tree oil                   |                      |           |
|                               | EO + Interfering substance    | 1                               | *Ocimum gratissimum* leaf oil  | Agar diffusion, broth dilution | [95]     |
|                               | Topical formulation           | 1-4                             |                               |                      |           |
|                               |                               |                                 | *Thymus vulgaris,* *Origanum*  |                      |           |
|                               |                               |                                 | *Onites*                       |                      |           |
|                               |                               |                                 | *Ocimum gratissimum* leaf oil  |                      |           |
|                               |                               |                                 |                               |                      |           |
|                               | Wound dressing films          | 3                               | lemon oil                      | Agar diffusion        | [99]      |
|                               | Topical formulation           | 1-4                             | *Ocimum gratissimum* leaf oil  | Agar diffusion        | [109]     |
|                               |                               |                                 |                               |                      |           |
| *Proteus* spp.                | Topical formulation           | 1-4                             |                               |                      |           |
|                               |                               |                                 | *Thymus vulgaris,* *Origanum*  |                      |           |
|                               |                               |                                 | *Onites*                       |                      |           |
|                               |                               |                                 | *Ocimum gratissimum* leaf oil  |                      |           |
|                               |                               |                                 |                               |                      |           |
| *Staphylococcus aureus*       | EO + Preservative             | 1                               | mint, oregano, rosemary, sage  | Broth dilution        | [110]     |
|                               | Carboxymethyl cellulose film  | 2                               | *Zataria multiflora Boiss* oil | Agar diffusion        | [96]      |
|                               | Water-based emulsion          | 2                               | garlic oil                     | Agar diffusion        | [100]     |
|                               | EO + Emulsifier               | 1                               | oregano oil, cinnamon oil,     | Agar diffusion        | [111]     |
|                               |                               |                                 | tea tree oil, lavender oil     |                      |           |
|                               | Chitosan film                 | 3                               | *Eucalyptus globulus* oil      | Agar diffusion        | [102]     |
|                               |                               |                                 | tea tree oil                   |                      |           |
|                               | EO + Interfering substance    | 1                               |                               |                      |           |
|                               | Gelatin film                  | 2                               | oregano, lavender oil          | Agar diffusion        | [104]     |
|                               | Cellulose film                | 2                               | CA, EUG                        | Vapor diffusion       | [93]      |
| Species                  | Product Type                        | No. of Components Other than EO | EO with Antibacterial Activity | Test Method                       | Reference |
|-------------------------|-------------------------------------|---------------------------------|--------------------------------|-----------------------------------|-----------|
| *Serratia marcescens*   | EO + Interfering substance          | 1                               | tea tree oil                    | Agar diffusion, broth dilution    | [95]      |
|                         | Carboxymethyl cellulose film        | 2                               | *Zataria multiflora Boiss* oil  | Agar diffusion                    | [99]      |
| *Salmonella Typhimurium*| Water-based emulsion                | 2                               | garlic oil                      | Agar diffusion                    | [100]     |
|                         | EO + Interfering substance          | 1                               | tea tree oil                    | Agar diffusion, broth dilution    | [95]      |
|                         | Edible coating                      | 2                               | ginger oil                      | Agar diffusion                    | [107]     |
| *Salmonella Enteritidis*| Emulsion                            | 1                               | thyme oil                       | Broth dilution                    | [105]     |
|                         | Cellulose film                      | 2                               | CA, EUG                         | Vapor diffusion                   | [93]      |

1 Major components are as follows: bonding agent, surfactant, thickener, emulsion stabilizer, emulsifier, ointment base, preservative, film former, plasticizer, detergent, cation, and organic substance. Solvents were excluded from the count.  
2 Abbreviations of essential oils: cinnamaldehyde (CA), carvacrol (CAR), and eugenol (EUG).
However, studies on the differences in the antibacterial activities of EO-based emulsions and free EOs alone have reported that the influences of the composition and/or constituents of the emulsions on the antibacterial characteristics of the EOs varied \[100,105,109,111\]. The evaluation of the antibacterial efficacies of various formulations of emulsions containing Ocimum gratissimum leaf oil revealed the factors that can improve the antibacterial effect, namely, increasing the Ocimum oil content and decreasing the content of the surfactant (Tween 80) \[109\]. Water-based emulsion systems suppressed the antimicrobial activity of garlic EO, and this negative effect was attributed to the relatively small water-soluble fraction of this EO \[100\]. In contrast, the antibacterial effect presented by the EOs alone against methicillin-resistant S. aureus was increased by emulsification with rhamnolipids \[111\]. No difference in the antibacterial activities of the free EO (thyme oil) and emulsion (thyme oil emulsions containing soluble soybean polysaccharide as an emulsifier) was reported based on the identical MIC and MBC values against S. Enteritidis, E. coli O157:H7, and L. monocytogenes, which indicated that the emulsifier did not affect the antibacterial properties of EO \[105\].

The effects of other types of components on the antimicrobial activities of EO have also been reported \[95,110\]. Patrone et al. \[110\] observed synergy in antibacterial effects against P. aeruginosa when eucalyptus and mint oils were combined with methylparaben used as a preservative. Synergistic antibacterial effects against S. aureus induced by combinations of preservatives (propylparaben and imidazolidinyl urea) with mint and oregano EO were also reported \[110\]. Investigations of the influences of organic matter (sheep blood, horse serum, bovine serum albumin, dry bakers’ yeast, and skim-milk powder), surfactants (Tween 20, Tween 80, alkyl dimethyl betaine, and sodium monododecyl sulphate), and cations (Ca\(^{2+}\) and Mg\(^{2+}\)) on the antimicrobial activity of tea tree oil showed that the incorporation of organic matter and surfactants compromised the antimicrobial efficacy of tea tree oil, although certain variations between organisms were observed \[95\].

6. Conclusions

To overcome the disadvantages of EOs (e.g., weak bactericidal effects, high price, and unpleasant odors), most studies regarding antibacterial complexes aim to achieve synergistic effects through combined treatments. This review provides comprehensive information regarding the findings and implications of using EOs as natural antibacterial agents, especially from the perspective of antibacterial complexes showing synergistic effects. However, most studies evaluating the antibacterial effects of EOs (in singular or combined treatments) and examining their MOAs are based on long-term exposure to pathogens. To encourage the practical application of EO, novel technologies that can eliminate target pathogens with short-term treatment by synergism from a small amount of antibacterial agent and a MOA linked to the combined effects should be developed. Since the formulation of EO-based disinfectant products can determine efficacy, subsequent studies on the interactions of the constituents of antibacterial complexes are expected to reveal key combinations for improving practical effects. Moreover, in-depth analyses on the combined effects of multiple agents in antibacterial complexes and the environmental conditions that can affect their efficiencies enables the identification of the optimum compositions for disinfectant products. This focus review provides practical information for the application of EO-based antibacterial complexes in the fields of food, public health, medical science, and pharmacology.

**Author Contributions:** Contributions for each author are as follows: conceptualization, T.J.C., H.W.K., S.A.K., M.S.R.; investigation, S.M.P., G.H.S., H.Y.; writing—original draft preparation, T.J.C., S.M.P., G.H.S., H.Y.; writing—review and editing, H.W.K., S.A.K., M.S.R.; supervision, M.S.R.; funding acquisition, M.S.R. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MEST), grant number NRF-2019R1H1A2080024.

**Acknowledgments:** The authors thank the School of Life Science and Biotechnology of Korea University for BK 21 PLUS and the Institute of Biomedical Science and Food Safety, Korea University Food Safety Hall, for access to the equipment and facilities.
Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kalemba, D.A.A.K.; Kunicka, A. Antibacterial and Antifungal Properties of Essential Oils. *Curr. Med. Chem.* 2003, 10, 813–829. [CrossRef]
2. Elshafie, H.S.; Camele, I. An Overview of the Biological Effects of Some Mediterranean Essential Oils on Human Health. *Biomed. Res. Int.* 2017, 2017, 9268468. [CrossRef]
3. Ruberto, G.; Baratta, M.T. Antioxidant Activity of Selected Essential Oil Components in Two Lipid Model Systems. *Food Chem.* 2000, 69, 167–174. [CrossRef]
4. Silva, J.; Abebe, W.; Sousa, S.M.; Duarte, V.G.; Machado, M.I.L.; Matos, F.J.A. Analgesic and Anti-Inflammatory Effects of Essential Oils of Eucalyptus. *J. Ethnopharmacol.* 2003, 89, 277–283. [CrossRef]
5. Deans, S.G.; Ritchie, G. Antibacterial Properties of Plant Essential Oils. *Int. J. Food Microbiol.* 1987, 5, 165–180. [CrossRef]
6. Mourey, A.; Canillac, N. Anti-Listeria monocytogenes Activity of Essential Oils Components of Conifers. *Food Control.* 2002, 13, 289–292. [CrossRef]
7. Burt, S.A.; Reinders, R.D. Antibacterial Activity of Selected Plant Essential Oils Against *Escherichia coli* O157:H7. *Lett. Appl. Microbiol.* 2003, 36, 162–167. [CrossRef] [PubMed]
8. Božović, M.; Garzoli, S.; Sabatino, M.; Pepi, F.; Baldisserotto, A.; Andreotti, E.; Romagnoli, C.; Mai, A.; Manfredini, S.; Rago, R. Essential Oil Extraction, Chemical Analysis and Anti-Candida Activity of Calamintha nepeta (L.) Sav subsp. glandulosa (Req.) Ball-New Approaches. *Molecules* 2017, 22, 203. [CrossRef]
9. Bae, Y.S.; Rhee, M.S. Short-Term Antifungal Treatments of Caprylic Acid with Carvacrol or Thymol Induce Synergistic 6-Log Reduction of Pathogenic *Candida albicans* by Cell Membrane Disruption and Efflux Pump Inhibition. *Cell. Physiol. Biochem.* 2019, 53, 285–300. [CrossRef] [PubMed]
10. Bishop, C.D. Antiviral Activity of the Essential Oil of *Melaleuca alternifolia* (Maiden amp; Betche) Cheel (Tea Tree) Against Tobacco Mosaic Virus. *J. Essent. Oil Res.* 1995, 7, 641–644. [CrossRef]
11. Azzouz, M.A.; Bullerman, L.B. Comparative Antimycotic Effects of Selected Herbs, Spices, Plant Components and Commercial Antifungal Agents. *J. Food Prot.* 1982, 45, 1298–1301. [CrossRef] [PubMed]
12. Anthony, J.-P.; Fyfe, L.; Smith, H. Plant Active Components–A Resource for Antiparasitic Agents? *Trends Parasitol.* 2005, 21, 462–468. [CrossRef] [PubMed]
13. Karpouhtsis, I.; Pardali, E.; Feggou, E.; Kokkini, S.; Scouras, Z.G.; Mavragani-Tsipidou, P. Insecticidal and Genotoxic Activities of Oregano Essential Oils. *J. Agric. Food Chem.* 1998, 46, 1111–1115. [CrossRef]
14. Kim, S.A.; Rhee, M.S. Marked Synergistic Bactericidal Effects of Selected Herbs, Spices, Plant Components and Antifungal Agents. *Int. J. Food Microbiol.* 2004, 94, 223–253. [CrossRef]
15. Bakkali, F.; Averbeck, S.; Averbeck, D.; Idiomar, M. Biological Effects of Essential Oils—A Review. *Food Chem. Toxicol.* 2008, 46, 446–475. [CrossRef] [PubMed]
16. Park, S.H.; Choi, M.R.; Park, J.W.; Park, K.H.; Chung, M.S.; Ryu, S.; Kang, D.H. Use of Organic Acids to Inactivate *Escherichia coli* O157:H7, *Salmonella Typhimurium*, and *Listeria monocytogenes* on Organic Fresh Apples and Lettuce. *J. Food Sci.* 2011, 76, M293–M298. [CrossRef]
17. Dima, C.; Dima, S. Essential Oils in Foods: Extraction, Stabilization, and Toxicity. *Curr. Opin. Food Sci.* 2015, 5, 29–35. [CrossRef]
18. Burt, S. Essential Oils: Their Antibacterial Properties and Potential Applications in Foods—A Review. *Int. J. Food Microbiol.* 2004, 94, 223–253. [CrossRef]
19. Lang, G.; Buchbauer, G. A Review on Recent Research Results (2008–2010) on Essential Oils as Antimicrobials and Antifungals. A Review. *Flavour Frag. J.* 2012, 27, 13–39. [CrossRef]
20. Raut, J.S.; Karuppayil, S.M. A Status Review on the Medicinal Properties of Essential Oils. *Ind. Crop. Prod.* 2014, 62, 250–264. [CrossRef]
21. Kim, S.S.; Kang, D.H. Synergistic Effect of Carvacrol and Ohmic Heating for Inactivation of *E. coli* O157:H7, *S. Typhimurium, L. monocytogenes*, and MS-2 Bacteriophage in Salsa. *Food Control.* 2017, 73, 300–305. [CrossRef]
22. Sivakumar, D.; Bautista-Baños, S. A Review on the Use of Essential Oils for Postharvest Decay Control and Maintenance of Fruit Quality During Storage. *Crop. Prot.* 2014, 64, 27–37. [CrossRef]
23. Bassolé, I.H.N.; Juliani, H.R. Essential Oils in Combination and Their Antimicrobial Properties. *Molecules* 2012, 17, 3989–4006. [CrossRef] [PubMed]

24. Ocampo, P.S.; Lazar, V.; Papp, B.; Arnoldini, M.; zur Wiesch, P.A.; dBusa-Fekete, R.; Fekete, G.; Pál, C.; Ackermann, M.; Banhoeffer, S. Antagonism between Bacteriostatic and Bactericidal Antibiotics is Prevalent. *Antimicrob. Agents Chemother.* 2014, 58, 4573–4582. [CrossRef]

25. Kim, S.A.; Rhee, M.S. Highly Enhanced Bactericidal Effects of Medium Chain Fatty Acids (Caprylic, Capric, and Lauric Acid) Combined with Edible Plant Essential Oils (Carvacrol, Eugenol, β-Resorcylic Acid, Trans-Cinnamaldehyde, Thymol, and Vanillin) Against *Escherichia coli* O157:H7. *Food Control*. 2016, 60, 447–454. [CrossRef]

26. Calo, J.R.; Crandall, P.G.; O’Bryan, C.A.; Ricke, S.C. Essential Oils as Antimicrobials in Food Systems—A Review. *Food Control*. 2015, 54, 111–119. [CrossRef]

27. Elshafie, H.S.; Aliberti, L.; Amato, M.; de Feo, V.; Camele, I. Chemical Composition and Antimicrobial Activity of Chia (*Salvia hispanica*) Essential Oil. *Eur. Food Res. Technol.* 2018, 244, 1675–1682. [CrossRef]

28. Elshafie, H.S.; Gruľ’ová, D.; Baranová, B.; Caputo, L.; De Martino, L.; Sdlæk, V.; Camele, I.; de Feo, V. Antimicrobial Activity and Chemical Composition of Essential Oil Extracted from *Solidago canadensis* L. Growing Wild in Slovakia. *Molecules* 2019, 24, 1206. [CrossRef]

29. Langeveld, W.T.; Veldhuizen, E.J.A.; Burt, S.A. Synergy Between Essential Oil Components and Antibiotics: A Review. *Crit. Rev. Microbiol.* 2014, 40, 76–94. [CrossRef]

30. Moon, H.; Rhee, M.S. Synergism Between Carvacrol or Thymol Increases the Antimicrobial Efficacy of Soy Sauce with No Sensory Impact. *Int. J. Food Microbiol.* 2016, 217, 35–41. [CrossRef]

31. Oussalah, M.; Caillet, S.; Lacroix, M. Mechanism of Action of Spanish Oregano, Chinese Cinnamon, and Savory Essential Oils Against Cell Membranes and Walls of *Escherichia coli* O157:H7 and *Listeria monocytogenes*. *J. Food Prot.* 2006, 69, 1046–1055. [CrossRef] [PubMed]

32. Helander, I.M.; Alakomi, H.-L.; Latva-Kala, K.; Mattila-Sandholm, T.; Pol, I.; Smid, E.J.; Gorris, L.G.M.; von Wright, A. Characterization of the Action of Selected Essential Oil Components on Gram-Negative Bacteria. *J. Agric. Food Chem.* 1998, 46, 3590–3595. [CrossRef]

33. Kim, J.; Marshall, M.R.; Wei, C.-I. Antibacterial Activity of Some Essential Oil Components Against Five Foodborne Pathogens. *J. Agric. Food Chem.* 1995, 43, 2839–2845. [CrossRef]

34. Gill, A.O.; Holley, R.A. Mechanisms of Bactericidal Action of Cinnamaldehyde Against *Listeria monocytogenes* and of Eugenol Against *L. monocytogenes* and *Lactobacillus sakei*. *Appl. Environ. Microbiol.* 2004, 70, 5750–5755. [CrossRef] [PubMed]

35. Fitzgerald, D.J.; Stratford, M.; Gasson, M.J.; Ueckert, J.; Bos, A.; Narbad, A. Mode of Antimicrobial Action of Vanillin Against *Escherichia coli*, *Lactobacillus plantarum* and *Listeria innocua*. *J. Appl. Microbiol.* 2004, 97, 104–113. [CrossRef]

36. Pei, R.S.; Zhou, F.; Ji, B.P.; Xu, J. Evaluation of Combined Antibacterial Effects of Eugenol, Cinnamaldehyde, Thymol, and Carvacrol against *E. coli* with an Improved Method. *J. Food Sci.* 2009, 74, M379–M383. [CrossRef]

37. Zhou, F.; Ji, B.; Zhang, H.; Jiang, H.; Yang, Z.; Li, J.; Li, J.; Yan, W. The Antibacterial Effect of Cinnamaldehyde, Thymol, Carvacrol and Their Combinations Against the Foodborne Pathogen *Salmonella* Typhimurium. *J. Food Saf.* 2007, 27, 124–133. [CrossRef]

38. Ullee, A.; Bennik, M.H.J.; Moezelaar, R. The Phenolic Hydroxyl Group of Carvacrol is Essential for Action Against the Food-Borne Pathogen *Bacillus cereus*. *Appl. Environ. Microbiol.* 2002, 68, 1561–1568. [CrossRef]

39. Kim, H.O.; Park, S.W.; Park, H.D. Inactivation of *Escherichia coli* O157:H7 by Cinnamic Aldehyde Purified from *Cinnamomum cassia* Shoot. *Food Microbiol.* 2004, 21, 105–110. [CrossRef]

40. Cosentino, S.; Tuberoso, C.I.G.; Pisano, B.; Satta, M.I.; Mascia, V.; Arzedi, E.; Palmas, F. *In-vitro* Antimicrobial Activity and Chemical Composition of Sardinian *Thymus* Essential Oils. *Lett. Appl. Microbiol.* 1999, 29, 130–135. [CrossRef]

41. Lamberts, R.J.W.; Skandamis, P.N.; Coote, P.J.; Nychas, G.E. A study of the minimum inhibitory concentration and mode of action of oregano essential oil, thymol and carvacrol. *J. Appl. Microbiol.* 2001, 91, 453–462. [CrossRef] [PubMed]

42. Bajpai, V.K.; Baek, K.-H.; Kang, S.C. Control of *Salmonella* in Foods by Using Essential Oils: A Review. *Food Res. Int.* 2012, 45, 722–734. [CrossRef]
43. Freires, I.A.; Denny, C.; Benso, B.; De Alencar, S.M.; Rosalen, P.L. Antibacterial Activity of Essential Oils and Their Isolated Constituents Against Cariogenic Bacteria: A Systematic Review. *Molecules* **2015**, *20*, 7329–7358. [CrossRef] [PubMed]

44. Kim, N.H.; Kim, H.W.; Moon, H.; Rhee, M.S. Sodium Chloride Significantly Enhances the Bactericidal Actions of Carvacrol and Thymol Against the Halotolerant Species *Escherichia coli* O157:H7, *Listeria monocytogenes*, and *Staphylococcus aureus*. *Lwt-Food Sci. Technol.* **2020**, *109015*. [CrossRef]

45. Chung, D.; Cho, T.J.; Rhee, M.S. Citrus Fruit Extracts with Carvacrol and Thymol Eliminated 7-log Acid-adapted *Escherichia coli* O157:H7, *Salmonella typhimurium*, and *Listeria monocytogenes*: A Potential of Effective Natural Antibacterial Agents. *Food Res. Int.* **2018**, *107*, 578–588. [CrossRef]

46. Abadías, M.; Alegre, I.; Usall, J.; Torres, R.; Viñas, I. Evaluation of Alternative Sanitizers to Chlorine Disinfection for Reducing Foodborne Pathogens in Fresh-cut Apple. *Postharvest Biol. Technol.* **2011**, *59*, 289–297. [CrossRef]

47. Lin, C.M.; Sheu, S.R.; Hsu, S.C.; Tsai, Y.H. Determination of Bactericidal Efficacy of Essential Oil Extracted from Orange Peel on the Food Contact Surfaces. *Food Control* **2010**, *21*, 1710–1715. [CrossRef]

48. Brnawi, W.I.; Hettiarachchy, N.S.; Horax, R.; Kumar-Phillips, G.; Ricke, S. Antimicrobial Activity of Leaf and Bark Cinnamon Essential Oils Against *Listeria monocytogenes* and *Salmonella typhimurium* in Broth System and on Celery. *J. Food Process. Preserv.* 2019, *43*, e13888. [CrossRef]

49. Ma, Q.; Davidson, P.M.; Zhong, Q. Antimicrobial Properties of Microemulsions Formulated with Essential Oils, Soybean Oil, and Tween 80. *Int. J. Food Microbiol.* **2016**, *238*, 183–192. [CrossRef]

50. Bor, T.; Gyawali, R.; Ibrahim, S.A. Evaluating the Effectiveness of Essential Oils and Combination of Copper and Lactic Acid on the Growth of *E. coli* O157: H7 in Laboratory Medium. *Foods* **2016**, *5*, 14. [CrossRef]

51. Piskernik, S.; Klančnik, A.; Riedel, C.T.; Brøndsted, L.; Možina, S.S. Reduction of *Listeria monocytogenes* Growth in Fish Model Systems. *J. Food Saf.* **2013**, *33*, 137–144. [CrossRef]

52. Azadbakht, E.; Maghsoudlou, Y.; Khomiri, M.; Kashiri, M. Development and Structural Characterization of Chitosan Films Containing *Eucalyptus globulus* Essential Oil: Potential as an Antimicrobial Carrier for Packaging of Sliced Sausage. *Food Packag. Shelf Life* **2018**, *17*, 65–72. [CrossRef]

53. Shah, B.; Davidson, P.M.; Zhong, Q. Antibacterial Activity of Nanodispersed Thymol in Tryptic Soy Broth. *J. Food Prot.* **2013**, *76*, 440–447. [CrossRef]

54. Ribes, S.; Ruiz-Rico, M.; Pérez-Esteve, É.; Fuentes, A.; Barat, J.M. Enhancing the Antimicrobial Activity of Eugenol, Carvacrol and Vanillin Immobilised on Silica Supports Against *Escherichia coli* or Zygosaccharomyces rouxii in Fruit Juices by Their Binary Combinations. *Lwt-Food Sci. Technol.* **2019**, *113*, 108326. [CrossRef]

55. Campion, A.; Morrissey, R.; Field, D.; Cotter, P.D.; Hill, C.; Ross, R.P. Use of Enhanced Nisin Derivatives in Combination with Food-grade Oils or Citric Acid to Control *Cronobacter sakazakii* and *Escherichia coli* O157:H7. *Food Microbiol.* **2017**, *65*, 254–263. [CrossRef]

56. Smid, E.J.; Gorris, L.G.M. *Handbook of Food Preservation*; Rahman, M.S., Ed.; Marcel Dekker, Inc.: New York, NY, USA, 1999; pp. 285–308.

57. Gill, A.O.; Delaquis, P.; Russo, P.; Holley, R.A. Evaluation of Antilisterial Action of Cilantro Oil on Vacuum Packed Ham. *Int. J. Food Microbiol.* **2002**, *73*, 83–92. [CrossRef]

58. Choi, M.J.; Kim, S.A.; Lee, N.Y.; Rhee, M.S. New Decontamination Method Based on Caprylic Acid in Combination with Citric Acid or Vanillin for Eliminating *Cronobacter sakazakii* and *Salmonella enterica* serovar Typhimurium in Reconstituted Infant Formula. *Int. J. Food Microbiol.* **2013**, *166*, 499–507. [CrossRef]
63. Roller, S.; Seedhar, P. Carvacrol and Cinnamic Acid Inhibit Microbial Growth in Fresh-Cut Melon and Kiwifruit at 4 °C and 8 °C. Lett. Appl. Microbiol. 2002, 35, 390–394. [CrossRef] [PubMed]

64. Juneja, V.K.; Thippareddi, H.; Friedman, M. Control of Clostridium perfringens in Cooked Ground Beef by Carvacrol, Cinnamaldehyde, Thymol, or Oregano Oil During Chilling. J. Food Prot. 2006, 69, 1546–1551. [CrossRef] [PubMed]

65. Weissinger, W.R.; McWatters, K.H.; Beuchat, L.R. Evaluation of Volatile Chemical Treatments for Lethality to Salmonella on Alfalfa Seeds and Sprouts. J. Food Prot. 2001, 64, 442–450. [CrossRef] [PubMed]

66. Park, J.B.; Kang, J.H.; Song, K.B. Antibacterial Activities of a Cinnamon Essential Oil with Cetylpyridinium Chloride Emulsion Against Escherichia coli O157:H7 and Salmonella Typhimurium in Basil Leaves. Food Sci. Biotechnol. 2018, 27, 47–55. [CrossRef]

67. Scandorieiro, S.; de Camargo, L.C.; Lancheros, C.A.C.; Yamada-Ogatta, S.F.; Nakamura, C.V.; de Oliveira, A.G.; Andrade, C.G.T.J.; Duran, N.; Nakazato, G.; Kobayashi, R.K.T. Synergistic and Additive Effects of Various Extracts of Tetraclinis articulata (Vahl) Masters with Antibiotic and Anti-Inflammatory Effect of Extracts of Thyme Essential Oil, Lactic Acid, and Clove Oil or a Sequential Washing in Killing Escherichia coli O157:H7 on Lettuce and Baby Carrots. Lwt-Food Sci. Technol. 2002, 35, 720–729. [CrossRef] [PubMed]

68. Rhoades, J.; Kargioutou, C.; Katsanidis, E.; Koutsoumanis, K.P. Use of Marination for Controlling Salmonella enterica and Listeria monocytogenes in Raw Beef. Food Microbiol. 2013, 36, 248–253. [CrossRef]

69. Desai, M.A.; Soni, K.A.; Nannapaneni, R.; Schilling, M.; Silva, J.L. Reduction of Listeria monocytogenes in Raw Catfish Fillets by Essential Oils and Phenolic Constituent Carvacrol. J. Food Sci. 2012, 77, M516–M522. [CrossRef]

70. Tassou, C.C.; Drosinos, E.H.; Nychas, G.J.E. Effects of Essential Oil from Mint (Mentha piperita) on Salmonella enteritidis and Listeria monocytogenes in Model Food Systems at 4 °C and 10 °C. J. Appl. Bacteriol. 1995, 78, 593. [CrossRef]

71. Menon, K.V.; Garg, S.R. Inhibitory Effect of Clove Oil on Listeria monocytogenes in Meat and Cheese. Food Microbiol. 2001, 18, 647–650. [CrossRef]

72. Singh, N.; Singh, R.K.; Bhunia, A.K.; Stroshine, R.L. Efficacy of Chlorine Dioxide, Ozone, and Thyme Essential Oil or a Sequential Washing in Killing Escherichia coli O157:H7 on Lettuce and Baby Carrots. Lwt-Food Sci. Technol. 2002, 35, 720–729. [CrossRef] [PubMed]

73. Ultee, A.; Slump, R.A.; Steging, G.; Smid, E.J. Antimicrobial Activity of Carvacrol Toward Bacillus cereus on Rice. J. Food Prot. 2000, 63, 620–624. [CrossRef]

74. Hyldgaard, M.; Mygind, T.; Meyer, R.L. Essential Oils in Food Preservation: Mode of Action, Synergies, and Interactions with Food Matrix Components. Front. Microbiol. 2012, 3, 12. [CrossRef] [PubMed]

75. Iten, F.; Saller, R.; Abel, G.; Reichling, J. Additive Antimicrobial Effects of the Active Components of the Essential Oils of Thymus vulgaris—Chemotype Carvacrol. Planta Med. 2009, 75, 1231–1236. [CrossRef] [PubMed]

76. Djouahri, A.; Saka, B.; Bourdarenne, L.; Benseradji, F.; Aberrane, S.; Aitmoussa, S.; Chelghoum, C.; Lamari, L.; Saboua, N.; Baaliouamer, A. In vitro Synergistic/Antagonistic Antibacterial and Anti-Inflammatory Effect of Various Extracts/Essential Oil from Cones of Tectaclis articulata (Vahl) Masters with Antibiotic and Anti-Inflammatory Agents. Ind. Crop. Prod. 2014, 56, 60–66. [CrossRef]

77. Wendakoan, C.N.; Sakaguchi, M. Combined Effect of Sodium Chloride and Clove on Growth and Biogenic Amine Formation of Enterobacter aerogenes in Mackerel Muscle Extract. J. Food Prot. 1993, 56, 410–413. [CrossRef]

78. Hulankova, R.; Berilova, G.; Steinhauserova, I. Combined Antimicrobial Effect of Oregano Essential Oil and Caprylic Acid in Minced Beef. Meat Sci. 2013, 95, 190–194. [CrossRef]

79. Pol, I.E.; Smid, E.J. Combined Action of Nisin and Carvacrol on Bacillus cereus and Listeria monocytogenes. Lett. Appl. Microbiol. 1999, 29, 166–170. [CrossRef]

80. Solomakos, N.; Govaris, A.; Koidis, P.; Botsoglou, N. The Antimicrobial Effect of Thyme Essential Oil, Nisin, and Their Combination Against Listeria monocytogenes in Minced Beef During Refrigerated Storage. Food Microbiol. 2008, 25, 120–127. [CrossRef]

81. Solomakos, N.; Govaris, A.; Koidis, P.; Botsoglou, N. The Antimicrobial Effect of Thyme Essential Oil, Nisin and Their Combination Against Escherichia coli O157:H7 in Minced Beef During Refrigerated Storage. Meat Sci. 2008, 80, 159–166. [CrossRef]
82. Govaris, A.; Solomakos, N.; Pexara, A.; Chatzopoulou, P.S. The Antimicrobial Effect of Oregano Essential Oil, Nisin and Their Combination Against Salmonella Enteritidis in Minced Sheep Meat During Refrigerated Storage. *Int. J. Food Microbiol.* **2010**, *137*, 175–180. [CrossRef]

83. Moon, H.; Kim, N.H.; Kim, S.H.; Kim, Y.; Ryu, J.H.; Rhee, M.S. Teriyaki Sauce with Carvacrol or Thymol Effectively Controls *Escherichia coli* O157:H7, *Listeria monocytogenes*, *Salmonella* Typhimurium, and Indigenous Flora in Marinated Beef and Marinade. *Meat Sci.* **2017**, *129*, 147–152. [CrossRef]

84. Ma, Q.; Davidson, P.M.; Zhong, Q. Antimicrobial Properties of Lauric Arginate Alone or in Combination with Essential Oils in Tryptic Soy Broth and 2% Reduced Fat Milk. *Int. J. Food Microbiol.* **2013**, *166*, 77–84. [CrossRef]

85. Char, C.D.; Guerrero, S.N.; Alzamora, S.M. Mild Thermal Process Combined with Vanillin Plus Citral to Help Shorten the Inactivation Time for *Listeria innocua* in Orange Juice. *Food Bioprocess. Technol.* **2010**, *3*, 752–761. [CrossRef]

86. Xu, J.; Zhou, F.; Ji, B.P.; Pei, R.S.; Xu, N. The Antibacterial Mechanism of Carvacrol and Thymol Against *Escherichia coli*. *Lett. Appl. Microbiol.* **2008**, *47*, 174–179. [CrossRef] [PubMed]

87. Di Pasqua, R.; Hoskins, N.; Betts, G.; Mauriello, G. Changes in Membrane Fatty Acids Composition of Microbial Cells Induced by Addiction of Thymol, Carvacrol, Limonene, Cinnamaldehyde, and Eugenol in the Growing Media. *J. Agric. Food Chem.* **2006**, *54*, 2745–2749. [CrossRef] [PubMed]

88. Nazzaro, F.; Fratianni, F.; De Martino, L.; Coppola, R.; De Feo, V. Effect of Essential Oils on Pathogenic Bacteria. *Pharmaceuticals* **2013**, *6*, 1451–1474. [CrossRef]

89. Swamy, M.K.; Akhtar, M.S.; Sinniah, U.R. Antimicrobial Properties of Plant Essential Oils Against Human Pathogens and Their Mode of Action: An Updated Review. *Evid.-Based Complement. Altern. Med.* **2016**, *2016*, 3012462. [CrossRef]

90. Hamoud, R.; Sporer, F.; Reichling, J.; Wink, M. Antimicrobial Activity of a Traditionally Used Complex Essential Oil Distillate (Olbas® Tropfen) in Comparison to Its Individual Essential Oil Ingredients. *Phytomedicine* **2012**, *19*, 969–976. [CrossRef]

91. Perricone, M.; Arace, E.; Corbo, M.R.; Sinigaglia, M.; Bevilacqua, A. Bioactivity of Essential Oils: A Review on Their Interaction with Food Components. *Front. Microbiol.* **2015**, *6*, 76. [CrossRef] [PubMed]

92. Sanla-Ead, N.; Jangchud, A.; Chonhenchob, V.; Suppakul, P. Antimicrobial Activity of Cinnamaldehyde and Eugenol and Their Activity after Incorporation into Cellulose-Based Packaging Films. *Packag. Technol. Sci.* **2012**, *25*, 7–17. [CrossRef]

93. Gayinsky, S.; Davidson, P.M.; Bruce, B.D.; Weiss, J. Growth Inhibition of *Escherichia coli* O157:H7 and *Listeria monocytogenes* by Carvacrol and Eugenol Encapsulated in Surfactant Micelles. *J. Food Prot.* **2005**, *68*, 2559–2566. [CrossRef] [PubMed]

94. Di Pasqua, R.; Hoskins, N.; Betts, G.; Mauriello, G. Changes in Membrane Fatty Acids Composition of Microbial Cells Induced by Addiction of Thymol, Carvacrol, Limonene, Cinnamaldehyde, and Eugenol in the Growing Media. *J. Agric. Food Chem.* **2006**, *54*, 2745–2749. [CrossRef] [PubMed]

95. Gaysinsky, S.; Davidson, P.M.; Bruce, B.D.; Weiss, J. Growth Inhibition of *Escherichia coli* O157:H7 and *Listeria monocytogenes* by Carvacrol and Eugenol Encapsulated in Surfactant Micelles. *J. Food Prot.* **2005**, *68*, 2559–2566. [CrossRef] [PubMed]

96. Dashipour, A.; Razavilar, V.; Hosseini, H.; Shojae-Aliabadi, S.; German, J.B.; Ghanati, K.; Khakpour, M.; Khaksar, R. Antioxidant and Antimicrobial Carboxymethyl Cellulose Films Containing Zataria multiflora Essential Oil. *Int. J. Biol. Macromol.* **2015**, *72*, 606–613. [CrossRef]

97. Yorgancioglu, A.; Bayramoglu, E.E. Production of Cosmetic Purpose Collagen Containing Antimicrobial Emulsion with Certain Essential Oils. *Ind. Crop. Prod.* **2013**, *44*, 378–382. [CrossRef]

98. Song, X.; Zuo, G.; Chen, F. Effect of Essential Oil and Surfactant on the Physical and Antimicrobial Properties of Corn and Wheat Starch Films. *Int. J. Biol. Macromol.* **2018**, *107*, 1302–1309. [CrossRef]

99. Liakos, I.; Rizzello, L.; Scurr, D.J.; Pompa, P.P.; Bayer, I.S.; Athanassiou, A. All-Natural Composite Wound Dressing Films of Essential Oils Encapsulated in Sodium Alginate with Antimicrobial Properties. *Int. J. Pharm.* **2014**, *463*, 137–145. [CrossRef]

100. El-Sayed, H.S.; Chizzola, R.; Ramadan, A.A.; Edris, A.E. Chemical Composition and Antimicrobial Activity of Garlic Essential Oils Evaluated in Organic Solvent, Emulsifying, and Self-Microemulsifying Water Based Delivery Systems. *Food Chem.* **2017**, *227*, 196–204. [CrossRef]

101. Herman, A.; Herman, A.P.; Domagalska, B.W.; Młynarczyk, A. Essential Oils and Herbal Extracts as Antimicrobial Agents in Cosmetic Emulsion. *Indian J. Microbiol.* **2013**, *53*, 232–237. [CrossRef]
102. Hafsa, J.; ali Smach, M.; Khedher, M.R.B.; Charfeddine, B.; Limem, K.; Majdoub, H.; Rouatbi, S. Physical, Antioxidant and Antimicrobial Properties of Chitosan Films Containing *Eucalyptus globulus* Essential Oil. *Lwt-Food Sci. Technol.* 2016, 68, 356–364. [CrossRef]

103. Salvia-Trujillo, L.; Rojas-Graü, A.; Soliva-Fortuny, R.; Martín-Bellosa, O. Physicochemical Characterization and Antimicrobial Activity of Food-Grade Emulsions and Nanoemulsions Incorporating Essential Oils. *Food Hydrocoll.* 2015, 68, 356–364. [CrossRef]

104. Martucci, J.F.; Gende, L.B.; Neira, L.M.; Ruseckaite, R.A. Oregano and Lavender Essential Oils as Antioxidant and Antimicrobial additives of Biogenic Gelatin Films. *Ind. Crop. Prod.* 2015, 71, 205–213. [CrossRef]

105. Wu, J.E.; Lin, J.; Zhong, Q. Physical and Antimicrobial Characteristics of Thyme Oil Emulsified with Soluble Soybean Polysaccharide. *Food Hydrocoll.* 2014, 39, 144–150. [CrossRef]

106. Zivanovic, S.; Chi, S.; Draughon, A.F. Antimicrobial Activity of Chitosan Films Enriched with Essential Oils. *J. Food Sci.* 2005, 70, M45–M51. [CrossRef]

107. Noori, S.; Zeynali, F.; Almasi, H. Antimicrobial and Antioxidant Efficiency of Nanoemulsion-Based Edible Coating Containing Ginger (*Zingiber officinale*) Essential Oil and Its Effect on Safety and Quality Attributes of Chicken Breast Fillets. *Food Control.* 2018, 84, 312–320. [CrossRef]

108. Fuselli, S.R.; Gende, L.B.; de la Rosa, S.B.G.; Eguaras, M.J.; Fritz, R. Inhibition of *Paenibacillus larvae* subsp. *larvae* by the Essential Oils of Two Wild Plants and Their Emulsifying Agents. *Span. J. Agric. Res.* 2005, 3, 220–224. [CrossRef]

109. Orafidiya, L.O.; Oyedele, A.O.; Shittu, A.O.; Elujoba, A.A. The Formulation of an Effective Topical Antibacterial Product Containing *Ocimum gratissimum* Leaf Essential Oil. *Int. J. Pharm.* 2001, 224, 177–183. [CrossRef]

110. Patrone, V.; Campana, R.; Vittoria, E.; Baffone, W. In vitro Synergistic Activities of Essential Oils and Surfactants in Combination with Cosmetic Preservatives Against *Pseudomonas aeruginosa* and *Staphylococcus aureus*. *Curr. Microbiol.* 2010, 60, 237–241. [CrossRef]

111. Haba, E.; Bouhdid, S.; Torrego-Solana, N.; Marqués, A.; Espuny, M.J.; García-Celma, M.J.; Manresa, A. Rhamnolipids as Emulsifying Agents for Essential Oil Formulations: Antimicrobial Effect Against *Candida albicans* and Methicillin-Resistant *Staphylococcus aureus*. *Int. J. Pharm.* 2014, 476, 134–141. [CrossRef]