Emulsion Techniques

Subjects: Engineering, Chemical
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Emulsion Techniques, for example, microencapsulation and nanoencapsulation, can be used in the formulation of food coatings. A variety of methods have been developed to obtain different emulsions, forming excellent biomaterials to be applied as edible films in combination with biopolymer matrices. The significance and widespread applications of edible films to obtain coatings to protect food are originated from their unique properties, such as biocompatibility, biodegradability, and no toxicity.

Keywords: emulsion ; coating ; polysaccharides ; functional compounds ; food shelf-life ; food preservation

1. Introduction

The current lifestyle of consumers has modified the fruit and vegetable consumption patterns. The request for natural, fresh, healthy, and minimally processed food is continuously increasing mainly due to the desire to consume beneficial health products driven by increased knowledge and awareness of the consumers related to the presence of healthy compounds in these products like antioxidant, antimicrobial or other micronutrients [1]. Minimally processed fruits and vegetables are products that have increased their consumption in a healthy diet. These types of foods have not been physically altered from their native state and remain in a fresh form [2], representing a very promising expansion sector for the food industry [3].

Nevertheless, the consumption of fruits and vegetables is directly related to the product's freshness and quality when purchased by consumers. Undesirable characteristics, such as color changes, browning, or sweating, could cause rejection and should be avoided, resulting in economic losses, and ethical problems due to the production and accumulation of high concentrations of agro-industrial wastes. These changes related to the products freshness and quality can occur during processing operations, such as cutting, washing, or peeling, altering their integrity, modifying their surface properties, and damaging their tissue structure by the presence of undesirable effects, such as enzymatic reactions [2][4]. These degradation processes cause surface browning, undesirable flavor, water loss, and texture collapse, which should be avoided as much as possible. Besides, the presence of microorganisms on the vegetables' surface could affect the products' safety and the final quality [5].

Consequently, any solution to reduce these problems is essential to improve fresh food acceptance, reducing costs, and decreasing economic losses into food processing plants. In this context, the use of edible coatings in fruits and vegetables has been proposed as a valid methodology to improve their overall quality, extending shelf-life, perishability, and increasing profit for growers and marketers. These additives could act as a barrier against microbial agents or UV radiation, maintaining or improving the overall quality of foodstuff [6]. In contrast, the application of these thin layers of polymeric materials suitable for human consumption to protect food formulations from external agents can cause several changes in their organoleptic, mechanical, and textural properties [7].

Different approaches have been evaluated to increase food shelf-life and reduce the impact of external agents on their essential properties. In this sense, the combination of biopolymer matrices and emulsified structures based on the encapsulation of functional compounds by dispersion, forming micro- or nano-drops, shows high potential for the formulation of new edible coatings. Some of the research work related to edible bio-coatings focused on improving their properties by exploring the advantages of combining functional compounds, such as vitamins [8], essential oils (EOs) [9], and polyphenols [10][11] with natural polysaccharides like pectin [12], chitosan [13], cellulose [14], or starch [15]. Besides, encapsulation of active compounds resulting in efficient delivery systems requires a complete understanding of how these functional compounds can be encapsulated and their release mechanisms for their application in food formulations [6].

It is well known that different strategies can be used to encapsulate active chemicals, where emulsions show great potential for the food industry. This technique improves the bioavailability of functional compounds, protecting them from environmental storage conditions, and controlling their release into food products [16]. The development of microparticles and nanoparticles using emulsion methods has been widely studied in the last years. Table 1 lists some examples of emulsion systems used in the encapsulation of functional compounds to be further applied to extend shelf-life in vegetable foods.

Table 1. Some emulsion systems applied to vegetables.

Emulsion Technique *	Functional Compounds	Benefits	Food	Ref.
Ionic gelation technique	**Cuminum cyminum EO**	**Antimicrobial activity.**	**Mushroom**	[17]
--	***Trans*-cinnamic acid**	**Antimicrobial and antibiofilm effects.**	**Lettuce**	[18]
Ultrasonication	**Oregano EO**	**Antimicrobial activity.**	**Lettuce**	[19]
HPH	**Carvacrol**	**Antimicrobial activity.**	**Zucchini**	[20]
HPH or ultrasonication	**Carvacrol**	**Antimicrobial activity.**	**Shredded cabbages**	[21]
HPH	**Lemongrass EO** **Citrus extract** **Fermented dextrose Prolong 2** **Concentrated cranberry juice**	**Antibacterial activity.**	**Green peppers**	[22]

* High pressure homogenization: HPH.

2. Application of Emulsion Techniques to Vegetables

Vegetables are known for their nutritional benefits since they provide antigenotoxic, anti-inflammatory, antioxidant, anti-allergic, anticancer, and anti-diabetic functions. The new trends focusing on the need of a healthy diet have propelled the consumption of fresh-cut and ready-to-eat vegetables and fruits, changing the traditional consumption patterns of these food products.

It is well known that the processing operations (i.e., washing, cutting, or peeling) can produce alterations in food by modifying the vegetables' final appearance and decreasing their nutritional value. In some of these operations, the outer layers of vegetable cells are damaged and, on many occasions, they are the trigger of enzymatic reactions, which are most detrimental for food. Some authors described these modifications as changes in the surface by browning, unexpected flavor, water loss, and texture breakdown [23]. Besides, organoleptic degradation effects due to the growing of microorganisms onto the surface of the vegetables are observed and they must be eliminated or limited since they cause consumer´s rejection and represent a risk for health. In summary, these limitations in processed vegetables should be minimized. With this background, the use of coatings can be considered a valid alternative to incorporate active substances to protect the food structure and their resistance against aggressive external factors while increasing shelf life, decreasing production costs, and improving consumer acceptance [24].

One of the most explored options for the utilization of coatings in fresh-cut and ready-to-eat vegetables is focused on the development of the film layer directly onto the product surface by spraying or dipping the coating solution formed by an edible film containing the encapsulated active principles [4][25]. Table 2 summarizes the most relevant works published in the last decade, related to the use of polysaccharides to obtain edible coating films with functional properties to extend their shelf-life and retain the quality of vegetables.

Table 2. Active coatings based on polysaccharides from fresh and minimally processed vegetables and fresh-cut fruit.

Material Edible Coating	Functional Ingredient	Benefits	Food	Ref.
Chitosan	**Carvacrol**	***Escherichia coli* reduction reaching >5 log UCF/g**	**Cucumber**	[26]
Chitosan	***Cinnamomum zeylanicum* EO**	**Inhibition of *Phytophthora drechsleri*, stored 7 days at 4 °C. Reduction of respiration rates, improving the microbiological quality, preserving the fruit weight.**	**Cucumber**	[27]

Material Edible Coating	Functional Ingredient	Benefits	Food	Ref.
Chitosan	Limonene	Prolongation of post-harvest life maintaining weight loss, color, firmness, pH, and organoleptic properties. Reduction of fungal growth	Cucumber	[7]
Quinoa protein and chitosan	Thymol	Cherry tomatoes inoculated with *Botrytis cinereal*. Considerable reduction in fungal growth after 7 days at 5 °C	Cherry tomatoes	[28]
Hydroxypropyl methylcellulose (HPMC), beeswax (BW)	Potassium carbonate, sodium propionate, ammonium carbonate, ammonium phosphate	Reduction of gray mold development on cherry tomatoes. Respiration rate, firmness, sensory flavor, color, off-flavor, and fruit appearance were not badly affected.	Cherry tomatoes	[29]
Chitosan	Chitosan	A 5 days delay in ripening, enhancing the phenolic content, and maintaining a low respiration level.	Tomatoes	[30]
Chitosan	Mandarin EO	Inhibition of *Listeria* species. No impact on firmness for 14 days and product color	Green beans	[31]
Chitosan	Mandarin EO	Control the growth of *Listeria innocua.* Reduction in the sample firmness and no color changes during storage.	Green beans	[32]
Chitosan	Bergamot, carvacrol, mandarin and lemon EOs	Inhibition during storage of *Escherichia coli* O157:H7 and *Salmonella Typhimurium* with carvacrol	Green beans	[33]
Pectin	Sesame oil	Antioxidant activity, preservation of quality attributes, and control of microbial growth after 12 days.	Cut carrots	[34]
Chitosan	Carvacrol	Control of microbial growth for 13 days at 5 °C.	Cut carrots	[35]
Pectin	Biosecur F440D (citrus extract) and a mixture of four EOs	Increase the shelf-life by 2 days and control of *Listeria* species and *Penicillium chrysogenum*.	Cut carrots	[36]
Maltodextrin and methylcellulose	Lactic acid, citrus extract, lemongrass EO	Inhibition against *Listeria monocytogenes and Escherichia coli.* Variations in the respiration rates with no major color modification.	Cauliflower florets	[37]
Starch and maltodextrin	Lactic acid, citrus extract, lemongrass EO	Inhibition against *Listeria monocytogenes.* No major changes in color, texture and respiration	Cauliflower florets	[38]
Chitosan	Lemongrass EO	Fungal growth was effectively controlled for 21 days at room temperature. Maintenance of the fruit quality: weight loss, firmness, color.	Bell pepper	[39]
Hydroxypropyl methylcellulose	Oregano and bergamot EOs	Reduction in the respiration rate and ethylene production, total weight loss, no surface color change, and total cell count.	Plum	[40]
Carboxymethyl cellulose	Potassium sorbate	Decrease in ripening and minimum changes in the green skin color with no loss of firmness.	Pears	[41]
Alginate	Lemongrass EO	Complete inhibition of the natural microflora for 2 weeks and no significant influence on the quality parameters during storage.	Fuji apples	[42]
Starch and carboxymethyl cellulose	Turmeric EO	Antioxidant activity and low weight loss, firmness loss, and moisture content	Fuji apples	[25]
Chitosan and carboxymethyl cellulose	Citral	Good antimicrobial protection (up to a 5-log reduction), and significant extension of the shelf-life up to 13 days.	Melons	[43]

Material Edible Coating	Functional Ingredient	Benefits	Food	Ref.
Chitosan	Lemongrass EO	High inhibition of *Salmonella typhimurium*; inhibition of yeasts, molds, and total mesophilic aerobes. Preservation of total soluble solid content, colour, and antioxidant activity during storage.	Grapes	[44]
Chitosan	Nisin, natamycin, pomegranate and grape seed extract	Antimicrobial effect against yeasts, molds, and mesophilic bacteria.	Strawberries	[45]
Chitosan	Lemon EO	Antifungal activity and no effect on sensorial perception	Strawberries	[46]
Alginate	Carvacrol Methyl cinnamate	Antimicrobial effect. Maintenance of firmness, color retention, and weight loss reduction up to 13 days. Antioxidant effect.	Strawberries	[47]
Alginate Pectin	Eugenol Citral	Antimicrobial and antioxidant effect.	Strawberries	[48]
Chitosan	Bergamot, thyme, and tea tree EOs	Reduction of microbial growth and no changes in the food quality.	Oranges	[49]
Chitosan	*Trans*-cinnamaldehyde Cinnamaldehyde Carvacrol	Reduction of the bacterial and yeasts/molds growth on the fruit. Antimicrobial effect. Shelf-life extension.	Blueberries	[50]
Alginate	Eugenol Citral	Preservation of nutritional and sensory attributes and reduction of microbial spoilage. Antioxidant effect.	*Arbutus unedo L.* fruit	[51]
Alginate	Lemongrass EO	Decrease in the firmness and sensory scores (taste, texture, and overall acceptability). Extension of the shelf-life up to 16 days.	Pineapple	[52]
Alginate and pectin	Eugenol Citral	Antimicrobial and antioxidant effect.	Raspberries	[53]
Pectin	Cinnamon leaf EO	Increase the antioxidant activity, odor acceptability, and inhibition of *Escherichia coli* O157:H7, *Staphylococcus aureus,* and *Listeria monocytogenes.* Preservation of food quality.	Peach	[54]
Pectin	Nisin Calcium chloride Citric acid	Antibrowning effect and maintenance of the sensorial and microbiological quality for more than 9 days.	Persimmon	[55]
Chitosan and pectin	*trans*-cinnamaldehyde-CD inclusion complex	Antimicrobial effect.	Papaya	[56]
Basil seed gum	Oregano EO	Reduction of the microbial population and antioxidant activity.	Apricot	[57]
Pullulan	Calcium chloride Lemon juice	Antibrowning. Enhancement of the overall quality and extension of the shelf-life.	Bananas	[58]

3. Conclusions

The encapsulation of functional substances, such as EO, by forming emulsions to maintain fresh-cut vegetables and fruits by forming coating systems in the food industry is owed to their particular and advantageous properties, such as:

-Antimicrobial activity: Vegetables coated with active emulsions have been proven to be less sensitive to microbial infection and proliferation than undamaged vegetables, resulting in increasing shelf-life and quality of minimally processed vegetables and fruits.

-Antioxidant performance to avoid or limit the lipid oxidation and quality parameters as appearance and color.

-Film-forming systems help to preserve cell wall integrity and the texture during storage to avoid enzymatic degradation and rejection by the consumers

Much research has been performed in the last few years and much more is currently underway to explore possible commercial applications of polysaccharide-based coatings with functional properties in minimally processed vegetables and fruits, but most of it has been carried out at the laboratory scale. However, the next step to get final commercial applications of these active coatings is still pending, and scale-up and industrial trials at a bulk volume should be carried out in the next future.

References

1. Hasan, S.M.K.K.; Ferrentino, G.; Scampicchio, M. Nanoemulsion as advanced edible coatings to preserve the quality of fresh-cut fruits and vegetables: A review. Int. J. Food Sci. Technol. 2020, 55, 1–10.
2. Prakash, A.; Baskaran, R.; Paramasivam, N.; Vadivel, V. Essential oil based nanoemulsions to improve the microbial quality of minimally processed fruits and vegetables: A review. Food Res. Int. 2018, 111, 509–523.
3. Scarano, P.; Naviglio, D.; Prigioniero, A.; Tartaglia, M.; Postiglione, A.; Sciarrillo, R.; Guarino, C. Sustainability: Obtaining natural dyes from waste matrices using the prickly pear peels of opuntia ficus-indica (L.) miller. Agronomy 2020, 10, 528.
4. Jung, J.; Deng, Z.; Zhao, Y. A review of cellulose nanomaterials incorporated fruit coatings with improved barrier property and stability: Principles and applications. J. Food Process Eng. 2020, 43.
5. Palou, L.; Valencia-Chamorro, S.A.; Pérez-Gago, M.B. Antifungal edible coatings for fresh citrus fruit: A review. Coatings 2015, 5, 962–986.
6. Galus, S.; Kadzińska, J. Food applications of emulsion-based edible films and coatings. Trends Food Sci. Technol. 2015, 45, 273–283.
7. Maleki, G.; Sedaghat, N.; Woltering, E.J.; Farhoodi, M.; Mohebbi, M. Chitosan-limonene coating in combination with modified atmosphere packaging preserve postharvest quality of cucumber during storage. J. Food Meas. Charact. 2018, 12, 1610–1621.
8. Ktari, N.; Feki, A.; Trabelsi, I.; Triki, M.; Maalej, H.; Slima, S.B.; Nasri, M.; Ben Amara, I.; Ben Salah, R. Structure, functional and antioxidant properties in Tunisian beef sausage of a novel polysaccharide from Trigonella foenum-graecum seeds. Int. J. Biol. Macromol. 2017, 98, 169–181.
9. Almasi, H.; Azizi, S.; Amjadi, S. Development and characterization of pectin films activated by nanoemulsion and Pickering emulsion stabilized marjoram (Origanum majorana L.) essential oil. Food Hydrocoll. 2020, 99, 105338.
10. Liu, J.; Wang, X.; Yong, H.; Kan, J.; Jin, C. Recent advances in flavonoid-grafted polysaccharides: Synthesis, structural characterization, bioactivities and potential applications. Int. J. Biol. Macromol. 2018, 116, 1011–1025.
11. Luo, S.Z.; Hu, X.-F.; Jia, Y.J.; Pan, L.H.; Zheng, Z.; Zhao, Y.Y.; Mu, D.-D.; Zhong, X.Y.; Jiang, S.-T. Camellia oil-based oleogels structuring with tea polyphenol-palmitate particles and citrus pectin by emulsion-templated method: Preparation, characterization and potential application. Food Hydrocoll. 2019, 95, 76–87.
12. Jiang, W.; Qi, J.R.; Huang, Y.; Zhang, Y.; Yang, X.Q. Emulsifying properties of high methoxyl pectins in binary systems of water-ethanol. Carbohydr. Polym. 2020, 229, 115420.
13. Liu, C.; Tan, Y.; Xu, Y.; McCleiments, D.J.; Wang, D. Formation, characterization, and application of chitosan/pectin-stabilized multilayer emulsions as astaxanthin delivery systems. Int. J. Biol. Macromol. 2019, 140, 985–997.
14. Cook, S.L.; Methven, L.; Parker, J.K.; Khutoryanskiy, V.V. Polysaccharide food matrices for controlling the release, retention and perception of flavours. Food Hydrocoll. 2018, 79, 253–261.
15. Mendes, J.F.; Norcino, L.B.; Martins, H.H.A.; Manrich, A.; Otoni, C.G.; Carvalho, E.E.N.; Piccoli, R.H.; Oliveira, J.E.; Pinheiro, A.C.M.; Mattoso, L.H.C. Correlating emulsion characteristics with the properties of active starch films loaded with lemongrass essential oil. Food Hydrocoll. 2020, 100, 105428.
16. Kakran, M.; Antipina, M.N. Emulsion-based techniques for encapsulation in biomedicine, food and personal care. Curr. Opin. Pharmacol. 2014, 18, 47–55.
17. Karimirad, R.; Behnamian, M.; Dezhsetan, S. Application of chitosan nanoparticles containing Cuminum cyminum oil as a delivery system for shelf life extension of Agaricus bisporus. LWT 2019, 106, 218–228.
18. Letsididi, K.S.; Lou, Z.; Letsididi, R.; Mohammed, K.; Maguy, B.L. Antimicrobial and antibiofilm effects of trans-cinnamic acid nanoemulsion and its potential application on lettuce. LWT 2018, 94, 25–32.
19. Bhargava, K.; Conti, D.S.; da Rocha, S.R.P.; Zhang, Y. Application of an oregano oil nanoemulsion to the control of foodborne bacteria on fresh lettuce. Food Microbiol. 2015, 47, 69–73.

20. Donsì, F.; Cuomo, A.; Marchese, E.; Ferrari, G. Infusion of essential oils for food stabilization: Unraveling the role of na noemulsion-based delivery systems on mass transfer and antimicrobial activity. Innov. Food Sci. Emerg. Technol. 2014, 22, 212–220.
21. Sow, L.C.; Tirtawinata, F.; Yang, H.; Shao, Q.; Wang, S. Carvacrol nanoemulsion combined with acid electrolysed water to inactivate bacteria, yeast in vitro and native microflora on shredded cabbages. Food Control 2017, 76, 88–95.
22. Maherani, B.; Harich, M.; Salmieri, S.; Lacroix, M. Antibacterial properties of combined non-thermal treatments based o n bioactive edible coating, ozonation, and gamma irradiation on ready-to-eat frozen green peppers: Evaluation of their f reshness and sensory qualities. Eur. Food Res. Technol. 2019, 245, 1095–1111.
23. Oms-Oliu, G.; Rojas-Graü, M.A.; González, L.A.; Varela, P.; Soliva-Fortuny, R.; Hernando, M.I.H.; Munuera, I.P.; Fiszm an, S.; Martín-Belloso, O. Recent approaches using chemical treatments to preserve quality of fresh-cut fruit: A review. Postharvest Biol. Technol. 2010, 57, 139–148.
24. Chaudhary, S.; Kumar, S.; Kumar, V.; Sharma, R. Chitosan nanoemulsions as advanced edible coatings for fruits and v egetables: Composition, fabrication and developments in last decade. Int. J. Biol. Macromol. 2020, 152, 154–170.
25. Sharif, Z.I.M.M.; Jai, J.; Subuki, I.; Zaki, N.A.M.M.; Mustapha, F.A.; Mohd Yusof, N. Characterisation of polysaccharide composite incorporated with turmeric oil for application on fresh-cut apples. J. Phys. Conf. Ser. 2019, 1349, 012058.
26. Taştan, Ö.; Pataro, G.; Donsì, F.; Ferrari, G.; Baysal, T. Decontamination of fresh-cut cucumber slices by a combination of a modified chitosan coating containing carvacrol nanoemulsions and pulsed light. Int. J. Food Microbiol. 2017, 260, 7 5–80.
27. Mohammadi, A.; Hashemi, M.; Hosseini, S.M. Chitosan nanoparticles loaded with Cinnamomum zeylanicum essential o il enhance the shelf life of cucumber during cold storage. Postharvest Biol. Technol. 2015, 110, 203–213.
28. Robledo, N.; Vera, P.; López, L.; Yazdani-Pedram, M.; Tapia, C.; Abugoch, L. Thymol nanoemulsions incorporated in qu inoa protein/chitosan edible films; antifungal effect in cherry tomatoes. Food Chem. 2018, 246, 211–219.
29. Fagundes, C.; Palou, L.; Monteiro, A.R.; Pérez-Gago, M.B. Effect of antifungal hydroxypropyl methylcellulose-beeswax edible coatings on gray mold development and quality attributes of cold-stored cherry tomato fruit. Postharvest Biol. Te chnol. 2014, 92, 1–8.
30. Mustafa, M.A.; Ali, A.; Manickam, S.; Siddiqui, Y. Ultrasound-assisted chitosan–surfactant nanostructure assemblies: To wards maintaining postharvest quality of tomatoes. Food Bioprocess Technol. 2014, 7, 2102–2111.
31. Donsì, F.; Marchese, E.; Maresca, P.; Pataro, G.; Vu, K.D.; Salmieri, S.; Lacroix, M.; Ferrari, G. Green beans preservati on by combination of a modified chitosan based-coating containing nanoemulsion of mandarin essential oil with high pr essure or pulsed light processing. Postharvest Biol. Technol. 2015, 106, 21–32.
32. Severino, R.; Vu, K.D.; Donsì, F.; Salmieri, S.; Ferrari, G.; Lacroix, M. Antibacterial and physical effects of modified chit osan based-coating containing nanoemulsion of mandarin essential oil and three non-thermal treatments against Listeri a innocua in green beans. Int. J. Food Microbiol. 2014, 191, 82–88.
33. Severino, R.; Ferrari, G.; Vu, K.D.; Donsì, F.; Salmieri, S.; Lacroix, M. Antimicrobial effects of modified chitosan based c oating containing nanoemulsion of essential oils, modified atmosphere packaging and gamma irradiation against Esche richia coli O157:H7 and Salmonella Typhimurium on green beans. Food Control 2015, 50, 215–222.
34. Ranjitha, K.; Sudhakar Rao, D.V.; Shivashankara, K.S.; Oberoi, H.S.; Roy, T.K.; Bharathamma, H. Shelf-life extension a nd quality retention in fresh-cut carrots coated with pectin. Innov. Food Sci. Emerg. Technol. 2017, 42, 91–100.
35. Martínez-Hernández, G.B.; Amodio, M.L.; Colelli, G. Carvacrol-loaded chitosan nanoparticles maintain quality of fresh-c ut carrots. Innov. Food Sci. Emerg. Technol. 2017, 41, 56–63.
36. Ben-Fadhel, Y.; Maherani, B.; Manus, J.; Salmieri, S.; Lacroix, M. Physicochemical and microbiological characterization of pectin-based gelled emulsions coating applied on pre-cut carrots. Food Hydrocoll. 2020, 101, 105573.
37. Boumail, A.; Salmieri, S.; Lacroix, M. Combined effect of antimicrobial coatings, gamma radiation and negative air ioniz ation with ozone on Listeria innocua, Escherichia coli and mesophilic bacteria on ready-to-eat cauliflower florets. Posth arvest Biol. Technol. 2016, 118, 134–140.
38. Boumail, A.; Salmieri, S.; St-Yves, F.; Lauzon, M.; Lacroix, M. Effect of antimicrobial coatings on microbiological, sensor ial and physico-chemical properties of pre-cut cauliflowers. Postharvest Biol. Technol. 2016, 116, 1–7.
39. Ali, A.; Noh, N.M.; Mustafa, M.A. Antimicrobial activity of chitosan enriched with lemongrass oil against anthracnose of bell pepper. Food Packag. Shelf Life 2015, 3, 56–61.
40. Choi, W.S.; Singh, S.; Lee, Y.S. Characterization of edible film containing essential oils in hydroxypropyl methylcellulos e and its effect on quality attributes of “Formosa” plum (Prunus salicina L.). LWT Food Sci. Technol. 2016, 70, 213–222.

41. Kowalczyk, D.; Kordowska-Wiater, M.; Zięba, E.; Baraniak, B. Effect of carboxymethylcellulose/candelilla wax coating containing potassium sorbate on microbiological and physicochemical attributes of pears. Sci. Hortic. (Amsterdam) 2017, 218, 326–333.

42. Salvia-Trujillo, L.; Rojas-Graü, M.A.; Soliva-Fortuny, R.; Martín-Belloso, O. Use of antimicrobial nanoemulsions as edible coatings: Impact on safety and quality attributes of fresh-cut fuji apples. Postharvest Biol. Technol. 2015, 105, 8–16.

43. Arnon-Rips, H.; Porat, R.; Poverenov, E. Enhancement of agricultural produce quality and storability using citral-based edible coatings; the valuable effect of nano-emulsification in a solid-state delivery on fresh-cut melons model. Food Chem. 2019, 277, 205–212.

44. Oh, Y.A.; Oh, Y.J.; Song, A.Y.; Won, J.S.; Song, K.B.; Min, S.C. Comparison of effectiveness of edible coatings using emulsions containing lemongrass oil of different size droplets on grape berry safety and preservation. LWT 2017, 75, 742–750.

45. Duran, M.; Aday, M.S.; Zorba, N.N.D.; Temizkan, R.; Büyükcan, M.B.; Caner, C. Potential of antimicrobial active packaging “containing natamycin, nisin, pomegranate and grape seed extract in chitosan coating” to extend shelf life of fresh strawberry. Food Bioprod. Process. 2016, 98, 354–363.

46. Perdones, A.; Escriche, I.; Chiralt, A.; Vargas, M. Effect of chitosan-lemon essential oil coatings on volatile profile of strawberries during storage. Food Chem. 2016, 197, 979–986.

47. Peretto, G.; Du, W.X.; Avena-Bustillos, R.J.; De, J.; Berrios, J.; Sambo, P.; McHugh, T.H. Electrostatic and conventional spraying of alginate-based edible coating with natural antimicrobials for preserving fresh strawberry quality. Food Bioprocess Technol. 2017, 10, 165–174.

48. Guerreiro, A.C.; Gago, C.M.L.; Faleiro, M.L.; Miguel, M.G.C.; Antunes, M.D.C. The use of polysaccharide-based edible coatings enriched with essential oils to improve shelf-life of strawberries. Postharvest Biol. Technol. 2015, 110, 51–60.

49. Cháfer, M.; Sánchez-González, L.; González-Martínez, C.; Chiralt, A. Fungal decay and shelf life of oranges coated with chitosan and bergamot, thyme, and tea tree essential oils. J. Food Sci. 2012, 77, 182–187.

50. Sun, X.; Narciso, J.; Wang, Z.; Ference, C.; Bai, J.; Zhou, K. Effects of chitosan-essential oil coatings on safety and quality of fresh blueberries. J. Food Sci. 2014, 79.

51. Guerreiro, A.C.; Gago, C.M.L.; Faleiro, M.L.; Miguel, M.G.C.; Antunes, M.D.C. The effect of alginate-based edible coatings enriched with essential oils constituents on Arbutus unedo L. fresh fruit storage. Postharvest Biol. Technol. 2015, 100, 226–233.

52. Azarakhsh, N.; Osman, A.; Ghazali, H.M.; Tan, C.P.; Mohd Adzahan, N. Lemongrass essential oil incorporated into alginate-based edible coating for shelf-life extension and quality retention of fresh-cut pineapple. Postharvest Biol. Technol. 2014, 88, 1–7.

53. Guerreiro, A.C.; Gago, C.M.L.; Faleiro, M.L.; Miguel, M.G.C.; Antunes, M.D.C. Raspberry fresh fruit quality as affected by pectin- and alginate-based edible coatings enriched with essential oils. Sci. Hortic. (Amsterdam) 2015, 194, 138–146.

54. Ayala-Zavala, J.F.; Silva-Espinoza, B.A.; Cruz-Valenzuela, M.R.; Leyva, J.M.; Ortega-Ramírez, L.A.; Carrazco-Lugo, D.K.; Pérez-Carlón, J.J.; Melgarejo-Flores, B.G.; González-Aguilar, G.A.; Miranda, M.R.A. Pectin-cinnamon leaf oil coatings add antioxidant and antibacterial properties to fresh-cut peach. Flavour Fragr. J. 2013, 28, 39–45.

55. Sanchís, E.; Ghidelli, C.; Sheth, C.C.; Mateos, M.; Palou, L.; Pérez-Gago, M.B. Integration of antimicrobial pectin-based edible coating and active modified atmosphere packaging to preserve the quality and microbial safety of fresh-cut persimmon (Diospyros kaki Thunb. cv. Rojo Brillante). J. Sci. Food Agric. 2017, 97, 252–260.

56. Brasil, I.M.; Gomes, C.; Puerta-Gomez, A.; Castell-Perez, M.E.; Moreira, R.G. Polysaccharide-based multilayered antimicrobial edible coating enhances quality of fresh-cut papaya. LWT Food Sci. Technol. 2012, 47, 39–45.

57. Hashemi, S.M.B.; Mousavi Khaneghah, A.; Ghaderi Ghahfarrokhi, M.; Eş, I. Basil-seed gum containing Origanum vulgare subsp. viride essential oil as edible coating for fresh cut apricots. Postharvest Biol. Technol. 2017, 125, 26–34.

58. Ganduri, V.S.R. Evaluation of pullulan-based edible active coating methods on Rastali and Chakkarakeli bananas and their shelf-life extension parameters studies. J. Food Process. Preserv. 2020, 44.