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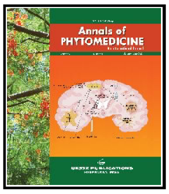


Review Article : Open Access

# Nanoemulsion: A futuristic approach to disease elimination for food safety

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**Abstract**

The increased demand for healthy food among consumers has sparked research into cutting-edge ways to preserve minimally processed fresh produce without the use of preservatives. Given the high-water activity in fruits and vegetables and the fact that microorganisms that cause digestive infectious diseases have been discovered as a significant contributor to human illnesses, efforts must be done to reduce their presence. Herbaceous plants are used for the extraction of edible oils and edible plants have been reported to contain natural antifungal and antibacterial components. These coatings are made from a variety of organic, inorganic, protein, polysaccharide, and essential oil in the formation of nanoemulsion that increases the fluidity, longevity, and potency of the biopolymers they contain. This prevents bacterial, fungal, and other pathogenic damage while preserving the farmer's produce for a long time. A wide number of scientific fields, including agriculture, have adopted nanotechnology as a potential tool. They provide significant prospects in a variety of pharmaceutical, industries, including cosmetics and, food, and have distinguishing qualities and longer-term stability than conventional dosage forms.

## 1. Introduction

In the contemporary days, with modernization and the development of technology which shifts people's lifestyles, consumers now want a broader range of safe and healthful food products that can improve their health. Massive quantities of agricultural produce are being wasted in the after-harvest and processing parts throughout the globe, exclusively in underdeveloped nations, due to improper handling and insufficient storage technologies (Flores-López *et al.*, 2016). To prevent this postharvest loss, many techniques are used, and coating is one of them. Due to an increase in environmental and various health issues by using the chemical which acts as an active agent in the wrapping of material (Ribeiro-Santos *et al.*, 2017). As consumers are aware of these various post-harvest, treatments for fruit and vegetable products to prevent degradation, they prefer chemical-free fruits and vegetables. So edible coating is a potential option for the post-harvest treatment of horticultural commodities to prevent them from rotting and reaching the consumer. Recently, nanotechnology has become a novel approach in the food processing sector, opening fresh ideas for post-harvest storage solutions (He *et al.*, 2019) and a significant area of current scientific research at the moment, which is cantered on the unique characteristics (size, form, and distribution) of nanoparticles (Husain, 2023). Nanoemulsion and nanoparticles are the techniques that act as a protective layer and contribute to a novel approach in an edible coating of fruits and vegetables. The preparation of nanoparticles was done by using ecofriendly technique like green synthesis without using any harmful chemicals (Deshmukh *et al.*, 2022). The functional and remedial qualities of the edible coatings are crucial for improving the benefits of the food product (Acevedo-Fani *et al.*, 2017). Since they contain more water than other foods, microbial deterioration is more prevalent in fruits and vegetables. Many natural antibacterial compounds, such as lemon oil, clove oil, mandarin oil, and others, are used as essential oils to prevent the microbial deterioration of food.

To provide ready-to-eat fruits and vegetables with high stability, quality, and antibacterial activity, these oils are encapsulated in a nanometric delivery system. These chemicals help to increase the after-harvest storage life of commodities, while preserving their original flavour, taste, and scent (Sessa *et al.*, 2015). Several procedures can be used to apply these coatings on the surface of fruits and vegetables, including spraying, dipping and rubbing. These coatings are created using a variety of organic and inorganic substances, proteins, polysaccharides and essential oils as well as other natural materials. When more sophisticated technologies are developed over time, nanosystem such as nanoemulsion, nanocomposites, and nanoparticles are introduced. An active stable system with an average radius of 100 nm and distinct physicochemical and functional properties is an aqueous solution of nanoemulsion (Rashid *et al.*, 2020). As an edible coating, nanoemulsion has many advantages over conventional emulsions, including the capacity to form transparent films with tiny droplet sizes, emulsifiable hydrophilic components, high kinetic and thermodynamic stability to prevent coalescence and aggregation (Mehmood *et al.*, 2018).

## 2. Edible coating

The edible substance is the edible coating that is coated as a thin layer on the surface of food material by the method of dipping. Different types of materials are used as coating materials such as polysaccharides, cellulose with its derivative, starch with its derivatives, alginates, carrageenan, chitin, chitosan and pectin. Moreover, animal or plant origin materials like whey, casein, gelatine, collagen, egg albumen, soya protein, wheat gluten, mineral oils, wax, vegetable residues, silk wastes, compost materials, *etc.*, are being used as a coting material. Out of these materials utilized as an edible coating is water dissolvable and water-in dissolvable. Water-dissolvable compounds comprise probiotics, vitamins, prebiotics,

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antimicrobial proteins, and peptides, which readily combine privileged a matrix of protein to generate edible glazes. Contrarily, hydrophobic compounds need extra work and special methods to combine and stabilize inside the watery matrix to create edible coatings (Tripathi *et al.*, 2021). Apart from this, other coating materials are resins, waxes, oils, corn zein a coating material for candy, nutmeats, and pharmaceuticals, *etc*. (Gennadios *et al.*, 1997). Modern agricultural researchers have recommended the application of a nanoemulsion that comprises consumable essential oil coating for numerous food products that can be stored to prevent numerous physiochemical processes like firmness, respiration, colour change, and other deterioration (Hasan and Nicolai, 2014). The shelf-life and quality of certain foods are significantly increased or improved by nanoemulsion. Along with the several synthetic preparations of nanoemulsion containing essential oils, is a novel way for improving the superior features while preserving their antioxidant colour, and flavour characteristics in fruits (Hasan *et al.*, 2020).

### 2.1 Essential oils

Oils are naturally essential and show bifunctional structures composed of chiefly unstable terpenes and hydrocarbons that are classified as subordinate metabolites from plants and herbs with a distinguishable aroma (Baptista-Silva *et al.*, 2020). These oils, which may be extracted from bark, roots, rhizomes, leaves, flowers, branches, seeds, and fruits, can make up to 5% of the vegetative dry matter. Numerous essential oils and metabolites have been found in plant extracts that are generally accepted as being safe (Pandey *et al.*, 2017). Deterioration can happen at several points, such as postharvest processing, shipping, and storage, in the food supply chain. Fresh produce mainly deteriorates during storage of the number of fungi, bacteria, molds, and toxins produced by these pathogens. Essential oils have antifungal, antibacterial, immunomodulatory, antimutagenic, antioxidant, and anti-inflammatory activities that help in retaining the phytochemicals and sensory parameters of fresh produce. Essential oils have found mainstream popularity in the agriculture, health, food and cosmetic industries.

## 3. Food loss and food safety

Periods of sturdy waning, the trend of global deprivation, as restrained by the incidence of famine, reversed in 2015, remained nearly steady in the preceding few years at a level close below 12%. In the meantime, the figure of hungry people has gradually increased (Figure 1).

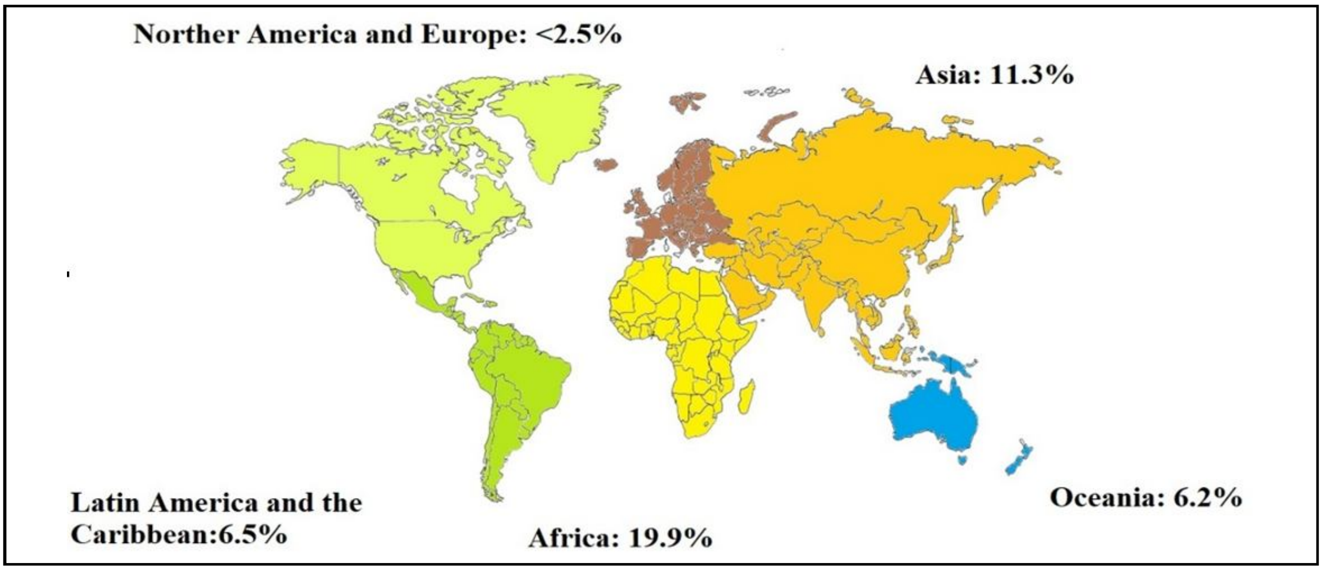


**Figure 1: Prevalence of undernourishment (%) in the world.**

**Table 1: The new major diseases introduced in different horticultural crops**

| Farmer produce | Major degrading agent | Septicity caused | Symptoms | References |
|---|---|---|---|---|
| Onion | *Pernospora destructor* | Downy mildew | Infected bulbs are fragile and shriveled, and they may sprout too soon. | Odoemenam, 2016 |
| Tomato | *Rhizopus stolonifer* | Soft rot | It hides pectolytic enzymes that degrade the cellulose cell partition of ripe fruit tissues. | Enyiukwu, 2020 |
| Yellow passion fruit | *Collectotrichum gloeosporoids* | Anthracnose | Water-soaked, uneven, light brown blemishes occurred on diseased fruits. | Anaruma *et al.*, 2010 |
| Papaya | *Lasiodiplodia theobromae* | Stem end rot | Spores may pierce the papaya flesh via cracks between the peduncle and the flesh which cause stem end rot. | Shiraz, 2020 |

While a consequence, likewise 820 million people worldwide are still starved today, highlighting the enormous difficulty of meeting the zero starvation objective by 2030. This present trend is supported by approximations of unadorned nutrition uncertainty throughout the globe grounded on the FIES another method of tracking hunger.

The incidence of famine is the major measure used to track global progress toward hunger eradication (FAO, 2019). Several biotic factors like plant pathogenic fungi can cause serious losses in farmer produce which includes, *Botrytis cinerea*, *Penicillium italicum*, *Rhizopus stolonifer*, *Monilia fructicola*, *M. laxa*, *Altrnaria alternate*, *Colletotrichum gloeosporoids*, *etc.* (Youssef *et al.*, 2022) which plays important role in loss after harvest (Table 1). The only way to prevent these losses is by the mean of chemicals like fungicides. But, due to their residual imprints, environmental and human solicitude and other regulatory barriers have limited use (Hashim *et al.*, 2019). Gram-negative and positive bacteria, yeasts, fungi, and molds are major spoiling agents of fruits and vegetables (Sperber, 2009).

## 4. Characteristics of nanoemulsion

### 4.1 Nanoemulsion as an antifungal

The nanoemulsion of eugenol containing limonin minimized the fungal activity by retard the formation of conidia and mycelia growth at a lower concentration. The treatment of nanoemulsion disrupts the cell membrane, deformed the cell morphology, and deluges the protein and nucleic acid (Li *et al.*, 2021) in the same context. The nanoemulsion of cinnamaldehyde, eugenol, and carvacrol was sprayed with a high-pressure microfluidizer which improved its antifungal effect and immense capabilities to retain phytochemical parameters and extend the storage life of fruit (Figure 2). The mycelia of treated and untreated fruit show different structural formations and had an inhibitory effect and immense capabilities to upsurge the storage life of fruit (Yang *et al.*, 2021), whereas *Laurus nobilis* based essential oil nanoemulsion obstructs the surface browning, retained the total phenolics-and inhibit the increase of spoilage microorganism (Ru *et al.*, 2022).

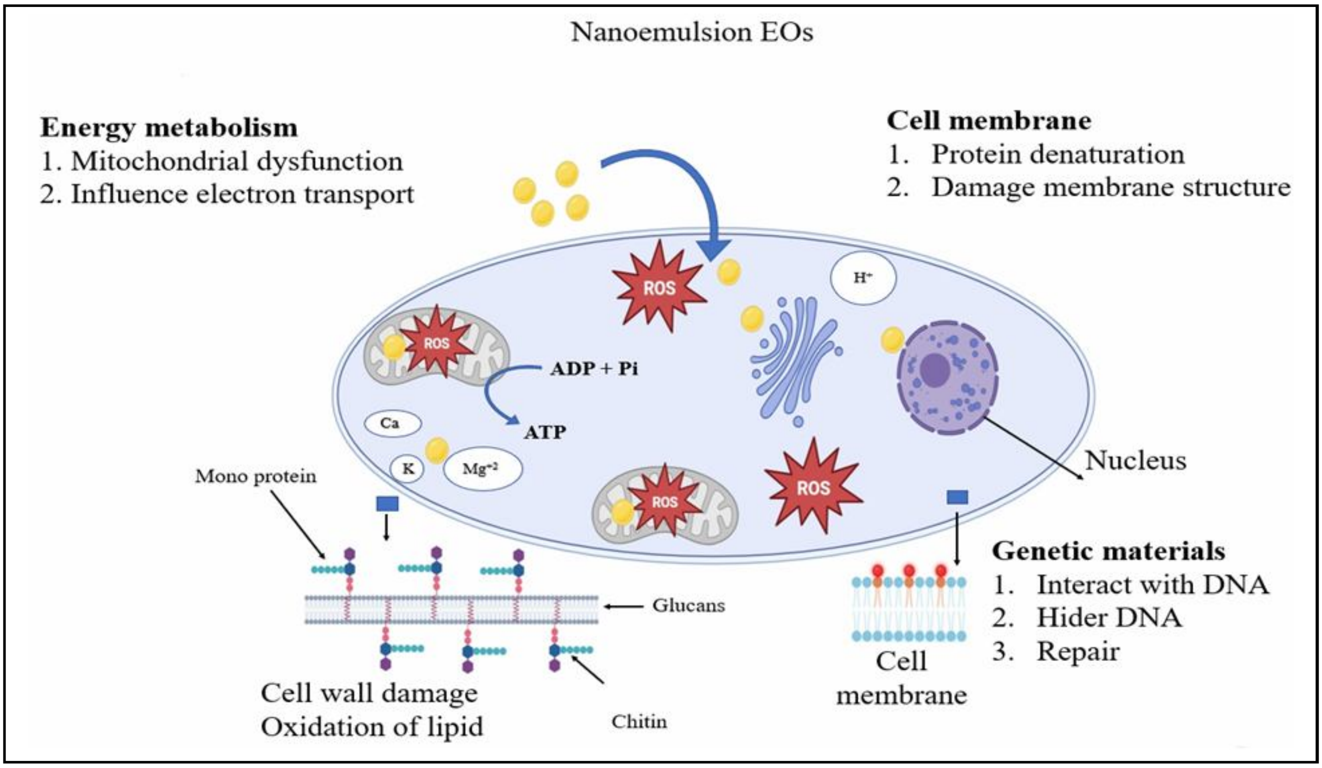


**Figure 2: Diagrammatic illustration of conceivable antifungal reaction mechanisms of essential oil nanoemulsion.**

Carnauba wax and *Cymbopogon martini* based essential oil (EO) nanoemulsion minimize the occurrence of rots during storage, and hence retained the quality parameters (Oliveira Filho *et al.*, 2022). The nanoemulsion of *Illicium verum* essential oil retards the *Aspergillus flavus* fungal growth of by the contortion of mycelia and phialides inhibiting the formation of fungal spores and destroying the membrane (Dwivedy *et al.*, 2018). Nanoemulsion contained essential oils which enhanced antimycotic activity such technique has been related to increased dispersion and alterations in plasma membrane absorptivity triggered by shifts in osmotic pressure and cellular pH (Chaudhari *et al.*, 2021). The antifungal ability of eugenol (2%) which is encapsulated in nanoemulsion form towards the fungus mainly *Fusarium oxysporum* is ascribed to the minimize the growth of conidial spores (Abd-Elsalam and Khokhlov, 2015). Similarly, essential oil of garlic, citronella and lemongrass retard the growth of *Colletotrichum gloeosporoids* (Pol *et al.*, 2023).

### 4.2 Nanoemulsion as a post-harvest life enhancer

Post-harvest handling and supply chain deterioration is the main reason for the losses. The nanoemulsion serves as an alternative to artificial chemicals. The nanoemulsion of carnauba wax for postharvest application reduced decay and helps to increase the shelf- life (Miranda *et al.*, 2022) whereas, nanoemulsion of orange essential oil and *Opuntia oligacantha* significantly retained the total phenols, total flavonoid, and antioxidants activity (Cenobio-Galindo *et al.*, 2019). It is speculated that chitosan-based nanoemulsion was reviewed as adequate and increased the phytochemicals property, post-harvest life, and capacity to promote health (Ishkeh *et al.*, 2021). The nanoemulsion coating of pullulan possessed of cinnamon oil maintained the standard attributes and increased the storage life (Chu *et al.*, 2020).

### 4.3 Nanoemulsion as an antibacterial

The nanoemulsion of carnauba wax which contains lemongrass oil inhibits the bacterial development of *E. coli* O157:H7 and *Salmonella typhimurium*. The nanoemulsion minimized cell development which significantly decreased bacterial growth (Kim *et al.*, 2013). The nanoemulsion of polysaccharides such as fenugreek and flax seed slows down the activity of surface microbes (Rashid *et al.*, 2020). The contribution of plant-extracted volatile oil upsurges the backflow of essential fundamental ions ($Na^+$, $K^+$, $Mg^{2+}$) foremost to substantial alterations in the bacterial cell that trigger cell death (Figure 3).

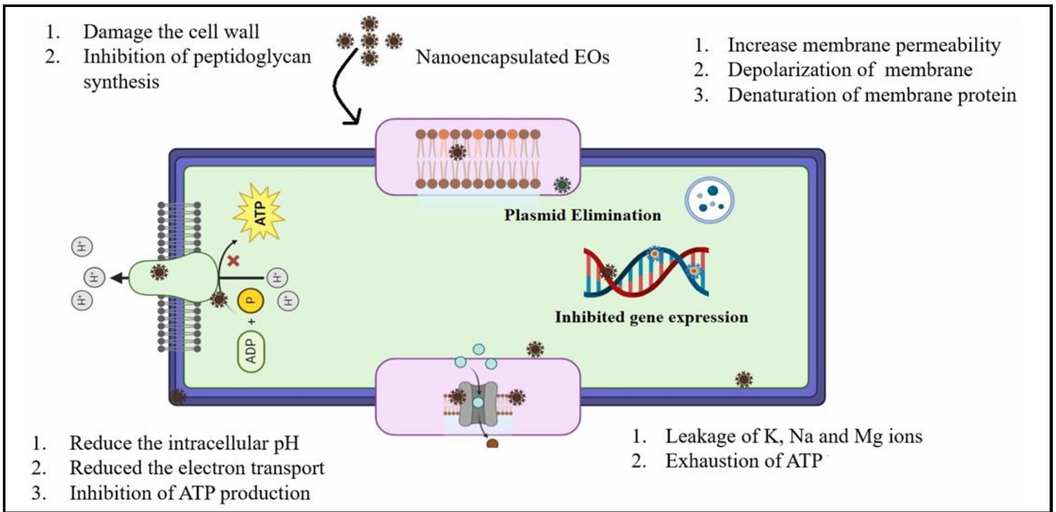


**Figure 3: Alterations in the bacterial cell that trigger cell death.**

### 4.4 Nanoemulsion as an antioxidant agent

Fruits and vegetables seem to be full of antioxidants because they contain significant levels of polyphenolic compounds and anthocyanin. The oxidation of phenolic components by polyphenol oxidase is evidenced as a dark colour pigment due to the longer storage of fresh-cut fruits and vegetables which shows an overall reduction in antioxidant activity (Table 2).

**Table 2: Inhibitory action of different types of nanoemulsion on pathogenic activity**

| S.No. | Component of nanoemulsion | Disease | The function of nanoemulsion coating | References |
|---|---|---|---|---|
| 1. | Cinnamaldehyde, eugenol, and carvacrol | *P. digitatum* | Spore germination was restricted and the morphology of mycelia the changed | Yang *et al.*, 2021 |
| 2. | Lemongrass essential oil | *E. coli* | Significantly inactivate the microbial activity faster | Salvia-Trujillo *et al.*, 2015 |
| 3. | Alginate-based thyme essential oil loaded with nanostructured lipid carrier | *P. digitatum* | Minimize injury from mold and reduce the decay percentage | Radi *et al.*, 2022 |
| 4. | Cinnamon EO loaded NLC | *P. citrinum and P. expansum* | Noticeably retard the growth | Radi *et al.*, 2017 |
| 5. | Garlic oil | *Penicillium italicum* | Structure and morphology of fungal spore deformed | Long *et al.*, 2020 |
| 6. | Cleome viscose essential oil | *Candida albicans* | Retard the biosynthesis of the cell wall | Krishnamoorthy *et al.*, 2021 |
| 7. | *Coriandrum sativum* | *Aspergillus flavus and aflatoxin* | Inhibited the biosynthesis of methylglyoxal | Long *et al.*, 2020 |
| 8. | *Mentha piperita, Cymbopogon citrus, Lavandula angustifolia* | *Staphylococcus aureus, Escherichia coli/dilution* | Minimize the antimicrobial activity | Gishen *et al.*, 2020 |
| 9. | Orange essential oil | *Aspergillus flavus* | Retard the growth of mycelia | Kringel *et al.*, 2021 |
| 10. | Silver nanoparticles (AgNps) | *Rhizoctonia solani* | Inhibit the spores of Fungal spores | Mistry *et al.*, 2022 |

Essential oil-based nanoemulsion have a noticeable impact on the antioxidant efficacy of produce because of enhanced antioxidant substances with higher ROS-free radical scavenging activity. Lipid oxidation is the primary cause of farmer produce deterioration. Due to this pungency and abatements in the flavour taste, nutritional quality, and aroma of food occurred (Rehman *et al.*, 2021). Peppermint oil and borage seed oil nanoemulsion was significantly improved the antioxidant activity up to one month (Rehman *et al.*, 2020). Nanoemulsion of tarragon significantly minimizes the deterioration as compared to the pure oil of tarragon (Azizkhani *et al.*, 2021). The antioxidant activity property of neem essential oil retains in the nanoemulsion form and is cytotoxic to a lesser extent than the pure extracted neem oil (Rinaldi *et al.*, 2017). The nanoemulsion of cordyceps militaris was encapsulated as oil in water by using an ultrasonic method and exhibited relatively high antioxidant activity (Rupa *et al.*, 2020). The essential oil in the form of nanoemulsion of transdermal significantly retains the high antioxidant activity which is concentration dependent (Mostafa *et al.*, 2015).

## 5. Agricultural use of nanoemulsion

Biotic factors such as pests and diseases play an important influence in the deterioration of agricultural produce after harvest. Insects, viruses, animals, and weeds cause produce deterioration, which accounts 20-40% of global agricultural production losses (Oerke, 2006). Post-harvest fungal disease-caused economic losses in supply chain are variable which ranged from 30 to 50% depending on agricultural techniques and geography (Youssef and Ruffo, 2014). Food safety and quality are becoming increasingly important as infected fruits can serve as a vector for the spread of dangerous diseases. Synthetic fungicides which are applies as pre and post harvest treatments including thiabendazole, pyrimethanil, fludioxonil, and imazalil are used to control the rot of fruits and vegetables (Patologia, 2018). Nanotechnology has been employed in a variety of scientific areas as a promising method., including agriculture. Due to its widespread application in numerous fields over the past few decades, nanotechnology is becoming a blessing for humanity (Mandadi and Srinivas, 2023). Nanomaterial's outstanding qualities make them a viable option for sustainable agriculture in general, colloidal types of plant-based insecticides, such as antibacterial nanoemulsion, are getting more popular (McClements, 2020) and specifically for post-harvest diseases of plant-based food material (Feregrino-Perez *et al.*, 2018). This nanoemulsion must be deliberately planned to prevent the disinfectants from evaporation or biochemical deprivation through storage and application while staying effective in contradiction of the target spoilage or pathogenic microorganisms (McClements *et al.*, 2021). For example, an oregano, rosemary, and cinnamon nanoemulsion oils applied on fresh celery minimized the number of bacteria and inhibit the growth (Dávila-rodríguez *et al.*, 2019), oregano oil-based nanoemulsion sustained with Tween 80 applied on fresh lettuce leaves which hamper the growth of *Escherichia coli* O157:H7, *L. monocytogenes and Salmonella Typhimurium* (Bhargava *et al.*, 2014), fresh cut musk melon treated with *Laurus nobilis* essential oil nanoemulsion stabilized with Tween 80 decreased surface browning (Ru *et al.*, 2022).

## 6. Conclusion

The ceaseless use of synthetic chemicals for the control of pre and post-harvest diseases caused various antagonistic health hazards, occurrence of antimicrobial resistance and environmental pollution. Nanoemulsion as an antimicrobial, antioxidants, and texture promoters. These are effective alternatives to artificial additives, representing a promising technique to achieve the consumer's claim. Nanoemulsion of essential oils has been used as a sustainable substitute for synthetic stabilizers due to their various antifungal and anti-mycotoxigenic properties. Nanoemulsion as encapsulated essential oils come up with numerous advantages for the preservation of agricultural produce such as fresh-cut fruit and vegetables. Nanoemulsion is used as a biodegradable biopolymer which increases their fluidity, longevity, and potency thereby reducing fungal, bacterial, and other pathogenic damage while storing the farmer's produce for a long time. Essential oils of cinnamon, garlic, citral, lemongrass, eugenol, orange, limonin, clove, *etc*., counter different fungal, bacterial, and other diseases such as *P. italicum*, *Rhizopus species*, *Aspergillus flavus*, yeast, mold, salmonella, and *E. coli* which lead to cause the pre and post harvest diseases in the agriculture sector. In the essential oil-based nanoemulsion demonstrates high antifungal and high antibacterial properties due to being affordable, non-phospholipids, stable, and non-toxic with medicinal use.

## Conflict of interest

The authors declare no conflicts of interest relevant to this article.

## References


**Acevedo-Fani, A.; Soliva-Fortuny, R. and Martín Belloso, O. (2017).** Nanoemulsions as edible coatings. Curr. Opin. Food Sci., **15**:43-49. https://doi.org/10.1016/j.cofs.2017.06.002.

**Abd-Elsalam, K.A. and Khokhlov, A.R. (2015).** Eugenol oil nanoemulsion: antifungal activity against *Fusarium oxysporum* f. sp. vasinfectum and phytotoxicity on cottonseeds. Appl. Nanosci., **5**:255-265. https://doi.org/10.1007/s13204-014-0398-y

**Azizkhani, M.; Jafari Kiasari, F.; Tooryan, F.; Shahavi, M.H. and Partovi, R. (2021).** Preparation and evaluation of food-grade nanoemulsion of tarragon (*Artemisia dracunculus* L.) essential oil: Antioxidant and antibacterial properties. J. Food Sci. Technol., **58**(4):1341-1348. https://doi.org/10.1007/s13197-020-04645-6

**Baptista Silva, S.; Borges, S.; Ramos, O.L.; Pintado, M. and Sarmento, B. (2020).** The progress of essential oils as potential therapeutic agents: A review. J. Essent. Oil Res., **32**(4):279-295. https://doi.org/10.1080/10412905.2020.1746698

**Bhargava, K.; Conti, D.S.; Rocha, S.R.P. and Zhang, Y. (2014).** Application of an oregano oil nanoemulsion to the control of foodborne bacteria on fresh lettuce. Food Microbiol., **47**:69-73. https://doi.org/10.1016/j.fm.2014.11.007.

**Cenobio-Galindo, Ad. J.; Ocampo-López, J.; Reyes-Munguía, A.; Carrillo-Inungaray, M.L.; Cawood, M.; Medina-Pérez, G.; Fernández-Luqueño, F. and Campos-Montiel, R.G. (2019).** Influence of bioactive compounds incorporated in a nanoemulsion as coating on avocado fruits (*Persea americana*) during postharvest storage: Antioxidant activity, physicochemical changes and structural evaluation. Antioxidants, **8**(10):500. https://doi.org/10.3390/antiox8100500

**Chaudhari, A.K.; Singh, V.K.; Das, S. and Dubey, N.K. (2021).** Nanoencapsulation of essential oils and their bioactive constituents: A novel strategy to control mycotoxin contamination in food system. Food Chem. Toxicol., **149**:112019. https://doi.org/10.1016/j.fct.2021.112019

**Chu, Y.; Gao, C.C.; Liu, X.; Zhang, N.; Xu, T.; Feng, X.; Yang, Y.; Shen, X. and Tang, X. (2020).** Improvement of storage quality of strawberries by pullulan coatings incorporated with cinnamon essential oil nanoemulsion. LWT, **122**:109054. https://doi.org/10.1016/j.lwt.2020.109054.

**Dávila-rodríguez, M.; López-malo A, Palou E.; Ramírez corona, N. and Jiménez-munguía, M.T. (2019).** Antimicrobial activity of nanoemulsions of cinnamon, rosemary, and oregano essential oils on fresh celery. LWT, **112**:108247. https://doi.org/10.1016/j.lwt.2019.06.014

**Deshmukh, M.; Makde, P.; Baheti, J. and Thote, L. (2022).** Green synthesis of zinc oxide nanoparticles (Zno-Nps) *Ailanthus excelsa* Roxb. stem bark extract and its antibacterial activity. Ann. Phytomed., **11**(2):743-747. https://doi.org/10.54085/ap.2022.11.2.90

**Dwivedy, A.K.; Singh, V.K.; Prakash, B. and Dubey, N.K. (2018).** Nanoencapsulated *Illicium verum* Hook.f. essential oil as an effective novel plant-based preservative against aflatoxin B1 production and free radical generation. Food Chem. Toxicol., **111**:102-113. https://doi.org/10.1016/j.fct.2017.11.007

**Enyiukwu, D. (2020).** Postharvest spoilage and management of fruits and vegetables: A perspective on small-holder agricultural systems of the tropics. Greener Trends in Plant Pathology and Entomology, **3**(1):1-17.

**FAO (2019).** Food Security and Nutrition in the World 2019. In IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing.Safeguarding against economic slowdowns and downturns. Rome, FAO. Licence: CC BY-NC-SA 3.0 IGO.

**Feregrino-perez, A.A.; Magaña-lópez, E.; Guzmán, C. and Esquivel, K. (2018).** A general overview of the bene fits and possible negative eff ects of the nanotechnology in horticulture. Sci. Hortic., **238**:126-137. https://doi.org/10.1016/j.scienta.2018.03.060.

**Flores-López, M.L.; Cerqueira, M.A.; de Rodríguez, D.J. and Vicente, A.A. (2016).** Perspectives on utilization of edible coatings and nano-laminate coatings for extension of postharvest storage of fruits and vegetables. Food Eng. Rev., **8**(3):292-305. https://doi.org/10.1007/s12393-015-9135-x

**Gennadios, A.; Hanna, M.A. and Kurth, L.B. (1997).** Application of edible coatings on meats, poultry and seafoods: A Review. LWT, 350:337-350.

**Gishen, N.Z.; Taddese, S.; Zenebe, T.; Dires, K.; Tedla, A.; Mengiste, B.; Shenkute, D.; Tesema, A.; Shiferaw, Y. and Lulekal, E. (2020).** *In vitro* antimicrobial activity of six Ethiopian medicinal plants against *Staphylococcus aureus*, *Escherichia coli* and *Candida albicans*. Eur. J. Integr. Med., **36**:101121. https://doi.org/10.1016/j.eujim.2020.101121

**Hasan, S.M.K; Ferrentino, G. and Scampicchio, M. (2020).** Nanoemulsion as advanced edible coatings to preserve the quality of fresh-cut fruits and vegetables: A review. Int. J. Food Sci. Technol., **55**(1):1-10. https://doi.org/10.1111/ijfs.14273

**Hasan, S.M.K. and Nicolai, B. (2014).** Quality of pears with permeability of Bio-Fresh TM edible coatings. Afr. J. Food Sci., **8**:410-418.https://doi.org/10.5897/AJFS2014.1172

**Hashim, A.F.; Youssef, K. and Abd-Elsalam, K.A. (2019).** Ecofriendly nanomaterials for controlling gray mold of table grapes and maintaining postharvest quality. Eur. J Plant Pathol., **154**(2):377-388. https://doi.org/10.1007/s10658-018-01662-2

**He, X.; Deng, H. and Hwang, H. (2019).** The current application of nanotechnology in food and agriculture. Journal Food Drug Anal., **27**(1):1-21. https://doi.org/10.1016/j.jfda.2018.12.002

**Husain, M. K. (2023).** Nanotechnology and current advances in plant tissue culture. J. Phytonanotech. Pharmaceutical Sciences., **3**(1):1-8.

**Ishkeh, S.R.; Shirzad, H.; Asghari, M.R.; Alirezalu, A.; Pateiro, M. and Lorenzo, J.M. (2021).** Effect of chitosan nanoemulsion on enhancing the phytochemical contents, health-promoting components, and shelf life of raspberry (*Rubus sanctus* schreber). Appl. Sci. (Switzerland)., **11**(5):1-16. https://doi.org/10.3390/app11052224.

**Kim, I.H.; Lee, H.; Kim, J.E.; Song, K. Bin.; Lee, Y.S.; Chung, D.S. and Min, S.C. (2013).** Plum coatings of lemongrass oil-incorporating carnauba wax-based nanoemulsion. J. Food Sci., **78**(10):551-559. https://doi.org/10.1111/1750-3841.12244

**Kringel, D.H.; Lang, G.H.; Dias, Á.R.G.; Gandra, E.A.; Valente Gandra, T.K. and da Rosa Zavareze, E. (2021).** Impact of encapsulated orange essential oil with α-cyclodextrin on technological, digestibility, sensory properties of wheat cakes as well as *Aspergillus flavus* spoilage. J. Sci. Food Agri., **101**(13):5599–5607. https://doi.org/10.1002/jsfa.11211

**Krishnamoorthy, R.; Gassem, M.A.; Athinarayanan, J.; Periyasamy, V.S.; Prasad, S. and Alshatwi, A.A. (2021).** Antifungal activity of nanoemulsion from Cleome viscosa essential oil against food-borne pathogenic *Candida albicans*. Saudi J. Biol. Sci., **28**(1): 286-293. https://doi.org/10.1016/j.sjbs.2020.10.001

**Li, Y.; Zhao, R.; Li, Y. and Zhou, Z (2021).** Limonin enhances the antifungal activity of eugenol nanoemulsion against *Penicillium italicum* in *vitro* and *in vivo* tests. Microorganisms, **9**(5):969. https://doi.org/10.3390/microorganisms9050969

**Long, Y.; Huang, W.; Wang, Q. and Yang, G. (2020).** Green synthesis of garlic oil nanoemulsion using ultrasonication technique and its mechanism of antifungal action against *Penicillium italicum*. Ultrason. Sonochem., **64**:104970. https://doi.org/10.1016/j.ultsonch.2020.104970

**Mandadi, S.R. and Srinivas, L. (2023).** Synthesis and characterization of letrozole-loaded polymer based nanoparticulate formulations for treating breast cancer. Ann. Phytomed., **12**(1):1-8.

**Mcclements, D.J. (2020).** Nanotechnology approaches for improving the healthiness and sustainability of the modern food supply. ACS Omega, **5**(46):29623-29630. https://doi.org/10.1021/acsomega. 0c04050

**Mcclements, D.J.; Das, A.K.; Dhar, P. and Nanda, P.K. (2021).** Nanoemulsion-based technologies for delivering natural plant-based antimicrobials in foods. Frontier in Sustainable Food System, **5**:1-23. https://doi.org/10.3389/fsufs.2021.643208

**Mehmood, T.; Ahmed, A.; Ahmad, M.S. and Sandhu, M.A. (2018).** Optimization of mixed surfactants-based α-carotene nanoemulsions using response surface methodology: An ultrasonic homogenization approach. Food Chem., 253: 179-184. https://doi.org/10.1016/j.foodchem. 2018.01.136

**Miranda, M.; Ribeiro, M.D. M.M.; Spricigo, P.C.; Pilon, L.; Mitsuyuki, M.C.; Correa, D.S. and Ferreira, M.D. (2022).** Carnauba wax nanoemulsion applied as an edible coating on fresh tomato for postharvest quality evaluation. Heliyon, **8**(7):e09803. https://doi.org/10.1016/j.heliyon.2022.e09803

**Mistry, S.J.; Gohel, N.M.; Parmar, R.G. and Parmar, D.M. (2022).** Biosynthesis of silver nanoparticles (AgNPs) using fresh oyster mushroom extract and their antifungal activity against *Rhizoctonia solani*. Ann. Phytomed., **11**(2):748-754. https://doi.org/10.54085/ap.2022.11.2.91

**Mostafa, D.M.; Kassem, A.A.; Asfour, M.H.; Al Okbi, S.Y.; Mohamed, D.A. and Hamed, T.E.S. (2015).** Transdermal cumin essential oil nanoemulsions with potent antioxidant and hepatoprotective activities: *In vitro* and *in vivo* evaluation. J. Mol. Liq., **212**:6-15. https://doi.org/10.1016/j.molliq.2015.08.047

**Nina Duarte, Anaruma.; Flávio Luís, Schmidt.; Marta Cristina Teixeira, Duarte.; Glyn Mara, F. and Camila Delarmelina, E.A.B.V. (2010).** Control of *Colletotrichum gloeosporioides* (Penz.) Sacc. In yellow passion fruit using *Cymbopogon citratus* essential oil. Nina. Braz. J. Microbiol., **41**:66-73.

**Odoemenam, A.A.D.E.V. (2016).** Influence of plant gleaned compounds on the initiation and development of fungal diseases of onion (*Allium cepa* L.). Journal of Biology, Agriculture and Healthcare, **6**(9):71-80.

**Oerke, E.C. (2006).** Crop losses to pests. J. Agric. Sci., 144:31-43. https://doi.org/10.1017/S0021859605005708.

**Oliveira Filho, J.Gd.; Silva, Gd. C.; Oldoni, F.C.A.; Miranda, M.; Florencio, C.; Oliveira, R.M.Dd.; Gomes, Md.P. and Ferreira, M.D. (2022).** Edible coating based on carnauba wax nanoemulsion and *Cymbopogon martinii* essential oil on papaya postharvest preservation. Coatings, **12**(11):1700. https://doi.org/10.3390/coatings12111700

**Pandey, A.K.; Kumar, P.; Singh, P.; Tripathi, N.N. and Bajpai, V.K. (2017).** Essential oils: Sources of antimicrobials and food preservatives. Front. Microbiol., **7**:1-14. https://doi.org/10.3389/fmicb.2016.02161

**Patologia, L.De. (2018).** Postharvest treatments with GRAS salts to control fresh fruit decay. Horticultrae, **4**(4):46.https://doi.org/10.3390/horticulturae4040046.

**Pol, V.S.; Ingle, Y.V. and Lengare, K.A. (2023).** Antifungal effects of plant essential oils against *Colletotrichum gloeosporioides*, the fungus associated with citrus twig blight. Ann. Phytomed., **12**(1):1-8.

**Prakash, A.; Baskaran, R. and Vadivel, V. (2020).** Citral nanoemulsion incorporated edible coating to extend the shelf life of fresh cut pineapples. LWT, **118**:108851. https://doi.org/10.1016/j.lwt.2019.108851.

**Radi, M.; Akhavan-Darabi, S.; Akhavan, H.R. and Amiri, S. (2018).** The use of orange peel essential oil microemulsion and nanoemulsion in pectin-based coating to extend the shelf life of fresh-cut orange. J. Food Process. Pres., **42**(2):1-9. https://doi.org/10.1111/jfpp.13441

**Radi, M.; Firouzi, E.; Akhavan, H. and Amiri, S. (2017).** Effect of gelatin-based edible coatings incorporated with Aloe vera and black and green tea extracts on the shelf life of fresh-cut oranges. J. Food Qual., **2017**:10. https://doi.org/10.1155/2017/9764650.

**Radi, M.; Shadikhah, S.; Sayadi, M.; Kaveh, S.; Amiri, S. and Bagheri, F. (2022).** Effect of *Thymus vulgaris* essential oil-loaded nanostructured lipid carriers in alginate-based edible coating on the postharvest quality of tangerine fruit. Food Bioprocess Technol., pp:185-198. https://doi.org/10.1007/s11947-022-02914-0

**Rashid, F.; Ahmed, Z.; Ameer, K.; Amir, R.M. and Khattak, M. (2020).** Optimization of polysaccharides-based nanoemulsion using response surface methodology and application to improve postharvest storage of apple (*Malus domestica*). J. Food Meas. Charact., **14**(5): 2676-2688. https://doi.org/10.1007/s11694-020-00514-0

**Rehman, A.; Jafari, S.M.; Tong, Q.; Karim, A.; MahdiA, A.; Iqbal, M.W.; Aadil, R.M.; Ali, A. and Manzoor, M.F. (2020).** Role of peppermint oil in improving the oxidative stability and antioxidant capacity of borage seed oil-loaded nanoemulsions fabricated by modified starch. Int. J. Biol. Macromol., **153**:697-707. https://doi.org/10.1016/j.ijbiomac.2020.02.292

**Rehman, A.; Qunyi, T.; Sharif, H.R.; Korma, S.A.; Karim, A.; Manzoor, M.F.; Mehmood, A.; Iqbal, M.W.; Raza, H.; Ali, A. and Mehmood, T. (2021).** Biopolymer based nanoemulsion delivery system: An effective approach to boost the antioxidant potential of essential oil in food products. Carbohydrate Polymer Technologies and Applications., **2**: 100082. https://doi.org/10.1016/j.carpta.2021.100082.

**Ribeiro-Santos, R.; de MeloN, R.; Andrade, M. and Sanches-Silva, A. (2017).** Potential of migration of active compounds from protein-based films with essential oils to a food and a food simulant. Packag. Technol. Sci., **30**(12):791-798. https://doi.org/10.1002/pts.2334.

**Rinaldi, F.; Hanieh, P.N.; Longhi, C.; Carradori, S.; Secci, D.; Zengin, G.; Ammendolia, M. G.; Mattia, E.; Del Favero, E.; Marianecci, C. and Carafa, M. (2017).** Neem oil nanoemulsions: characterization and antioxidant activity. J. Enzyme Inhib. Med. Chem., **32**(1):1265-1273. https://doi.org/10.1080/14756366.2017.1378190.

**Ru, Q.; Hu, Q.; Dai, C.; Zhang, X. and Wang, Y. (2022).** Formulation of *Laurus nobilis* essential oil nanoemulsion system and its application in fresh-cut muskmelons. Coatings, **12**(2):159. https://doi.org/10.3390/coatings12020159.

**Rupa, E.J.; Li, J.F.; Arif, M.H.; Yaxi, H.; Puja, A.M.; Chan, A.J.; Hoang, V.A.; Kaliraj, L.; Yang, D.C. and Kang, S.C. (2020).** Cordyceps militaris fungus extracts-mediated nanoemulsion for improvement antioxidant, antimicrobial, and anti-inflammatory activities. Molecules, **25**(23):1-14. https://doi.org/10.3390/molecules25235733.

**Salvia-Trujillo, L.; Rojas-Graü, M.A.; Soliva-Fortuny, R. and Martín-Belloso, O. (2015).** Use of antimicrobial nanoemulsions as edible coatings: Impact on safety and quality attributes of fresh-cut fuji apples. Postharvest Biol. Technol., **105**:8-16. https://doi.org/10.1016/j.postharvbio.2015.03.009

**Sessa, M.; Ferrari, G. and Donsì, F. (2015).** Novel edible coating containing essential oil nanoemulsions to prolong the shelf-life of vegetable products. Chem. Eng. Trans., **43**:55-60. https://doi.org/10.3303/CET1543010

**Shiraz, F.R. (2020).** Effect of Betel leaf extract on the control of stem-end rot disease and overall quality retention of papaya (*Carica papaya* L.) during cold storage, Doctoral dissertation, University of Nottingham.

**Sperber, W. (2009).** Compendium of the microbiological spoilage of foods and beverages. Sperber W.H and Doyle M.P. (eds) In compendium of the microbiological spoilage of foods and beverages. Springer, New York, pp:1-40. https://doi.org/10.1007/978-1-4419-0826-1

**Tripathi, A.D.; Sharma, R. and Agarwal, A. (2021).** Nanoemulsions based edible coatings with potential food applications. Int. J. Biobased Plast., 3(1):112-125. https://doi.org/10.1080/24759651.2021.1875615

**Yang, R., Miao, J., Shen, Y., Cai, N., Wan, C., Zou, L., Chen, C., and Chen, J. (2021).** Antifungal effect of cinnamaldehyde, eugenol and carvacrol nanoemulsion against *Penicillium digitatum* and application in postharvest preservation of citrus fruit. LWT, **141**:110924. https://doi.org/10.1016/j.lwt.2021.110924

**Youssef, K.; Ippolito, A. and Roberto, S.R. (2022).** Editorial: Post-harvest diseases of fruit and vegetable: Methods and mechanisms of action. Front. Microbiol., **13**:1-2. https://doi.org/10.3389/fmicb.2022.900060

**Youssef, K. and Ruffo, S. (2014).** Salt strategies to control *Botrytis* mold of 'Bentaka' table grapes and to maintain fruit quality during storage. Postharvest Biol. Technol., **95**:95-102. https://doi.org/10.1016/j.postharvbio.2014.04.009.

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