Journal of Postharvest Technology
2020, **08**(4): 52-63
www.jpht.in

REVIEW ARTICLE

Nano edible coatings and their applications in food preservation

Unique Mahela, D. K. Rana, Udit Joshi*, Yashwant Singh Tariyal[2]

Department of Horticulture, H.N.B.G.U Srinagar Garhwal Uttarakhand, and 2High Altitude Plant Physiology Research Centre H.N.B.G.U Srinagar Garhwal Uttarakhand

Received: 19.08.2020 Accepted: 13.10.2020

ABSTRACT

Due to a lack of adequate infrastructure and limited use of modern postharvest technologies, 20 to 30% of the produce is lost annually. Using nano-edible coatings is among the suitable ways for preserving food characteristics at reasonable costs. For increasing the shelf life of food articles, a very thin layer is created on their surface. In a nanosystem, in contrast to a larger particle system, materials are supplied with improved and distinct properties. The shelf life of many products like fresh vegetables and fruits, nuts, etc., gets increased by this technology via the incorporation of substances having hydrophilic, antimicrobial, and antioxidant properties. The substances are generally released during storage periods of the food products. Different nanocoatings are nanoemulsion, polymeric nanoparticles, solid lipid nanoparticles, lipid nanocarriers, nanotubes, nanofibers, etc. Besides several advantages, some nanocoatings might carry allergic properties associated with them and also are economically not viable to use. Nanosystems nowadays are gaining a lot of importance in food preservation-related research areas, and their development as efficient edible coatings offer great potential in the relevant fields. Hence, there is a need for more research work to apply the nanoparticles and their consumption perspective.

Keywords: Antimicrobial, food, nanoparticles, postharvest, shelf life

Citation: Mahela, U., Rana, D. K., Joshi, U., and Tariyal, Y. S. 2020. Nano edible coatings and their applications in food preservation. *Journal of Postharvest Technology*, **8** (4): 52-63.

INTRODUCTION

Globally, it is being observed that there are a great demand and consumption of fresh natural and organic products. Demands from consumers' side have shown that processing in the recent past is required to a lesser extent in products as the market favors lesser substantial changes in food articles' characteristics for maintaining functional and nutritional properties of vegetables, fruits, seeds, nuts, etc. For achieving this, the food surface is supplied by a thin edible layer for shelf-life extension and for preserving the characteristics and functionality of food articles. The edible coatings can be applied by rubbing, immersing, or spraying to the food items, and generally, eco-friendly materials are used for their preparation. Also, in rare conditions, the edible coatings needed to be eliminated before their consumption (Yousuf et al*.,* 2018). Vectorization of natural products with antioxidant and antimicrobial activity to maximize effects on quality of fresh produce has been considered an effective method (Dhall, 2013). An excellent edible coating should have to be compatible both functionally and organoleptically with the food in question (Sahe et al*.*, 2017). Nowadays, nanotechnology has created an opportunity to develop means for transportation of plant extracts such as polyphenols and several vitamins with antioxidant and antimicrobial activities. Nanotechnology involves every submicron-size system (<1000 nm), most preferably between 100–500 nm (Mora et al*.*, 2010). The incorporation of nanoparticles leads to a higher surface area per amount of mass compared to larger-sized particles with the same chemical composition,

* *For correspondence*: U. Joshi (Email: uditjoshi444@gmail.com)
ISSN: 2348-4330

which makes them more active biologically and highly stable. The hydrophilic substance of active nature does not modify the transparency and look of the food products in nano-coating. Simultaneously, the appearance is maintained along with enhancement of shelf life (Dan, 2016 and Ranjan et al., 2014).

Significant advantages of using edible nano-coating include a reduction in water loss, movement of fats and oils, gas diffusion, solute movement, losses in volatile flavors and aromas, as it helps in improving structural properties (holding it together), easy incorporation of food additives, pigments and flavoring agents. These coatings also restrict oxygen and moisture transfer, improve the food product's appearance, reduce mould and fungal growth, and reduce adhesion of food particles to the cooking surface.

ACTION OF EDIBLE COATINGS

Fresh food products like vegetables and fruits use all available oxygen in products and remain in their respiring phase even after they get harvested. In contrast, the edible coatings replace the oxygen and produce CO_2, which gets trapped inside the product as the layer does not let it pass through. Hence the produce shifts towards partial anaerobic respiration in which less oxygen is required (1–3%). With the lesser amount of available oxygen, the production of ethylene gets disrupted. Also, water loss by physiological means is minimized, leading to extended firmness and doubling the shelf life of vegetables and fruits. They remain fresh and highly nutritious for a more comprehensive range of periods (McHugh and Senesi, 2000).

PROPERTIES OF EDIBLE COATINGS

Edible coating's properties primarily depend upon the coating's molecular structure rather than its chemical constitution and molecular size. According to Arvanitoyannis and Gorris (1999), specific requirements associated with edible coatings are:

- The edible coating needs to be water-resistant and impervious to water vapors for keeping the product intact and making a covering that covers the product adequately.
- The covering should not degrade a higher level of oxygen or accumulate elevated carbon dioxide inside the package. As at least 1–3% amount of oxygen is required surrounding a product for avoiding anaerobic respiration.
- The coating should maintain structural integrity, enhance appearance, improve mechanical handling properties.
- It should carry active agents like vitamins, antioxidants, etc. also should help retain volatile flavour compounds.
- The coating material should be non-sticky, easily emulsifiable.
- It should be efficient while drying and should not melt quickly (<40 ^{o}C).
- The coating should not impart unwanted odour and should never interfere with the quality of fresh commodities.
- It should be lower in terms of viscosity and should be translucent to opaque.
- It should be capable of tolerating slight pressure also, most importantly, should be economically viable.

EDIBLE COATINGS AND NANOSYSTEMS AS THEIR COMPONENTS

The development of Nanosystems, which involves mixtures acceptable for food and related products, has cleared the path of exploration of modifications of edible coatings combinations of inorganic and organic components that are Nano-sized. These

Nanosystems are generally mixed in a protein or polysaccharide matrices known as "nanocomposites," which can be stated as the mixture of two or greater than two materials, forming a mixture which helps in improving the characteristics of a component in which at least one of them comes under nanometric scale (Mallakpour et al., 2016). Progress made in the field of nano-composites has lead edible coatings to be applied as "temporal distribution systems," releasing active substances from a material film to the food for conservation improvement (Liu et al., 2017).

NANOEMULSION

These are some colloidal systems in which the oil phase gets dispersed in liquid or aqueous phase, leading to the surrounding of every drop of oil by a thin interfacial layer made up of emulsifying nature molecules. The range of Nanoemulsions particles is from 50 nm to 500 nm (Ranjan et al., 2014). Generally, two kinds of nanoemulsion coatings can be seen depending on the phases involved in the first, water/oil (w/o) and second oil/water (o/w). Oil/water systems are most accepted in edible coatings because of their property of allowing lipophilic substances to generate antimicrobial effects into a hydrophilic polymeric matrix. Antioxidants, essential oils extracted from plants, phytosterols, and quinones are some lipophilic materials generally mixed in nanoemulsions (Salvia et al., 2017).

Polymeric Nanoparticles

These structures are colloidal with particle sizes ranging from 100 nm–1000 nm. Two types of common polymeric nanoparticles are often discussed on morphology, first particles formed by dense polymeric matrix known as nanospheres and second particles having an oil core encircled by a polymeric membrane known as nanocapsules. The target bioactive molecule, which is trapped in the case of nanospheres, can get surface absorbed or dispersed molecularly in the matrix. A bioactive molecule might get retained in an oily core surrounded by polymeric wall thin in the case of nanocapsules. Although the dissolution of polymeric nanoparticles in the oil core can be more common, monomers could also prepare polymeric nanoparticles. However, there is a prevalence of toxic residual compounds formed after polymerization reaction; hence it is usually avoided (Salvia et al., 2017). There has been a report of the inclusion of curcumin in nanospheres or nanocapsules in the case of various nano-formulations. Using chitosan as a polymer, curcumin nanospheres are also applied (Liu et al*.,* 2017). The incorporation of jasmine essential oil nanocapsules is composed of two biocompatible polymers, gelatin and Arabic gum (Lv et al*.,* 2014).

Solid Lipid Nanoparticles

The use of these types of nanoparticles can be observed since the 1900s for delivery and encapsulation of bioactive nature components when these were made by replacing the liquid state lipid (oil) in the emulsion with a solid one. In that case, lipids are solid at both body temperature and ambient temperature (Sabliov et al., 2015). The SLN system ranges from 50 nm–1000 nm (submicron range) consisting, solid lipid spherical particles, water-insoluble core dispersed, and surfactants stabilized (Geszke et al., 2016). The solid core part has a bioactive compound, either dispersed or dissolved in the solid oil matrix or the fatty acid chains, which after the transition, move to relatively many stable forms from α to β^0 to β (Sabliov et al., 2015).

Lipid Nanocarriers

These are evolved as ideal systems for delivering and transporting substances for protection from biological and enzymatic degradation and solubility-related problem resolution that can affect lipophilic substances. Generally, a mixture of solid and liquid lipids, usually in a ratio of 70:30, is used to formulate nanostructured lipid carriers (Sala et al., 2018). They are nanoemulsions based on oil-in-water having bioactive compound's inner phase in a lipid-based matrix generally formed by a mixture of lipids which are solid and liquid. In contrast, the outer phase mixed with emulsifiers is usually water. Nanostructured lipid carriers are commonly designed for the encapsulation of hydrophobic compounds. The lipid in the liquid phase allows the active substance's dispersion to a better extent, and the melting point is also reduced in contrast to pure solid lipid. Defects in the structure of crystal lead to the prevention of lipid polymorphism and avoidance of perfect crystalline structure to provide the active components with more space.

Inorganic/Organic Nanocomposites in Edible Films

It is now commonly explored to create nano-composites combining nanosystems blended with organic and inorganic substances. These sorts of mixtures are a choice for improving the edible coating's properties as they allow for improved transparency, controlled release, mechanical resistance, and a more efficient gaseous exchange barrier (Arora et al*.,* 2010). Montmorillonite (MMT), nano-Si oxides, nano-TiO_2, and nano-ZnO, and silver nanoparticles, are the most commonly used inorganic components modification edible coatings. However, it is necessary to remember that the latter can only be used for coating whole vegetables and fruits. Nanoclay is an abundant, natural nanoparticle material that can be transformed into reinforcing agents. Nanoclays comprise silicate and have a multi-layered shape, such as montmorillonite (MMT), with a width and length of 100-150 nm. Still, their thickness (1 nm) is the critical factor in achieving composite films' mechanical properties (Klangmuang et al*.,* 2016).

Nanotubes and Nanofibers

Nanotubes and nanofibres have recently been recommended as beneficial active material carriers (antimicrobials or antioxidants). Nanotubes have 8 nm diameter cavities that can encapsulate various functional materials in the food articles. There are few limitations to their introduction into edible coatings when these materials are formulated with milk proteins to preserve food. At the same time, the influence of humidity on their stability needs to be noted. They typically stay on the nanotube's surface like the substance to be encapsulated, achieving a controlled release based on the service polymer supplied by the edible coatings (Ramos et al*.,* 2017). Carbon nanotubes have been extensively researched, but they are primarily used in container production to be integrated into polymeric matrixes to alter mechanical properties.

Their future use concerning the encapsulation of antimicrobial and antioxidant compounds has been studied to protect food quality and protection. As components of edible coatings, they can be used. Nanofibers are classified as nanometric-size fibrous scaffolds with diameters of <100 nm or even 500 nm. They are also used to immobilize enzymes, modify the film's properties and encapsulate various active ingredients. In this case, they are seen as a modern solution to edible coatings production (Fahami et al*.,* 2018).

APPLICATION OF NANO EDIBLE COATINGS

Due to particle size, there are diverse possibilities for the incorporation of nano-coating into food-grade polymeric matrixes. When interacting with the coating matrix, various types of systems make different contributions. The critical changes recorded were related to the optical and mechanical properties, the antimicrobial and antioxidant effects, and the probability of achieving regulated release at varying temperatures during storing food products, particularly in the cold storage of minimally processed products (Luo et al., 2017). With nanosystems, this is possible as they allow smaller ratios of such materials to be used and therefore do not pass changes in the food products' flavour.

Nanoemulsions in Edible Coatings

Nanoemulsions have considerable potential as delivery channels for active ingredients in edible coatings and other applications in food production. Table 1 provides a list of active lipophilic compounds nanostructured in nanoemulsion solutions, demonstrating their versatility and application fields. Scientific investigations have shown that nanostructuring in nanoemulsions of bioactive lipophilic materials improves their bioavailability (Salvia et al., 2017).

Table 1: Research on the effects of nanoemulsion as edible coatings in different foods on antioxidant capacity, shelf life, antimicrobial properties, and enzymatic suppression. (Sow et al*.,* 2017, respectively)

Bioactive Substance	Functionality	Biopolymer Matrix	Food material	Findings
Carvacrol	Antimicrobial	-	Cabbage	Based on the outcome of P. *Pastoris* and *E. coli* inhibition in the nutrient medium, the antibacterial property of carvacrol nanoemulsion was established.
Carvacrol	Antimicrobial	Chitosan	Cucumber	The mixture of edible coating (0.08 % carvacrol) with pulsed light (12 J/cm2) ended in a powerful synergistic effect, with >5 log cycles reduction of *E. coli*.
Lemongrass essential oil	Antimicrobial	Sodium alginate	Fresh-cut apple	Edible coatings based on nanoemulsion showed a higher suppression of *E. coli* and sluggish development of psychrophilic microbes at the same concentration as traditional emulsions.
Lemongrass oil	Antimicrobial Antioxidant	Chitosan	Grape berry	Initial growth of *S. typhimurium,* moulds, yeast, and mesophiles was significantly lowered through nanoemulsion and showed persistence of antioxidant ability.
Mandarin essential oil	Antimicrobial	Chitosan	Green beans	By combining bioactive coating and UV-C treatment, the population of *L. innocua* was reduced while the microbial load was preserved to a constant degree during storage.
Alfa tocopherol	Extension of shelf life and enzyme-based activities	Nopal mucilage	Fresh-cut apples	The coatings developed with the nanoemulsion had a significant inhibitory effect on PME and PPO behavior than conventional emulsions.

Polymeric Nanoparticles in Edible Coatings

As their antimicrobial activity has been known for several years, essential oils are several other compounds with higher quality for use in polymeric nanoparticles accompanied by use in edible coatings. There have been reports of turmeric oil and lemongrass oil nanocapsules of alginate-chitosan. Although there are many formulated polymers present for the preparation of polymeric nanoparticles, particular attention is given to the formulation of chitosan nanoparticles in food applications. It is biodegradable, non-toxic, biocompatible, better mechanical properties and film-forming capability and fungicidal and antimicrobial property, and selective gas permeability. Research published by Pilon et al. (2015) reveals that chitosan nanoparticles were controlled effectively to reduce weight loss and maintain firmness by ionotropic gelation on fresh strawberries while also delaying respiratory rate changes three weeks. Chitosan-based edible coatings are more affordable in terms of price than other polymers, like PLA or PCL. The release may be carried out by diffusion in all cases (nanospheres or nanocapsules) or by membrane breaking in the case of nanocapsules (Martínez, 2010).

Solid Lipid Nanoparticles (SLNs)

Due to the considerable stability and high loading capacity of solid lipid nanoparticles, they provide a potential method for supplying bioactive compounds to food products and as a component of edible coatings. The SLNs include lipophilic antioxidants, nutraceutical and antimicrobial agents with active delivery mechanisms, enhancing their safety, bioavailability, and dispersibility in aqueous media. Compounds including polyphenols, flavonoids, vitamins, minerals, oils, carotenoids, lipophilic vitamins, and phytosterols are good options as bioactive compounds that could be used to modify food products and improve their functionality (Table 2 and 3).

Table 2: Usage of Solid Lipid Nanoparticles in industries associated with food products. (Aditya et al., 2017)

Lipid matrix	Stabilizer or surfactant	Food Product	Uses
Wax Candeuba wax (Registered)	Poloxamer 407	Guava	To mitigate the senescence of multiple items, the possible use of SLNs may easily be applied to edible coatings.
Wax Candeuba (Registered)	Poloxamer 407	Edible Films	These findings suggest that SLN films can be used for preservation purposes as nano-coatings for whole fruits and vegetables.
Wax Candeuba (Registered)	Poloxamer 407	Pear	Candeuba wax (SLN) application helps, but at a slower pace, to maintain the natural aging process.

Table 3: Integration of active compounds into NLCs for applications within the food industry. (Acevedo et al., 2017)

Active compound	Solid Lipid	Liquid Lipid (Oil)	Findings
Beta carotene	Tristearin	Sunflower oil	The addition of β-carotene decreased the polydispersity of particles, and NLCs showed an increase in the loading capability of β-carotene comparison with SLN. NLCs have shown positives over SLN, like improved loading capability and effective prevention of expulsion.
Vitamin D	Glycerol monostearate	Oleic acid	Digestion in *in vitro* conditions demonstrated their potential for controlled release in simulated gastrointestinal fluids.

Pomegranate seed oil	Beeswax, propolis wax	Glyceryl behenate	Formulation variables had a significant impact on the physical properties of NLCs and demonstrated outstanding physical stability. Lecithin, Tween 80 10 percent oil, and 6 percent surfactant were the optimal formulations.
Rutin	Cacao butter	Oleic acid	NLCs with a 10 percent rutin-to-lipid ratio were optimized as an ideal formulation to collect round-shaped NLCs to fortify food samples as a method for developing new food items.
Quercetin	Glyceryl monostearate	Linseed oil	The in vitro antioxidant feature of a sustained pattern of quercetin-loaded NLCs was improved by incorporating linseed oil. Lower lipid oxidation in quercetin and linseed oil co-loaded NLCs were observed to be stable at 25 degrees Celsius for more than three months compared to conventional linseed oil emulsion NLCs.
Lycopene	Glycerol distearate, glycerol monostearate		SLNs had lower encapsulation output as compared to NLCs. Glycerol monostearate comprising nanoparticles demonstrated separation of the caprylic/capric process after 30 days at 6 and 25 degree Celsius when a beverage product was incorporated into triglyceride. Sensory research showed that the low solubility and flavour of lycopene could be avoided by nanoencapsulation.

Inorganic Nanocomposites in Edible Coatings

Compounds of inorganic nature are vital in producing edible coatings in which certain components need a small proportion. However, there are endless quantities of proteins, lipids, and polysaccharides that can be identified based on each food product's unique traits, source, and structure when designing edible coatings for various foods.

Nanotubes and Nanofibers

The methodology of electrospinning has allowed nanofibers' production, which can be functionalized with various active substances, possibly having an antioxidant and antimicrobial impact. Due to its high crystallinity and negative-charged configuration, nanocrystals change the mechanical and barrier properties, allowing for a more significant association with the food's surface. These nanosystems are often integrated into polymer matrices (polysaccharides and proteins) that can be functionalized with various EOs and natural products (Deng et al*.,* 2017).

PROBLEMS ASSOCIATED WITH NANO EDIBLE COATINGS

While some edible coatings are successfully applied to fresh vegetables and fruits, other applications have adversely affected performance. Using edible coatings, altering the internal atmosphere may raise disorders related to the low amount of Oxygen and high amount of carbon dioxide. The noteworthy thing is that controlling the nanosystems application in food articles is a contentious topic. It must be called a 'Novel Food' if, as per Regulation 258/977, a nanomaterial is used in the United States as the main component (Gallocchio et al*.,* 2015).

Allergic Reaction

Several coatings are produced from components that can trigger allergic reactions. Nuts, wheat, dairy, soybeans, fish, peanuts are relevant within the sealer gens. Thus, a coating on a component of food with a recognized allergen must also be clearly labeled.

Costly

Plenty of edible coating products are expensive, and some of the coating operations are more expensive. So, by figuring out the substitute coating material sand methods rather than expensive coating material and process, we have to reduce service costs.

Lack of expertise and machinery

There is a lack of necessary details on the composition of film coatings, properties, efficient application methods on vegetable or fruit surfaces, and efficacy. Considerable research is required to apply edible coatings and films to vegetables and fruits. Also, since edible coatings and films are still in the testing phase, companies do not have the technology needed to adopt the procedure. Its current use is, for the moment, limited to items with high added value.

CONCLUSION

Nowadays, nanoparticles have become a crucial food research field that is the leading contender for creating more effective edible coatings with a strong potential for food preservation applications. Due to consumer preferences, the critical uses will be for fresh items, as the creation of edible nanosystem coatings allows antioxidants and antimicrobials to be incorporated. The ideal type of the submicron system will depend on the food's characteristics, the material to be encapsulated, and the expected shelf life improvement. The additives should preferably be non-toxic and derived from natural sources so that the functionalized nanosystem enables the controlled release of active substances with low solubility. Ultimately, the chosen nanosystem can preserve the volatiles' quality in essential oils and other natural products to protect food. Significant developments must include seeking novel approaches to regulate the mechanical properties, the transport of gases, and edible coatings' thermal resistance to adjusting to environmental conditions by changing their properties concerning factors such as temperature and relative humidity. Inorganic substances in nanocomposites would make it possible to build structures that have better control over O2, CO2, and water vapor transport. However, despite the studies outlined here, it is apparent that much more work is needed. In particular, researchers should necessarily understand these materials' behavior after ingestion to create stable nanosystems that could be used in commercial products.

REFERENCE

Acevedo-Fani, A., Soliva-Fortuny, R., and Martín-Belloso, O. (2017). Nanoemulsions and NLC as edible coatings. Current Opinion in Food Sciences, 15: 43-49.

Aditya, N. P., Espinosa, Y. G., and Norton, I. T. (2017). Encapsulation systems for the delivery of hydrophilic nutraceuticals: Food application. Biotechnological Advances, 35: 450-457.

Arora, A. and Padua, G. W. (2010). Review: Nanocomposites in food packaging. Journal of Food Science, 75: 43-49.

Arvanitoyannis, I., and Gorris, L. G. M. (1999). Edible and Biodegradable Polymeric Materials for Food Packaging or Coating. In: Processing Foods: Quality Optimization and Process Assessment, CRC Press, Boca Raton, Florida.

Aytac, Z., Ipek, S. Durgun, E. Tekinay, T. and Uyar, T. (2017). Antibacterial electrospun zein nanofibrous web encapsulating thymol/cyclodextrin-inclusion complex for food packaging. Food Chemistry, 233: 117-124.

Cortez-Vega, W. R., Pizato, S., de Souza, J. T. A., and Prentice, C. (2014). Using edible coatings from Whitemouth croaker (Micropogonias furnieri) protein isolate and organo-clay nanocomposite to improve the conservation properties of fresh-cut “Formosa” papaya. Innovative Food Science and Emerging Technolology, 22: 197-202.

Dan, N. (2016). Compound release from nanostructured lipid carriers (NLCs). Journal of Food Engineering, 171: 37-43.

Deng, Z., Jung, J., Simonsen, J., Wang, Y., and Zhao, Y. (2017). Cellulose nanocrystal reinforced chitosan coatings for improving the storability of postharvest pears under both ambient and cold storages. Journal of Food Science, 82: 453-462.

Dhall, R. K. (2013). Advances in Edible Coatings for Fresh Fruits and Vegetables: A Review. Critical Reviews in Food Science and Nutrition, 53: 435-450.

Gallocchio, F., Belluco, S., and Ricci, A. (2015). Nanotechnology and food: brief overview of the current scenario. Procedia Food Science, 5: 85-88.

Geszke-Moritz, M., and Moritz, M. (2016). Solid lipid nanoparticles as attractive drug vehicles: Composition, properties, and therapeutic strategies. Material Science and Engineering: C, 68: 982-994.

Guimarães, I. C., dos Reis, K. C., Menezes, E. G. T., Rodrigues, A. C., da Silva, T. F., de Oliveira, I. R. N., and Boas, E. V. D. (2016). Cellulose microfibrillated suspension of carrots obtained by mechanical defibrillation and their application in edible starch films. Industrial Crops and Products, 89: 285-294.

Huang, J., Wang, Q., Li, T., Xia, N., and Xia, Q. (2017). Nanostructured lipid carrier (NLC) as a strategy for encapsulation of quercetin and linseed oil: Preparation and in vitro characterization studies. Journal of Food Engineering, 215: 1-12.

Junqueira-Gonçalves, M. P., Salinas, G. E., Bruna, J. E., and Niranjan, K. (2017). An assessment of lactobiopolymer-montmorillonite composites for dip coating applications on fresh strawberries. Journal of Science of Food and Agriculture, 97: 1846-1853.

Katouzian, I., Faridi Esfanjani, A., Jafari, S.M., and Akhavan, S. (2016). Formulation and application of a new generation of lipid nano-carriers for the food bioactive ingredients. Trends in Food Science & Technology, 62: 974-983.

Klangmuang, P., and Sothornvit, R. (2016). Combination of beeswax and nanoclay on barriers, sorption isotherm, and mechanical properties of hydroxy propyl methyl cellulose-based composite films. LWT- Food Science and Technology, 65: 222-227.

Koushesh, S. M., and Amini, R. (2017). Nano-ZnO/carboxymethyl cellulose-based active coating impact on ready-to-use pomegranate during cold storage. Food Chemistry, 232: 721–726.

Liu, F., Jiang, Y., Du, B., Chai, Z., Jiao, T., Zhang, C., Ren, F., and Leng, X. (2013). Design and characterization of controlled-release edible packaging films prepared with synergistic whey-protein polysaccharide complexes. Journal of Agriculture and Food Chemistry, 61: 5824-5833.

Liu, R., Liu, D., Liu, Y., Song, Y., Wu, T., and Zhang, M. (2017). Using soy protein SiOx nanocomposite film coating to extend the shelf life of apple fruit. International Journal of Food Science and Technology, 52: 2018-2030.

Luo, X., Zhou, Y., Bai, L., Liu, F., Zhang, R., Zhang, Z., Zheng, B., Deng, Y., and McClements, D. J. (2017). Production of highly concentrated oil-in-water emulsions using dual-channel micro fluidization: Use of individual and mixed natural emulsifiers (saponin and lecithin). Food Research International, 96: 103-112.

Mallakpour, S. and Sadaty, M.A. (2016). Thiamine hydrochloride (vitamin B1) as modifier agent for TiO2 nanoparticles and the optical, mechanical, and thermal properties of poly (vinyl chloride) composite films. RSC Advances, 6: 92596-92604.

Marcuzzo, E., Sensidoni, A., Debeaufort, F., and Voilley, A. (2010). Encapsulation of aroma compounds in biopolymeric emulsion based edible films to control flavour release. Carbohydrate Polymers, 9: 84-88.

Martínez-Hernández, G. B., Amodio, M. L., and Colelli, G. (2017). Carvacrol-loaded chitosan nanoparticles maintain quality of fresh-cut carrots. Innovative Food Science and Emerging Technology, 41: 56-63.

McHugh, T. H., Aujard, J. F., and Krochta, J. M. (1994). Plasticized whey protein edible films: Water vapor permeability properties. Journal of Food Science, 59: 416–419.

McHugh, T. H., and Senesi, E. (2000). Apple wraps: A novel method to improve the quality and extend the shelf life of fresh-cut apples. Journal of Food Sciences, 65: 480-485.

Mora-Huertas, C. E., Fessi, H., and Elaissari, A. (2010). Polymer-based nanocapsules for drug delivery. International Journal of Pharmaceutics, 385: 113-142.

Mustafa, M. A., Ali, A., and Manickam, S. (2013). Application of a Chitosan Based Nanoparticle Formulation as an Edible Coating for Tomatoes (Solanum lycoperiscum L.). Acta Horticulturae, 1012: 445-452.

Natrajan, D., Srinivasan, S., Sundar, K., and Ravindran, A. (2015). Formulation of essential oil-loaded chitosan–alginate nanocapsules. Journal of Food and Drug Analysis, 23: 560-568.

Pilon, L., Spricigo, P. C., Miranda, M., deMoura, M. R., Assis, O. B. G., Mattoso, L. H. C., and Ferreira, M. D. (2015). Chitosan nanoparticle coatings reduce microbial growth on fresh-cut apples while not affecting quality attributes. International Journal of Food Science and Technology, 50: 440-448.

Ramos, O. L., Pereira, R. N., Martins, A., Rodrigues, R., Fuciños, C., Teixeira, J. A., Pastrana, L., Malcata, F. X., and Vicente, A. A. (2017). Design of whey protein nanostructures for incorporation and release of nutraceutical compounds in food. Critical Reviews in Food Science and Nutrition, 57: 1377–1393.

Ranjan, S., Dasgupta, N., Chakraborty, A. R., Melvin Samuel, S., Ramalingam, C., Shanker, R., and Kumar, A. (2014). Nanoscience and nanotechnologies in food industries: Opportunities and research trends. Journal of Nanoparticle Research, 16: 2464-2468.

Sabliov, C., Chen, H., and Yada, R. (2015). Nanotechnology and Functional Foods: Effective Delivery of Bioactive Ingredients; John Wiley and Sons: Hoboken, NJ, USA.

Saha, A., Tyagi, S., Gupta, R. K., and Tyagi, Y. K. (2017). Natural gums of plant origin as edible coatings for food industry applications. Critical Reviews in Biotechnology, 37: 959–973.

Salvia-Trujillo, L., Soliva-Fortuny, R., Rojas-Graü, M. A., McClements, D. J., and Martín-Belloso, O. (2017). Edible Nanoemulsions as Carriers of Active Ingredients: A Review. Annual Reviews in Food Science and Technology, 8: 439-466.

Shah, R. M., Rajasekaran, D., Ludford-Menting, M., Eldridge, D. S., Palombo, E. A., Harding, I. H. (2016). Transport of stearic acid-based solid lipid nanoparticles (SLNs) into human epithelial cells. Colloids and Surfaces Biointerfaces, 140: 204-221.

Shah, R. W., Aisar, M., Jahangir, M., Abbasi, K. S., Khan, S. U., Ali, N., and Liaquat, M. (2016). Influence of CMC- and guar gum-based silver nanoparticle coatings combined with low temperature on major aroma volatile components and the sensory quality of kinnow (Citrus reticulata). International Journal of Food Science and Technology, 512: 345-352.

Silva, H. D., Cerqueira, M.Â., and Vicente, A. A. (2012). Nanoemulsions for Food Applications: Development and Characterization. Food Bioprocess Technology, 5: 854-867.

Singh, S. K., Kumar, D. V., and Verma, P. R. P. (2015). Development and evaluation of biodegradable polymeric nano particles for the effective delivery of quercetin using a quality by design approach. LWT-Food Science and Technology, 61: 330-338.

Sow, L. C., Tirtawinata, F., Yang, H., Shao, Q., and Wang, S. (2017). Nanoemulsion combined with acid electrolysed water to inactivate bacteria, yeast in vitro and native microflora on shredded cabbages. Food Control, 76: 88-95.

Tamjidi, F., Shahedi, M., Varshosaz, J., and Nasirpour, A. (2013). Nanostructured lipid carriers (NLC): A potential delivery system for bioactive food molecules. Innovative Food Science and Emerging Technology, 19: 29-43.

Wang, W., Liu, Y., Jia, H., Liu, Y., Zhang, H., He, Z., and Ni, Y. (2017). Effects of Cellulose Nanofibers Filling and Palmitic Acid Emulsions Coating on the Physical Properties of Fish Gelatin Films. Food Biophysics, 12: 23-32.

Yousuf, B., Qadri, O. S., and Srivastava, A. K. (2018). Recent developments in shelf-life extension of fresh-cut fruits and vegetables by application of different edible coatings: A review. LWT-Food Science and Technology, 89: 198-209.

Zambrano-Zaragoza, M. L., Quintanar-Guerrero, D., DelReal, A., Piñon Segundo, E., and Zambrano-Zaragoza, J. F. (2017). The release kinetics of β-carotene nanocapsules/xanthan gum coating and quality changes in fresh-cut melon (cantaloupe). Carbohydrate Polymers, 157: 1874–1882.

© The Author(s)

This is an Open Access article licensed under a Creative Commons license: Attribution 4.0 International (CC-BY).