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Nano-technology enhanced edible coating application on climacteric and non-climacteric fruits: A review

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Abstract

In a world where the population is increasing and the demand for fruits is rising, minimizing food waste is necessary. The potential of edible covering is strengthened by nanotechnology to enhance the shelf life and quality of climacteric (ripening after harvest) and non-climacteric fruits is examined in this paper. Nucleus-infused coatings for climacteric fruits, like banana and mango, present fruits in a fresh way. As ethylene gas generation is a major ripening trigger, nanoparticles can slow down the ripening process. They also improve the fruit's firmness and minimize weight loss by strengthening the coating water vapor barrier qualities. Particularly efficient nanoparticles are those made of zinc, silver, and chitosan. Fruits that are not climacteric, such as strawberries and grapes, provide distinct difficulties. Here, antimicrobial nanoparticles, like silver, can be incorporated into coatings to fight bacteria that cause spoiling. Furthermore, some nanoparticles controlled release characteristics enable the continuous distribution of advantageous substances, thereby increasing shelf life. The benefits go beyond only keeping things intact. These coatings can be designed to carry natural smells and colors or even to offer vital nutrients. This presents opportunities for prospective uses in fruit fortification or aesthetic enhancement. But there are still difficulties. More investigation on the long-term health impacts of ingested nanoparticles is necessary to ensure their safety. It's also critical to maximize cost-effectiveness and scalability for large-scale production. In order to handle the special implications of nanomaterials in food applications, regulatory frameworks must be modified. In sum up, fruit preservation has never been easier thanks to edible coverings strengthened by nanotechnology. These coatings can help save food waste and prolong the shelf life of fresh, premium fruits by efficiently postponing ripening, decreasing spoiling, and possibly increasing nutrient content. A new era of effective and sustainable fruit preservation could be ushered in by nanotechnology-based solutions as research tackles safety and scalability issues.

Keywords: Nanocoating, edible coating, nanoparticles, nanocoating, nanotechnology, shelf life, coating types

Introduction

A rapidly growing field of study called nanotechnology deals with the development and fabrication of various new materials at the nanoscale. Objects in this range, measuring between 1 and 100 nano-meters, can exhibit properties quite different from their bulk counterparts due to their size. Currently, scientists are utilizing copper, zinc, titanium, magnesium, gold, alginate, and silver to create various metallic structures on the nanoscale. These nanoparticles have found applications in a vast array of fields, including medical therapies, energy storage in batteries like solar and oxide fuel cells, and even widespread incorporation into many everyday products like cosmetics and clothing (Saba Hasan, 2015) [37].

At the moment, nanotechnology is a useful tool and a cost-effective way to increase food shelf life. When particles are diminished to the nanoscale, materials exhibit distinct and improved traits compared to larger counterparts, as indicated by Onyeaka, Helen, *et al.* (2022) [43]. This innovation prolongs the viability of diverse food items like intact and pre-sliced fruits, vegetables, nuts, seeds, and cheese by integrating hydrophilic and lipophilic compounds possessing antimicrobial and antioxidant attributes, which can be discharged over storage durations. Typically, cost-effective, readily accessible, and harmless natural polymers are employed to produce edible coatings. (Díaz-Montes, Elsa, and Roberto Castro-Muñoz, 2021) [23].

For the food industry, nanotechnology is becoming more and more significant. The areas of nutrient delivery systems using bioactive nanoencapsulation, biosensors to detect and quantify pathogens, organic compounds, other chemicals, and food composition alteration, as well as edible film to preserve fruit or vegetables, are already showing promising results and applications (Nile, Shivraj Hariram, *et al.*, 2020) [70]. This article examines the use of nanotechnology and its advantages in several facets of the food industry, including bioactive nanoencapsulation, edible thin film, packaging, and nanosensors. From the review, it is possible to draw the conclusion that improvements in nanotechnology improve food quality and safety while also reducing pathogen detection times (Biswas, Rahul, *et al.*, 2022) [8].

Due to their vitamins, minerals, antioxidants, and fibre, fruits and vegetables are high on customer shopping lists and play a significant role in a healthy diet (Nishikito, Daniela Franceschi, *et al.*, 2023) [71]. The main issue with preserving fruits and vegetables, however, is their short shelf life due to their high moisture content (75-95%), which causes quick deterioration and decomposition of these items as well as an unattractive look (Poonam, Raj Kumar Jakhar, *et al.*, 2022) [77]. Vegetables and fruits are living things that go through the processes of ripening and aging, during which the plant tissues begin to disintegrate. Even after the goods have been gathered, many biological processes continue to take place. The rates of ethylene generation and respiration differ significantly between fruits and vegetables (Brady, C. J. *et al.*, 1987) [12].

Fruits and Vegetables are typically divided into two categories: climacteric and non-climacteric. The former group of fruits cannot ripen once they are removed from the plant, whereas climacteric fruits can. They also produce much increased amounts of ethylene than non-climacteric fruits, which makes them more vulnerable to bacterial, fungal, and mold-related spoilage (Barry, Cornelius S., and James J. Giovannoni, 2007) [6]. Fresh fruits and vegetables must therefore be packaged and coated appropriately because, in most cases, under normal circumstances, fruits dry quickly and lose their firmness Vegetables and fruits should be packaged with low water vapor permeability (WVP) to reduce desiccation rates (Matche, R. S., 2005) [61].

Additionally, oxygen permeability (OP) should be reduced to slow down respiration but not too low to create an anaerobic environment that is conducive to the formation of off flavors and the production of ethanol, high physical and mechanical properties that must exhibit adequate resistance and durability during distribution and transport, and high antimicrobial properties that must show sufficient resistance and durability to prevent the growth of microorganisms (Jafarzadeh, Shima, *et al.*, 2021) [41].

The use of suitable packaging and preservation techniques could be used to increase the shelf life of fruits and vegetables. Since they have superior mechanical, barrier, thermal, and antibacterial capabilities, nanocomposite antimicrobial packaging technologies are strong options. After giving a brief overview of post-harvest difficulties, this paper discusses the main types of edible coatings and nanocomposite films used on fruits and vegetables, along with the benefits and drawbacks that have been recently researched (Ashfaq, Alweera, *et al.*, 2022) [2].

Synthesis of Nano Particles

Microorganisms may biosynthesize nanoparticles, which is a green and environmentally beneficial technique. Metal oxides like titanium oxide and zinc oxide, as well as a variety of prokaryotes and eukaryotes, are employed in the production of metallic nanoparticles like silver, gold, platinum, zirconium, palladium, iron, and cadmium. These microorganisms include bacteria, fungus, algae, and actinomycetes. Depending on where the nanoparticles are produced, the process may be intracellular or extracellular. (Hulkoti and Taranath, *et al.* 2014) [39].

Intracellular synthesis of nanoparticles by fungi: In this process, ions are transported into microbial cells where they combine with enzymes to produce nanoparticles. The size of intracellularly generated nanoparticles is less than that of extracellularly reduced nanoparticles. The size restriction is likely connected to the particles that form clusters inside the organisms. (Narayanan and Sakthivel, *et al.* 2010 and Singh, Namita Ashish, *et al.*, 2023) [68, 89].

Extracellular synthesis of nanoparticles by fungi: Extracellular synthesis of nanoparticles has more applications as compared to intracellular synthesis since it is void of unnecessary adjoining cellular components from the cell. Mostly, fungi are known to produce nanoparticles extracellularly because of their enormous secretory components, which are involved in the reduction and capping of nanoparticles (Narayanan and Sakthivel, *et al.* 2010 and Guilger-Casagrande, Mariana, and Renata de Lima., 2017) [68, 35].

Microbes for production of nanoparticles: Organisms with one cell or several cells create inorganic materials either intracellularly or extracellularly (Li, Xiangqian, *et al.*, 2011) [31]. In the hunt for novel materials, the capacity of microbes like bacteria and fungus to regulate the creation of metallic nanoparticles is used. Fungi have dominated research on the biological production of metallic nanoparticles due to their tolerance and capacity for metal bioaccumulation (Sastry, Ahmad, *et al.* 2003 and Boroumand Moghaddam, Amin, *et al.*, 2015) [83, 10].

Microbes for production of nanoparticles

Particle	Microorganism (Fungi)	Synthesis	Size
Ag	*Phoma sp.*	Extracellular	71.06–74.46
Au	*Fusarium oxysporum*	Extracellular	20–40
Ag	*Verticillium sp.*	Intracellular	25 ± 12
Ag	*Aspergillus fumigates*	Extracellular	5–25
Ag	*Trichoderma asperellum*	Extracellular	13–18
Ag	*Phaenerochaete chrysosporium*	Extracellular	50–200

Types of Nano-coatings

Numerous varieties of nano-coatings have been created to improve fruit quality and prolong their shelf life. Chitosan-based nano-coatings, which are made from the natural biopolymer chitin, are one example of such innovation., these coatings help preserve fruit quality by providing protection against microbial development. An alternative method uses antibacterial silver nanoparticle coatings to stop bacterial and fungal growth on the fruit's surface (Durán, N., *et al*., 2019) [25].

Fruit spoiling can be efficiently prevented and their shelf life extended by using nano-coatings composed of montmorillonite nanoclays, which function as a barrier to both moisture and oxygen (Rhim, J. W., *et al*., 2019) [78]. Coatings containing zeolite nanoparticles have the ability to absorb ethylene gas, which promotes fruit ripening and extends shelf life (Sankar, R., *et al*., 2013) [26]. Furthermore, fruit color and nutritional value are preserved by slowing down oxidative processes by the application of antioxidant-rich nanoparticles in nano-coatings (Gao, Y., *et al*., 2021) [27]. Another advantage of some nano-coatings is their ability to inhibit ethylene, the hormone that causes fruit to mature. Fruits' shelf life is significantly increased by this restriction. When it comes to aesthetics, fruits coated with nano-coatings might appear glossy, increasing their consumer appeal - a crucial aspect of marketing and sales.

The use of environmentally friendly nano-coatings, which do away with the need for conventional chemical preservatives and packaging materials, has further advantages for the environment. Furthermore, research on the perception and acceptance of fruits coated with nanoparticles by consumers is essential. Studies look at sensory aspects, safety issues, and labeling to reassure consumers.

Nano emulsion based coatings

A number of researchers have made symbolic progress in finding environmentally friendly active compounds with minimal health risks to address sustainability and health concerns in the food industry. This endeavor responds to the increasing consumer demand for food products devoid of harmful pesticide residues and supportive of environmental well-being. Natural pesticides can be made safer and more sustainable by using plant-based extracts as preservatives and pesticides (Teshome, Ejigayehu, *et al*., 2022) [92]. Notably, these extracts play a vital role in preventing postharvest diseases and maintaining food quality, signifying a crucial shift towards eco-friendly and health-conscious food preservation methods. Various fruits, vegetables, seeds, leaves, herbs, and spices contain active compounds with antimicrobial and antioxidant properties, showcasing the potential of natural phytochemicals in food preservation. Examples include guava, garlic, pepper, onion, cabbage, olive leaves, nutmeg, parsley, caraway, fennel, grape seeds, lemongrass, basil, oregano, ginger, rosemary, thyme, and cinnamon (Tajkarimi, M. M., Salam A. Ibrahim, and D. O. Cliver., 2010) [91]. As mentioned earlier, nanoemulsion active compounds have become indispensable elements in modern food industry practices. Within this category, essential oils (EOs) extracted from plant sources have attracted considerable attention due to their versatile applications and potential health advantages. Renowned for their aromatic and therapeutic properties, EOs represent a valuable class of natural extracts with diverse functionalities. They are natural phytochemicals widely utilized as a rich source of bioactive components possessing antioxidant and antibacterial properties, making them of interest to the food industry as they are generally recognized as safe (GRAS) for both the environment and human health (Pandey, Vinay Kumar, *et al*., 2022) [74]. Consequently, there is a growing inclination towards employing these oils for sustainable agriculture, supported by extensive research demonstrating their potential as medicinal agents and food preservatives, where many active ingredients are EOs. Investigations into the efficacy of EOs and their constituents against microbial pathogens affecting horticultural products have yielded a wealth of insights that can inform the development of practical strategies for ensuring food safety. Furthermore, these essential oils vary in their biological activity, physical and chemical attributes, and aroma profiles. Hence, careful selection of the most suitable option or combination is essential for each specific application (Bolouri, Parisa, *et al*., 2022) [9].

Nanocoating Production Methods

Nanoemulsion coatings have become increasingly popular across a range of industries because of their capacity to distribute and encapsulate active substances, improve product functioning, and increase stability (Mushtaq, Abeeda, *et al*., 2023) [67]. There are multiple techniques used in the creation of nanoemulsion coatings, each having specific benefits and uses. These techniques are essential for maximizing nanoemulsions' potential for a range of industrial applications. Low-intensity and high-intensity approaches are the two categories into which nanoemulsion production techniques are divided (Sambhakar, Sharda, *et al*., 2023) [81]. The phase- inversion temperature, conflation- inversion point system, robotic and membrane emulsification, and other low-intensity styles are grounded on the robotic conformation of small driblets in surfactant- oil- water fusions when changes in the system composition or environmental conditions occur (Kruglyakov, P., and A. Nushtayeva., 2004) [50]. Conversely, industrial applications have begun to employ high-intensity approaches. Intense turbulence, shear, and cavitation flow profiles are produced by these techniques, which use mechanical devices such valve homogenization, micro fluidization, and sonication to split and combine the oil and water phases (Chandrapala, Jayani, *et al*., 2012). While the majority of fabrication techniques are high-energy ones, the use of specific techniques varies depending on the components and the necessary properties of the nanoemulsions. However, a strong formulation is necessary to guarantee the long-term stability of nanoemulsions because they may undergo destabilizing events. Stability is defined as the capacity to tolerate physical change. Emulsions are destabilized by two processes: coalescence and Ostwald ripening. Intense turbulence, shear, and cavitation flow profiles are produced by these techniques, which use mechanical devices such valve homogenization, micro fluidization, and sonication to split and combine the oil and water phases (Kruglyakov, P., and A. Nushtayeva., 2004) [50]. The first step in creating nanoemulsion films and coatings is dissolving polymers in a suitable solvent. Subsequently, active chemicals (as part of nanoemulsions or unattended), plasticizers, and additives are added to the solution of the selected polymer or combination of polymers to create the final formulation of the coating. The dry-process and wet-process procedures are the two process approaches used to create nanoemulsion coatings. The first technique, which involves molding or extrusion, is based on the thermoplastic properties of polymers. The films produced by this environmentally friendly technology cannot cover uneven surfaces because it does not use solvents. Conversely, the casting process is the most often employed technique in laboratory settings. To achieve solvent evaporation in this wet-process method, a coating solution is applied to the surface and allowed to air dry for a predetermined period of time. When the solution is spread out on a flat surface and then peeled off, edible films are produced. Nevertheless, if the solution is directly applied to food goods using the most popular application techniques, coatings are created on the product surface (dipping or spraying)

Problems faced by Climacteric-Fruits

In fruits like bananas, mangoes, guavas, apricots, pear, papayas, apples, avocados, tomatoes, and plantains are distributed as Climacteric fruits due to the respiration sequence and ethylene production (Atkinson *et al*., 2011) [3]. Climacteric fruits are generally picked- up at physiological maturity, holding their firmness until the starting of development without perceptible changes to peel color, texture, or composition (Mendoza & Aguilera, 2006) [64]. After harvesting, these fruits witness a series of progressive downfalls that include reduced postharvest survival, elevated respiratory rates, the development of autocatalytic ethylene, heightened vulnerability to pathogenic infections, and changes in texture, color, and taste, including softening (Palapol *et al*., 2009; Paul *et al*., 2012) [75].

Because postharvest fruits are perishable, the agrarian sector must manage them precisely to insure their marketability, especially in transnational trade (Singh *et al*., 2014) [88]. A significant quantum of fruits are lost before they're consumed encyclopedically, with precious types counting for nearly half of these losses. The fruit deterioration, physical damage, and physiological problems caused by unintentional climacteric growing account for about 34.6 of these losses, according to the U.S.D.A. Economic Research Service (Barth *et al*., 2009; Kader, 2004) [7, 45]. Fruits come perishable due to inimical physicochemical changes, similar as weight loss brought on by respiration, softening of the meat, microbial attack-convinced quality declination, and changes in acidity and sugar content.

Impurity by fungi is a serious threat to the world's fruit force chain. presently, phytopathogens similar fungus cause post-harvest losses of roughly half of the agrarian fruit product (Zhang *et al*., 2017) [98]. Fungal pathogen irruption and natural physiological aging are the main causes of postharvest losses.During the conveyance and storehouse of climactic fruits, anthracnose, a common fungal illness caused by *Colletotrichum spp*., presents a huge fiscal threat as well as significant postharvest damage (Bautista- Baos *et al*., 2013; Pavitra Kumari & Singh, 2017) [76]. Sunken black lesions that appear on the fruit face during growing are reflective of postharvest anthracnose (Tian *et al*., 2016). Colletotrichum gloeosporioides is the cause of mango anthracnose, which poses a serious threat to growers around the world and causes significant pre- and post-harvest losses in mangoes (Lima *et al*., 2013; Pavitra Kumari & Singh, 2017) [76]. Anthracnose, substantially caused by *Colletotrichum fructicola* and *Colletotrichum gloeosporioides* Penz, constantly compromises postharvest storehouse and import of papaya, performing in declination (Madani *et al*., 2014; Vilaplana *et al*., 2020) [57, 95]. The most dangerous postharvest illness that affects bananas, anthracnose, is brought on by the fungus *Colletotrichum musae*.

It reduces the fruit's nutritive value and quality, making it unfit for trade or consumption. This results in large losses for farmers and distributors (Khaliq *et al*., 2019) [47].

Problems faced by Climacteric-Fruits

Climacteric fruit	Non-climacteric fruit
Apple	Blackberry
Apricot	Cherry
Avocado	Cucumber
Banana	Eggplant
Blueberry	Grape
Cantaloupe	Grapefruit
Fig	Lemon
Honeydew melon	Lime
Kiwifruit	Orange
Mango	Pepper (all)
Nectarine	Pineapple
Papaya	Pomegranate
Peach	Pumpkin
Persimmon	Raspberry
Plantain	Squash
Plum	Strawberry
Quince	Watermelon
Tomato	Zucchini

Formulations of Edible-Coatings

Dhall (2013) [21] mentioned films made from comestible coatings generally contain polymers like lipids, hydrocolloids (which are made up of polysaccharides and protein), or compound coatings, which are a combination of the two. In addition, plasticizers are frequently included. To produce a thin subcaste of protection over the food product, comestible coatings can be applied in a variety of ways, similar as scattering, extrusion, solvent casting, brushing, or dipping (Thakur *et al*., 2019; Yousuf *et al*., 2018) [93, 96]. Nor and Ding (2020) [62] thorough analysis covers every possible coating that could be used on tropical fruits. The review also points out the fundamentals of coating attributes, accoutrements, and processes, which cover effects like sheeting protection, colorful operation ways, and the effectiveness of colorful coating accoutrements like polysaccharide, protein, lipid, and compound- grounded coatings. A brief overview of comestible films and coatings, as well as current advancements in the assiduity, was written by Dhaka and Upadhyay (2018) [20]. This exploration included a discussion of current trends and advancements in addition to a thorough examination of the numerous features of comestible films and coatings. Also, polymeric accoutrements generated from both factory and best sources can be used in the expression of comestible coatings. Due to disinclinations to best foods and the moldable nature of coatings, the use of best excerpts in the product of comestible coatings has been confined in comparison to factory excerpts with medicinal benefits (Flores- López *et al*., 2016) [29].

Comestible coatings made from factory excerpts can stop fruit from growing, enhance aesthetics by shining the yield, and hide small scars (Murmu & Mishra, 2018) [66]. They're also a cheap way to keep the newness of fresh fruit complete. It has been suggested that using comestible coatings made from factory excerpts might reduce the need of non-biodegradable storehouse polyethylene plastic films and holders, hence lowering environmental pollution (Bourtoom, 2008) [11]. Fruits' nutritive value can also be increased by adding factory excerpts with significant antioxidant goods. It has been delved how different climactic fruits similar bananas, apples, mangoes, and papaya are affected by factory comestible coatings in terms of their nutritive value. Ncama *et al*.'s (2018) [69] review handed a thorough account of the operation of comestible coatings made from factory excerpts for both climacteric and non-climacteric fruits. Moringa splint excerpt sludge bounce and rice bounce Thakur *et al*., 2019) [93], aloe vera (Khaliq *et al*., 2019) [47], and goo Arabic (Maqbool *et al*., 2011) [60] are a many of the shops whose excerpts are employed as comestible coverings for climacteric fruits.

A natural comestible coating excerpt has been shown to improve fruit quality and protect it, as it is both environmentally and consumer-friendly (Janisiewicz & Korsten, 2002) [43].

Effect of Nano-coatings on quality attributes

Enhancing durability, enhancing performance, and extending shelf life are just a few of the qualitative features of many items that nano-coatings have shown to have a significant influence on. For instance, Li *et al*.'s (2020) [53] study looked into how nano-coatings were used in the food business, especially on fruits. The study discovered that edible polymers and nanoparticle-based nano-coatings greatly increased the shelf life of fruits by forming a barrier against moisture loss and microbial contamination, which decreased spoiling and enhanced fruit quality. Additionally, it was discovered that these coatings preserved the fruit's natural flavor, texture, and appearance, improving the consumer's sensory experience. These results highlight the potential for nano-coatings to transform a variety of sectors by protecting and improving product quality while reducing waste and extending their usability.

Edible chitosan-based nano-coatings have been shown in a study by Barik *et al*. (2024) [5] published in the journal "Food Packaging and Shelf Life" to effectively reduce water loss and maintain the firmness and color of strawberries during cold storage, highlighting their beneficial effects on the quality attributes of perishable goods. The potential of nano-coatings to maintain and improve the quality of diverse products is being highlighted by similar research in other industries, making them a topic of significant interest and innovation.

Shah and Hashmi (2020) [84] looked at how chitosan and aloe vera gel affect the shelf life of mango fruits. In comparison to utilizing chitosan alone or control samples, they discovered that adding chitosan to aloe vera significantly reduced weight loss, respiration rate, and ethylene production. Additionally, fruit quality criteria including titratable acidity, total soluble solids, fruit firmness, ascorbic acid, and peel color were all protected by the combo treatment. This study demonstrates how chitosan and aloe vera applied together enhance the phenolic content of mango fruit while maintaining high levels of ascorbic acid, total phenolic content, and antioxidant activity throughout storage. According to this, adding aloe vera might strengthen the chitosan coating's barrier, boosting its antibacterial characteristics and reducing its permeability to water and gaseous substances.

Nanoparticles used as Edible Coatings

Chitosan: Chitosan's potential to improve fruit quality and shelf life has drawn attention to it, a natural biopolymer generated from chitin. Chitosan's antibacterial, barrier, and film-forming qualities are responsible for its beneficial effects on fruits. Chitosan forms a protective barrier when put as a coating on fruit surfaces. This barrier minimizes water loss and gas exchange, which delays ripening and increases shelf life. Chitosan also demonstrates antibacterial capabilities that limit the development of diseases and microorganisms that cause rotting, assisting in maintaining the freshness and safety of fruit (Riseh, Roohallah Saberi, *et al*., 2023) [80].

The effects of chitosan coating on strawberry postharvest quality were examined in a research by Han *et al*. (2017) [12]. In comparison to untreated strawberries, the researchers discovered that strawberries coated with chitosan had less weight loss, delayed fruit softening, and increased shelf life. The use of chitosan caused the treated fruits to have greater antioxidant and vitamin C levels as well as lowered decay and respiration rates. These results show the potential of chitosan as a natural and efficient technique for extending fruit quality and shelf life, which may have important ramifications for the fruit business and customers looking for healthier, longer-lasting products.

Chitosan coatings can successfully increase the shelf life of strawberries by preserving their firmness, color, and general quality throughout storage, according to research by Rhim *et al*. (2016) [79]. Chitosan coatings are a potential option for lowering post-harvest losses and boosting the quality and shelf life of fruits because they are also thought to be safe for eating and ecologically benign.

Zinc Oxide: Due to its antibacterial and UV-blocking qualities, zinc oxide (ZnO) nanoparticles have been investigated for their possible use in fruit preservation and quality enhancement. When applied to fruits as coatings or treatments, these nanoparticles can help increase fruit quality and shelf life (Sirelkhatim, Amna, *et al*., 2015) [90].

ZnO nanoparticles were employed as a covering for postharvest kiwifruits in a study by Xie *et al*. (2015) [97]. The study showed that the ZnO nanoparticle coating efficiently prevented harmful bacteria and fungus from growing on the surface of the fruit, hence lowering microbial contamination. In addition, compared to untreated fruits, the ZnO-coated kiwifruits showed a significant delay in ripening, improving firmness and extending shelf life. The study also found that the ZnO nanoparticles had no detrimental effects on the fruits' sensory quality.

By minimizing microbial deterioration and postponing ripening processes, our results imply that ZnO nanoparticles have the potential to be employed as a natural and secure way to improve the postharvest quality of fruits (Hmmam *et al*., 2023) [38]. Additionally, ZnO nanoparticles' UV-blocking abilities can shield fruits from damaging UV rays, helping to maintain their color, taste, and nutritional value. To guarantee the security and legal compliance of ZnO nanoparticle coatings for food applications, more research is necessary.

The effect of ZnO nanoparticle coatings on the pgost-harvest quality of kiwifruits was studied by Ghaani *et al*. 2019 [103]. The findings showed that ZnO nanoparticle coatings contributed to fruit firmness preservation and w eight loss reduction during storage. In addition, kiwifruits with ZnO coating had longer shelf lives and showed less degradation than untreated fruit. ZnO nanoparticles' antibacterial and barrier characteristics are responsible for this protective impact against microbial infections and physical harm.

Silver Nanoparticles: Because of their antibacterial qualities and possible uses in the food sector, such as fruit preservation, silver nanoparticles (AgNPs) have drawn interest. By preventing the growth of pathogens and microorganisms that cause spoiling, AgNPs have showed promise in increasing the shelf life of fruits, which can help decrease food waste and enhance fruit quality (Bruna, Tamara, *et al*., 2021) [15].

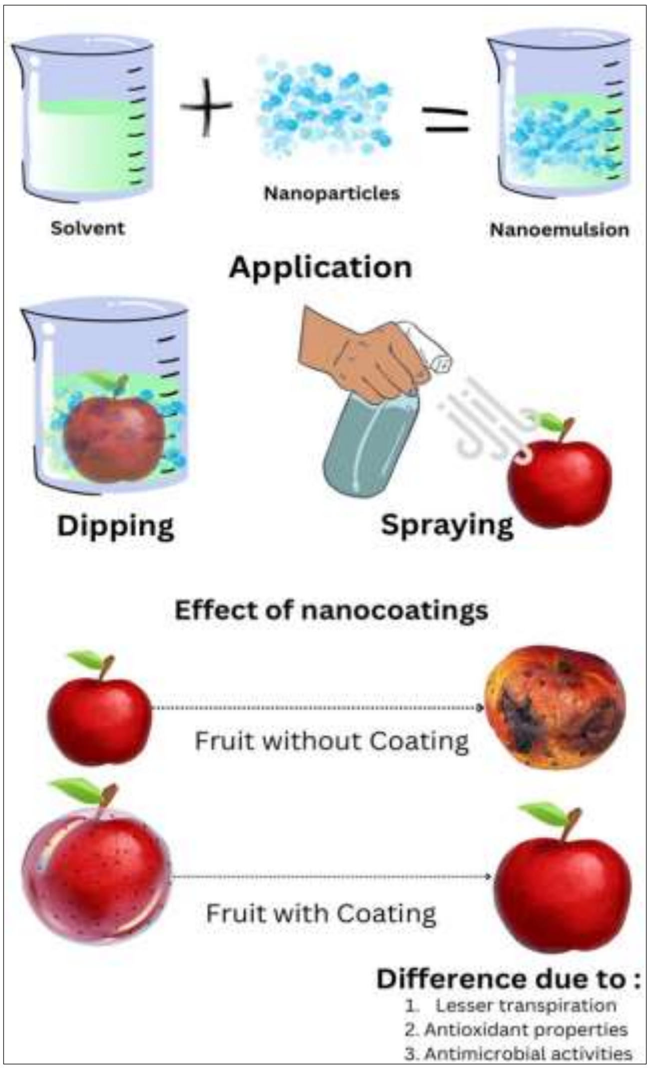
The impact of silver nanoparticles on the post-harvest quality of fresh-cut apples was examined in a study by Zhou *et al*. (2012) [104]. The study showed that AgNPs efficiently inhibited the growth of bacteria and fungus on apple slices when used as a coating, delaying spoiling and preserving the fruit's texture and appearance. AgNPs' capacity to release silver ions, which have strong antibacterial capabilities, is thought to be the cause of this antimicrobial action.

The ability of silver nanoparticles to preserve strawberries was examined in a study by Sharma *et al*. (2019) [105]. According to the study, AgNP coatings dramatically slowed the development of microorganisms that might cause fruit to decay during storage, such as molds and yeast. In comparison to untreated samples, this antimicrobial activity resulted in a slower ripening process, less degradation, and a longer shelf life for strawberries.

Nanoparticles used as Edible Coatings

Fruit	Nanoparticle	Other Compound	Benefit	References
Strawberry	Chitosan	Oleic Acid	Less respiration, transpiration and microbial activity due to combined application	Vargas *et al*. 2006 [94]
Strawberry	Methyl Cellulose	Curcumin and limonene	Lesser fungal growth, higher titrable acidity and total phenolic content	Dhital *et al*. 2017 [22]
Papaya	Chitosan and Pectin	microencapsulated beta-cyclodextrin and *trans*-cinnamaldehyde complex	Coated fruits were firmer, maintained color, β-carotene content, and showed lower juice leakage	Brasil *et al*. 2012 [13-14]
Papaya	Chitosan		1.5% more respiration was observed in uncoated samples	Ali *et al*. 2011 [1]
Peach	Methyl Cellulose	Alginate	Decreased transpiration and respiration rate observed	Maftoonazad *et al*. 2008 [59]
Orange	Chitosan	Locust bean gum & Pomegranate peel extract	Addition of 0.361 g dry WPPE/mL, both to CH and LBG coatings, significantly reduced disease incidence (DI) by 49 and 28%	Kharchoufi *et al*. 2018 [48]
Mango	Chitosan	Starch, cellulose, glycerol and tween-80	Chitosan performed superior to the other coatings	Kittur *et al*. 2001 [49]
Mango	Chitosan		Improved shelf life of sliced mango	Chien *et al*. 2007 [16]
Guava	Chitosan	Cassava starch & Lippa gracilis Schauer	Shelf life increased by 10 days	Aquino *et al*. 2015 [19]
Guava	Methyl cellulose	Cashew gum & glycerol	Edible coatings protected firmness, decreased of mass loss & delayed surface color change	Britto *et al*. 2012 [30]
Apricot	Chitosan		Increased storage quality	Ghasemnezhad *et al*. 2010 [34]
Apricot	Methyl Cellulose		Improved quality and decreased water loss and vitamin c content during storage	Ayranci and Tunc 2004 [99]
Apricot	Methyl cellulose	Stearic Acid	Decreased water loss	Ayranci and Tunc 2004 [99]
Apple	Chitosan	Acetic acid	In nine weeks of storage, the coating reduced weight loss by up to 2.5 times, improved color consistency, slowed softening of the fruit, and slow down the softening process of the fruit itself.	Gardesh *et al*. 2016 [33]
Apple	Silver/Zinc oxide	Gelatin/Chitosan	The qualitypf fruit was preserved, and the shelf life was extended by 42 days.	Bakhy *et al*. 2018 [100]
Banana	Zinc oxide	Soybean protein isolate & cinnamaldehyde	During the 7-day storage period, it delays banana ripening, maintains nutrient content and minimizes water loss, ensuring an extended shelf life.	Li *et al*. 2019 [54]
Banana	Chitosan		Coatings extended banana shelf life and maintained sensory quality	Lustriane *et al*. 2018 [56]
Banana	Chitosan	Acetic acid	The ripening was postponed by showing a slower rate of skin browning as compared to control during 6 days of storage	Esyanti *et al*. 2019 [26]
Banana	Zinc	Chitosan/gum-Arabica	The bananas remained consistent and had a prolonged shelf life of over 17 days in storage.	La *et al*. 2021 [51]
Banana	Silver	Neem & Ajwain	Controlled Anthracnose in banana	Jagana *et al*. 2017 [42]
Mango	Calcium	Ascorbic acid	It diminishes internal browning and retains the phenolic compound of mangoes while in cold store	Lo'ay *et al*. 2019 [55]
Mango	Zinc	Carrageenan	Decreased microbial activity and retained the shelf life of whole mango fruit	Meindrawan *et al*. 2018 [40]
Mango	Silver	Chitosan and Tween-80	The combination lessened postharvest decay by inhibiting anthracnose incidence in 7 days storage of mango	Chowdappa *et al*. 2014 [17]
Mango	Zinc	Aloe vera gel & glycerol	It improves quality parameters during storage (9 days)	Dubey *et al*. 2019 [24]

Mango	Zinc	Cassava starch & stearic acid	Fresh-cut mangoes were less likely to lose weight, microbial growth was delayed, and shelf life was improved when stored at 8 °C for 12 days.	Iuliani *et al*. 2018 [40]
Fig	Zinc	Chitosan & acetic acid	Fruits are coated to delay ripening and maintain quality during storage.	Lakshmi *et al*. 2018 [52]
Guava	Chitosan	Xanthan gum & tween	When stored cold and stored for a long time, it enhances the overall quality	Gad & Zag Zog, 2017 [31]
Papaya	Silver	hydroxypropyl methylcellulose	During storage, silver nanoparticles prolonged shelf life by 14 days, preserved postharvest quality, and acted against Colletotrichum gloeosporioides.	Vieira *et al*. 2020 [101]
Apricot	Silver	Glycerol	A 24 hour period at 6 °C significantly reduced weight loss and decay percentage, and the quality was maintained	Shahat *et al*. 2020 [84]



Graphical Representation of Process of Edible Coating Application on Fruits

Conclusion

The production of food must constantly rise to meet the demands of the world's expanding population, especially for fruits and vegetables. Nevertheless, spoiling during postharvest processing and storage puts these fragile goods at risk of suffering large losses. Traditional preservation techniques frequently use harsh chemicals or a lot of energy. Using nanotechnology to create innovative edible coatings infused with nanoparticles is a possible option.

The potential of edible coatings strengthened by nanotechnology to prolong the shelf life and maintain the quality of both climacteric and non-climacteric fruits has been investigated in this research. Climate-related fruits, such as bananas and mangoes, deteriorate more quickly because they continue to ripen after harvest. Here, ethylene gas production is a major ripening trigger, and nanoparticles serve a critical function in reducing its production. Furthermore, by improving the coating's water vapor barrier, nanoparticles prevent weight loss and preserve the firmness of the fruit. Nanoparticles of zinc, silver, and chitosan have demonstrated exceptional efficacy in these domains.

Fruits that are not climacteric, like strawberries and grapes, ripen more slowly but are nonetheless vulnerable to microbial development and moisture loss. These particular problems can be addressed by creating coatings for these fruits that are based on nanotechnology. Adding antimicrobial nanoparticles, such as silver, provides a strong barrier against germs that cause spoiling. Furthermore, some nanoparticles' controlled release characteristics enable the continuous distribution of advantageous substances, thereby increasing shelf life.

Edible coatings enhanced by nanotechnology offer advantages beyond freshness preservation. These coatings can be designed to carry natural smells and colors or even to offer vital nutrients. This creates opportunities for possible uses such as adding vitamins to fruits or improving their aesthetic appeal to consumers.

But there are difficulties in this fascinating sector. Further investigation on the possible long-term health impacts of ingested nanoparticles is necessary to ensure their safety. Additionally, for larger acceptance in the food business, it is imperative to maximize the scalability and economic viability of large-scale nanoparticle production. In order to address the particular issues pertaining to the usage of nanomaterials in food applications, regulatory frameworks must also change.

In conclusion, edible coatings enhanced by nanotechnology have great potential to transform fruit preservation practices. These coatings can help save food waste and prolong the shelf life of fresh, premium fruits by efficiently postponing ripening, decreasing spoiling, and possibly increasing nutrient content. Fruit preservation is about to enter a new era of sustainability and efficiency thanks to nanotechnology-based technologies, provided research addresses safety and scalability issues.

References

1. Ali A, Muhammad MTM, Sijam K, Siddiqui Y. Effect of chitosan coatings on the physicochemical characteristics of *Eksotika II* papaya (*Carica papaya* L.) fruit during cold storage. Food Chemistry. 2011 Aug 1;124(2):620-626. https://doi.org/10.1016/j.foodchem.2010.06.085
2. Ashfaq A, Khursheed N, Fatima S, Anjum Z, Younis K. Application of nanotechnology in food packaging: Pros and Cons. Journal of Agricultural and Food Research.

2022;7:100270. https://doi.org/10.1016/j.jafr.2022.100270

3. Atkinson RG, Gunaseelan K, Wang MY, Luo L, Wang T, Norling CL, *et al*. Dissecting the role of climacteric ethylene in kiwifruit (*Actinidia chinensis*) ripening using a 1-aminocyclopropane-1-carboxylic acid oxidase knockdown line. Journal of Experimental Botany. 2011 Jul 1;62(11):3821-3835. https://doi.org/10.1093/jxb/err063
4. Baños SB, Necha LLB, Luna LB, Torres KB. Antifungal activity of leaf and stem extracts from various plant species on the incidence of *Colletotrichum gloeosporioides* of papaya and mango fruit after storage. Revista Mexicana de Fitopatología. 2002;20(1):8-12.
5. Barik M, BhagyaRaj GVS, Dash KK, Shams R. A thorough evaluation of chitosan-based packaging film and coating for food product shelf-life extension. Journal of Agriculture and Food Research. 2024, 101164. https://doi.org/10.1016/j.jafr.2024.101164
6. Barry CS, Giovannoni JJ. Ethylene and fruit ripening. Journal of Plant Growth Regulation. 2007;26:143-159. https://doi.org/10.1007/s00344-007-9002-y
7. Barth M, Hankinson TR, Zhuang H, Breidt F. Microbiological spoilage of fruits and vegetables. Compendium of the Microbiological Spoilage of Foods and Beverages; c2009. p. 135-183.
8. Biswas R, Alam M, Sarkar A, Haque MI, Hasan MM, Hoque M. Application of nanotechnology in food: processing, preservation, packaging and safety assessment. Heliyon. 2022 Nov;8(11). https://doi.org/10.1016/j.heliyon.2022.e11795
9. Bolouri P, Salami R, Kouhi S, Kordi M, Asgari Lajayer B, Hadian J, *et al*. Applications of essential oils and plant extracts in different industries. Molecules. 2022 Dec;27(24):8999. https://doi.org/10.3390/molecules27248999
10. Moghaddam BA, Namvar F, Moniri M, Md. Tahir P, Azizi S, Mohamad R. Nanoparticles biosynthesized by fungi and yeast: a review of their preparation, properties, and medical applications. Molecules. 2015 Sep;20(9):16540-65. https://doi.org/10.3390/molecules200916540
11. Bourtoom T. Edible films and coatings: characteristics and properties. International Food Research Journal. 2008;15(3):237-248. DOI: 10.5937/FFR1501011S
12. Brady CJ. Fruit ripening. Annual Review of Plant Physiology. 1987;38(1):155-178. https://doi.org/10.1146/annurev.pp.38.060187.001103
13. Brasil IM, Gomes C, Puerta-Gomez A, Castell-Perez ME, Moreira RG. Polysaccharide-based multilayered antimicrobial edible coating enhances quality of fresh-cut papaya. LWT-Food Science and Technology. 2012;47(1):39-45. https://doi.org/10.1016/j.lwt.2012.01.005
14. Brasil IM, Gomes C, Puerta-Gomez A, Castell-Perez ME, Moreira RG. Polysaccharide-based multilayered antimicrobial edible coating enhances quality of fresh-cut papaya. LWT - Food Science and Technology. 2012;47(1):39–45. doi: 10.1016/j.lwt.2012.01.005.
15. Bruna T, Maldonado-Bravo F, Jara P, Caro N. Silver nanoparticles and their antibacterial applications. International Journal of Molecular Sciences. 2021;22(13):7202. https://doi.org/10.3390/ijms22137202
16. Chien PJ, Sheu F, Yang FH. Effects of edible chitosan coating on quality and shelf life of sliced mango fruit. Journal of Food Engineering. 2007;78(1):225-229. https://doi.org/10.1016/j.jfoodeng.2005.09.022
17. Chowdappa P, Gowda S, Chethana CS, Madhura S. Antifungal activity of chitosan-silver nanoparticle composite against *Colletotrichum gloeosporioides* associated with mango anthracnose. African Journal of Microbiology Research. 2014;8(17):1803-1812. https://doi.org/10.5897/AJMR2013.6584
18. Coma V, *et al*. Bioactive packaging technologies for extended shelf life of meat-based products. Trends in Food Science & Technology. 2012;24(2):86-93. https://doi.org/10.1016/j.meatsci.2007.07.035
19. de Aquino AB, Blank AF, de Aquino Santana LCL. Impact of edible chitosan–cassava starch coatings enriched with *Lippia gracilis* Schauer genotype mixtures on the shelf life of guavas (*Psidium guajava* L.) during storage at room temperature. Food Chemistry. 2015;171:108-116. https://doi.org/10.1016/j.foodchem.2014.08.077
20. Dhaka R, Upadhyay A. Edible films and coatings: a brief overview. The Pharma Innovation Journal. 2018;7(7):331-333.
21. Dhall RK. Advances in edible coatings for fresh fruits and vegetables: a review. Critical Reviews in Food Science and Nutrition. 2013;53(5):435-450. https://doi.org/10.1080/10408398.2010.541568
22. Dhital R, Mora NB, Watson DG, Kohli P, Choudhary R. Efficacy of limonene nano coatings on post-harvest shelf life of strawberries. Lwt. 2018;97:124-134. https://doi.org/10.1016/j.lwt.2018.06.038
23. Díaz-Montes E, Castro-Muñoz R. Edible films and coatings as food-quality preservers: An overview. Foods. 2021;10(2):249. https://doi.org/10.3390/foods10020249
24. Dubey PK, Shukla RN, Srivastava G, Mishra AA, Pandey A. Study on quality parameters and storage stability of mango coated with developed nanocomposite edible film. International Journal of Current Microbiology and Applied Sciences. 2019;8(4):2899-2935. https://doi.org/10.20546/ijcmas.2019.804.339
25. Durán N, Durán M, De Jesus MB, Seabra AB, Fávaro WJ, Nakazato G. Silver nanoparticles: A new view on mechanistic aspects on antimicrobial activity. Nanomedicine: Nanotechnology, Biology and Medicine. 2016;12(3):789-799. https://doi.org/10.1016/j.nano.2015.11.016
26. Esyanti RR, Zaskia H, Amalia A, Nugrahapraja DH. Chitosan nanoparticle-based coating as post-harvest technology in banana. In: Journal of Physics: Conference Series. 2019;1204:012109. IOP Publishing. DOI: 10.1088/1742-6596/1204/1/012109
27. European Commission. Attitudes of European citizens towards the environment. Special Eurobarometer 365; c2012.
28. Filho, Miranda, Ferreira, Plotto, *et al*. Nanoemulsions as Edible Coatings: A Potential Strategy for Fresh Fruits and Vegetables Preservation. MDPI. https://doi.org/10.3390/foods10102438
29. Flores-López ML, Cerqueira MA, de Rodríguez DJ, Vicente AA. Perspectives on utilization of edible coatings and nano-laminate coatings for extension of postharvest storage of fruits and vegetables. Food Engineering Reviews. 2016;8:292-305.

DOI: 10.1007/s12393-015-9135-x

30. Forato LA, de Britto D, de Rizzo JS, Gastaldi TA, Assis OB. Effect of cashew gum-carboxymethylcellulose edible coatings in extending the shelf-life of fresh and cut guavas. Food Packaging and Shelf Life. 2015;5:68-74. https://doi.org/10.1016/j.fpsl.2015.06.001
31. Gad MM, Zagzog OA. Mixing *Xanthan gum* and *Chitosan nano particles* to form new coating for maintaining storage life and quality of elmamoura guava fruits. International Journal of Current Microbiology and Applied Sciences. 2017;6(11):1582-1591. https://doi.org/10.20546/ijcmas.2017.611.190
32. Gao Y, *et al*. Development of a novel antioxidant nanocoating based on quercetin-loaded zein nanoparticles for fresh-cut apples. RSC Advances. 2021;11(25):15162-15171. https://doi.org/10.1111/1750-3841.14803
33. Gardesh ASK, Badii F, Hashemi M, Ardakani AY, Maftoonazad N, Gorji AM. Effect of nanochitosan based coating on climacteric behavior and postharvest shelf-life extension of apple cv. Golab Kohanz. LWT. 2016;70:33-40. https://doi.org/10.1016/j.lwt.2016.02.002
34. Ghasemnezhad M, Shiri MA, Sanavi M. Effect of *Chitosan coatings* on some quality indices of apricot (*Prunus armeniaca* L.) during cold storage. Caspian Journal of Environmental Sciences. 2010;8(1):25-33.
35. Guilger-Casagrande M, Lima RD. Synthesis of *silver nanoparticles* mediated by fungi: A review. Frontiers in Bioengineering and Biotechnology. 2019;7:287. https://doi.org/10.3389/fbioe.2019.00287
36. Han JH. Innovations in food packaging. Academic Press; c2014.
37. Hasan S. A review on nanoparticles: their synthesis and types. Research Journal of Recent Sciences. 2015;2277:2502.
38. Hmmam I, Ali MAS, Abdellatif A. Alginate-Based Zinc Oxide Nanoparticles Coating Extends Storage Life and Maintains Quality Parameters of Mango Fruits "cv. Kiett". Coatings. 2023;13(2):362. https://doi.org/10.3390/coatings13020362
39. Hulkoti NI, Taranath TC. Biosynthesis of nanoparticles using microbes: A review. Colloids and Surfaces B: Biointerfaces. 2014;121:474-483. https://doi.org/10.1016/j.colsurfb.2014.05.027
40. Iuliani S, Wardana AA, Meindrawan B, Edhi N, Muchtadi T. Nanocomposite edible coating from cassava starch, stearic acid and ZnO *nanoparticles* to maintain quality of fresh-cut mango cv. arumanis. The Annals of the University Dunarea De Jos of Galati. Fascicle VI - Food Technology. 2018;42(2):49-58. Retrieved from https://www.gup.ugal.ro/ugaljournals/index.php/food/article/view/1118
41. Jafarzadeh S, Nafchi AM, Salehabadi A, Oladzad-Abbasabadi N, Jafari SM. Application of bio-nanocomposite films and edible coatings for extending the shelf life of fresh fruits and vegetables. Advances in Colloid and Interface Science. 2021;291:102405. https://doi.org/10.1016/j.cis.2021.102405
42. Jagana D, Hegde YR, Lella R. Green nanoparticles: A novel approach for the management of banana anthracnose caused by *Colletotrichum musae*. International Journal of Current Microbiology and Applied Sciences. 2017;6(10):1749-1756. https://doi.org/10.20546/ijcmas.2017.610.211
43. Janisiewicz WJ, Korsten L. Biological control of postharvest diseases of fruits. Annual Review of Phytopathology. 2002;40:411-441. https://doi.org/10.1146/annurev.phyto.40.120401.130158
44. Jiménez-Gómez CP, Cecilia JA. *Chitosan*: a natural biopolymer with a wide and varied range of applications. Molecules. 2020;25(17):3981. https://doi.org/10.3390/molecules25173981
45. Kader AA, Rolle RS. The role of post-harvest management in assuring the quality and safety of horticultural produce (Vol. 152). Food & Agriculture Org. 2004.
46. Khafar EAA, Zidan NS, Aboul-Anean HED. The effect of nano materials on edible coating and films' improvement. International Journal of Pharmaceutical Research and Allied Sciences. 2018;7(3-2018):20-41.
47. Khaliq G, Ramzan M, Baloch AH. Effect of *Aloe vera* gel coating enriched with *Fagonia indica* plant extract on physicochemical and antioxidant activity of sapodilla fruit during postharvest storage. Food Chemistry. 2019;286:346-353. https://doi.org/10.1016/j.foodchem.2019.01.135
48. Kharchoufi S, Parafati L, Licciardello F, *et al*. Edible coatings incorporating pomegranate peel extract and biocontrol yeast to reduce *Penicillium digitatum* postharvest decay of oranges. Food Microbiology. 2018;74:107-112. https://doi.org/10.1016/j.fm.2018.03.011
49. Kittur FS, Saroja N, Habibunnisa, Tharanathan R. Polysaccharide-based composite coating formulations for shelf-life extension of fresh banana and mango. European Food Research and Technology. 2001;213:306-311. DOI:10.1007/s002170100363
50. Kruglyakov P, Nushtayeva A. Emulsions stabilised by solid particles: the role of capillary pressure in the emulsion films. Interface Science and Technology. 2004;4(C):641-676
51. La DD, Nguyen-Tri P, Le KH, *et al*. Effects of antibacterial *ZnO* nanoparticles on the performance of a chitosan/gum arabic edible coating for post-harvest banana preservation. Progress in Organic Coatings. 2021;151:106057. https://doi.org/10.1016/j.porgcoat.2020.106057
52. Lakshmi SJ, RS RB, Sharanagouda H, *et al*. Effect of biosynthesized zinc oxide nanoparticles coating on quality parameters of fig (*Ficus carica* L.) fruit. Journal of Pharmacognosy and Phytochemistry. 2018;7(3):10-14.
53. Li Y, *et al*. Nano-coatings for Food Preservation. In: Nanotechnology in Food Industry. Academic Press; c2020. p. 127-152.
54. Li J, Sun Q, Sun Y, Chen B, Wu X, Le T. Improvement of banana postharvest quality using a novel soybean protein isolate/cinnamaldehyde/zinc oxide bionanocomposite coating strategy. Scientia Horticulturae. 2019;258:108786. https://doi.org/10.1016/j.scienta.2019.108786
55. Lo'Ay AA, Ameer NM. Performance of calcium nanoparticles blending with ascorbic acid and alleviation internal browning of 'Hindi Be-Sennara' mango fruit at a low temperature. Scientia Horticulturae.

2019;254:199-207. https://doi.org/10.1016/j.scienta.2019.05.006

56. Lustriane C, Dwivany FM, Suendo V, Reza M. Effect of chitosan and chitosan-nanoparticles on post harvest quality of banana fruits. Journal of Plant Biotechnology. 2018;45(1):36-44.https://doi.org/10.5010/JPB.2018.45.1.036
57. Madani B, Mohamed MTM, Biggs AR, *et al*. Effect of pre-harvest calcium chloride applications on fruit calcium level and post-harvest anthracnose disease of papaya. Crop Protection. 2014;55:55-60. https://doi.org/10.1016/j.cropro.2013.10.009
58. Maftoonazad N, Ramaswamy HS, Moalemiyan M, Kushalappa AC. Effect of pectin-based edible emulsion coating on changes in quality of avocado exposed to *Lasiodiplodia theobromae* infection. Carbohydrate Polymers. 2007;68(2):341–349.u https://doi.org/10.1016/j.carbpol.2006.11.020
59. Maftoonazad N, Ramaswamy HS, Marcotte M. Shelf-life extension of peaches through sodium alginate and methyl cellulose edible coatings. International Journal of Food Science and Technology. 2008;43(6):951-957. https://doi.org/10.1111/j.1365-2621.2006.01444.x
60. Maqbool M, Ali A, Alderson PG, Zahid N, Siddiqui Y. Effect of a novel edible composite coating based on gum arabic and chitosan on biochemical and physiological responses of banana fruits during cold storage. Journal of Agricultural and Food Chemistry. 2011;59(10):5474-5482. https://doi.org/10.1021/jf200623m
61. Matche RS. Packaging aspects of fruits and vegetables. In: Plastics in Food Packaging. Indian Centre for Plastics in the Environment; c2005. p. 115-132.
62. Md Nor S, Ding P. Trends and advances in edible biopolymer coating for tropical fruit: A review. Food Research International. 2020;134:109208. https://doi.org/10.1016/j.foodres.2020.109208.
63. Meindrawan B, Suyatma NE, Wardana AA, Pamela VY. Nanocomposite coating based on carrageenan and ZnO nanoparticles to maintain the storage quality of mango. Food Packaging and Shelf Life. 2018;18:140-146.
64. Mendoza F, Dejmek P, Aguilera JM. Calibrated color measurements of agricultural foods using image analysis. Postharvest Biology and Technology. 2006;41(3):285-295. https://doi.org/10.1016/j.postharvbio.2006.04.004
65. Mishra A, Mann B, Poonia A, Rai DC, Hooda A. Milk protein-based edible coatings: Properties and applications. In: Edible Food Packaging: Applications, Innovations and Sustainability. Singapore: Springer Nature Singapore; c2022. p. 217-232. DOI:10.1007/978-981-16-2383-7_11
66. Murmu SB, Mishra HN. The effect of edible coating based on Arabic gum, sodium caseinate and essential oil of cinnamon and lemon grass on guava. Food Chemistry. 2018;245:820-828. https://doi.org/10.1016/j.foodchem.2017.11.104
67. Mushtaq A, Wani SM, Malik AR, *et al*. Recent insights into Nanoemulsions: Their preparation, properties and applications. Food Chemistry: X. 2023;100684. https://doi.org/10.1016/j.fochx.2023.100684
68. Narayanan KB, Sakthivel N. Biological synthesis of metal nanoparticles by microbes. Advances in Colloid and Interface Science. 2010;156(1-2):1-13. https://doi.org/10.1016/j.cis.2010.02.001
69. Ncama K, Magwaza LS, Mditshwa A, Tesfay SZ. Plant-based edible coatings for managing postharvest quality of fresh horticultural produce: A review. Food Packaging and Shelf Life. 2018;16:157-167. https://doi.org/10.1016/j.fpsl.2018.03.011
70. Nile SH, Baskar V, Selvaraj D, Nile A, Xiao J, Kai G. Nanotechnologies in food science: applications, recent trends, and future perspectives. Nano-micro Letters. 2020;12:1-34. https://doi.org/10.1007/s40820-020-0383-9
71. Nishikito DF, Borges ACA, Laurindo LF, *et al*. Anti-inflammatory, antioxidant, and other health effects of dragon fruit and potential delivery systems for its bioactive compounds. Pharmaceutics. 2023;15(1):159. https://doi.org/10.3390/pharmaceutics15010159
72. Odetayo T, Tesfay S, Ngobese NZ. Nanotechnology-enhanced edible coating application on climacteric fruits. Food Science & Nutrition. 2022;10(7):2149-2167. https://doi.org/10.1002/fsn3.2557
73. Onyeaka H, Passaretti P, Miri T, Al-Sharify ZT. The safety of nanomaterials in food production and packaging. Current Research in Food Science. 2022;5:763-774. https://doi.org/10.1016/j.crfs.2022.04.005
74. Pandey VK, Islam RU, Shams R, Dar AH. A comprehensive review on the application of essential oils as bioactive compounds in Nano-emulsion based edible coatings of fruits and vegetables. Applied Food Research. 2022;2(1):100042.
75. Paul V, Pandey R, Srivastava GC. The fading distinctions between classical patterns of ripening in climacteric and non-climacteric fruit and the ubiquity of ethylene—An overview. Journal of Food Science and Technology. 2012;49:1-21. doi: 10.1007/s13197-011-0293-4
76. Pavitra Kumari R, Singh R. Anthracnose of mango incited by Colletotrichum gloeosporioides: A comprehensive review. International Journal of Pure and Applied Bioscience. 2017;5(1):48-56. http://dx.doi.org/10.18782/2320-7051.2478
77. Poonam RKJ, Kumawat P, Prajapat A, Kumawat S. Post-Harvest Management of Fruits and Vegetables.
78. Rhim JW, *et al*. Chitosan nanoparticle-embedded food packaging film. ACS Omega. 2019;4(1):1310-1318. https://doi.org/10.1016/j.fpsl.2018.12.005
79. Rhim JW, Wang LF, Hong SI. Preparation and characterization of agar/chitosan blend films: Part 8. Antimicrobial activity, gas barrier properties, and biodegradability. Food Chemistry. 2016;196:1275-1282. https://doi.org/10.1016/j.foodchem.2015.10.052
80. Riseh RS, Vatankhah M, Hassanisaadi M, Shafiei-Hematabad Z, Kennedy JF. Advancements in coating technologies: Unveiling the potential of chitosan for the preservation of fruits and vegetables. International Journal of Biological Macromolecules. 2023;127677. https://doi.org/10.1016/j.ijbiomac.2023.127677
81. Sambhakar S, Malik R, Bhatia S, *et al*. Nanoemulsion: an emerging novel technology for improving the bioavailability of drugs. Scientifica; c2023. https://doi.org/10.1155/2023/6640103
82. Sankar R, *et al*. Anti-ripening effect of silver nanoparticles on stored fruits and vegetables. Journal of Agricultural and Food Chemistry. 2013;61(29):6999-7006. https://doi.org/10.1021/jf401509m

83. Sastry M, Ahmad A, Khan MI, Kumar R. Biosynthesis of metal nanoparticles using fungi and actinomycete. Current Science; c2003. p. 162-170.
84. Shah S, Hashmi MS. Chitosan–aloe vera gel coating delays postharvest decay of mango fruit. Horticulture, Environment, and Biotechnology. 2020;61:279-289. DOI:10.1007/s13580-019-00224-7
85. hahat MS, Ibrahim MI, Osheba AS, Taha IM. Preparation and characterization of silver nanoparticles and their use for improving the quality of apricot fruits. Al-Azhar Journal of Agricultural Research. 2020;45(1):38-55. DOI:10.21608/ajar.2020.126625
86. Shankar S, Reddy JP, Rhim JW, Kim HY. Preparation, characterization, and antimicrobial activity of chitin nanofibrils reinforced carrageenan nanocomposite films. Carbohydrate Polymers. 2015;117:468-475. https://doi.org/10.1016/j.carbpol.2014.10.010
87. Silva M, Chandrapala J. Ultrasonic emulsification of milk proteins stabilized primary and double emulsions: a review. Food Reviews International. 2023;39(3):1462-1484. https://doi.org/10.1080/87559129.2021.1934006
88. Singh V, Hedayetullah M, Zaman P, Meher J. Postharvest Technology of Fruits and Vegetables: An Overview. Journal of Postharvest Technology. 2014;2(2):124-135.
89. Singh NA, Narang J, Garg D, Jain V, Payasi D, Suleman S, Swami RK. Nanoparticles Synthesis via Microorganisms and their Prospective Applications in Agriculture. Plant Nano Biology. 2023;100047. https://doi.org/10.1016/j.plana.2023.100047
90. Sirelkhatim A, Mahmud S, Seeni A, *et al*. Review on zinc oxide nanoparticles: antibacterial activity and toxicity mechanism. Nano-Micro Letters. 2015;7:219-242. https://doi.org/10.1007/s40820-015-0040-x
91. Tajkarimi MM, Ibrahim SA, Cliver DO. Antimicrobial herb and spice compounds in food. Food Control. 2010;21(9):1199-1218. https://doi.org/10.1016/j.foodcont.2010.02.003
92. Teshome E, Forsido SF, Rupasinghe HP, Olika Keyata E. Potentials of natural preservatives to enhance food safety and shelf life: A review. The Scientific World Journal. 2022. https://doi.org/10.1155/2022/9901018
93. Thakur R, Pristijono P, Scarlett CJ, Bowyer M, Singh SP, Vuong QV. Starch-based edible coating formulation: Optimization and its application to improve the postharvest quality of "Cripps pink" apple under different temperature regimes. Food Packaging and Shelf Life. 2019;22:100409. https://doi.org/10.1016/j.fpsl.2019.100409
94. Vargas M, Albors A, Chiralt A, González-Martínez C. Quality of cold-stored strawberries as affected by chitosan–oleic acid edible coatings. Postharvest Biology and Technology. 2006;41(2):164-171. https://doi.org/10.1016/j.postharvbio.2006.03.016
95. Vilaplana R, Chicaiza G, Vaca C, Valencia-Chamorro S. Combination of hot water treatment and chitosan coating to control anthracnose in papaya (*Carica papaya* L.) during the postharvest period. Crop Protection. 2020;128:105007. https://doi.org/10.1016/j.cropro.2019.105007
96. Yousuf B, Wu S, Siddiqui MW. Incorporating essential oils or compounds derived thereof into edible coatings: Effect on quality and shelf life of fresh/fresh-cut produce. Trends in Food Science & Technology. 2021;108:245-257. https://doi.org/10.1016/j.tifs.2021.01.016
97. Zhai X, *et al*. Effect of chitosan-based edible coating containing nanoparticles on the postharvest quality of strawberry. Journal of Food Science. 2015;80(1). https://doi.org/10.1111/1750-3841.14803
98. Zhang M, Chen H, Mujumdar AS, Tang J, Miao S, Wang Y. Recent developments in high-quality drying of vegetables, fruits, and aquatic products. Critical Reviews in Food Science and Nutrition. 2017;57(6):1239-1255. https://doi.org/10.1080/10408398.2014.979280
99. Ayranci E, Tunc S. The effect of edible coatings on water and vitamin C loss of apricots (*Armeniaca vulgaris* Lam.) and green peppers (*Capsicum annuum* L.). Food chemistry. 2004 Sep 1;87(3):339-342.
100. Petretto GL, Fancello F, Bakhy K, Faiz CA, Sibawayh Z, Chessa M, *et al*. Chemical composition and antimicrobial activity of essential oils from *Cuminum cyminum* L. collected in different areas of Morocco. Food bioscience. 2018 Apr 1;22:50-58.
101. Gautret P, Lagier JC, Parola P, Meddeb L, Mailhe M, Vieira VE, *et al*. Hydroxychloroquine and azithromycin as a treatment of COVID-19: results of an open-label non-randomized clinical trial. International journal of antimicrobial agents. 2020 Jul 1;56(1):105949.
102. Tian M, Gao Z, Han H, Sun W, Hu Y. Improved flotation separation of cassiterite from calcite using a mixture of lead (II) ion/benzohydroxamic acid as collector and carboxymethyl cellulose as depressant. Minerals Engineering. 2017 Nov 1;113:68-70.
103. Aghamolaei R, Ghaani MR, Tahsildoost M, Zandi M. A comprehensive energy-oriented approach for optimization of solar potential in urban contexts: an application study for residential districts. Advances in Building Energy Research. 2019 Jul 3;13(2):205-219.
104. Zhou HC, Long JR, Yaghi OM. Introduction to metal–organic frameworks. Chemical reviews. 2012 Feb 8;112(2):673-674.
105. Naushad M, Sharma G, Alothman ZA. Photodegradation of toxic dye using Gum Arabic-crosslinked-poly (acrylamide)/Ni (OH) 2/FeOOH nanocomposites hydrogel. Journal of Cleaner Production. 2019 Dec 20;241:118263.