Chapter

Using Nanotechnology for Enhancing the Shelf Life of Fruits

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Abstract

Edible coatings are thin layers of edible materials formed directly on fruits, usually by immersing the fruits in a coating material solution, and they are one of the most intriguing food developments in recent years. Colorants, flavours, nutrients, and anti-browning and antimicrobial agents can all be carried by edible coatings, extending shelf life and reducing pathogen growth on food surfaces. To manage moisture transfer, gas exchange, or oxidative processes, edible coatings can be applied using various procedures such as dipping, spraying, or coating. Because these systems have a larger surface area, nanoparticles may help to improve the barrier characteristics and functionality of fruit preservation coatings. Antimicrobial nanoparticles (NPs) are employed as matrixes in edible coatings and films (ECF), which are then applied to fruits to extend shelf life and improve storage quality. Nano Chitosan is one of the most prevalent polysaccharides, protein, and lipid-based edible coatings. These are characterised by poor gas and water barrier qualities, and they are frequently used as moisture loss sacrifice agents. Therefore, the purpose of this book chapter is to study the effect of nano edible coatings such as chitosan/tripolyphosphate (TPP), chitosan-methyl cellulose/silica (SiO_2), gelatin-fiber/titanium dioxide (TiO_2), gelatin-chitosan/ (Ag/ZnO), Gelatin/kafirin to quality attributes and prolonging the shelf life of fruits.

Keywords: edible coatings, nanoparticles, chitosan, titanium dioxide, fruits, nano-silver, silicon dioxide, nanogold, nano liposome, colloidosomes

1. Introduction

Consumers these days are demanding high-quality fruits and vegetables that are rich in health-promoting compounds and also prefer fresh foods because of their high-value nutrition. To achieve more beneficial health, moreover, these foods should keep up the good physicochemical and sensory quality, as well as be safe for consumption and should be free from contaminants and pathogenic microorganisms [1]. This growing demand has now challenged the food and horticulture industries to develop relevant preservation practices. This has prompted a sense of urgency for scientists and food processing industries to evaluate different approaches to enhance the freshness, quality, shelf-life, and food safety, through the use of natural, edible, and biodegradable polymers [2]. These edible coatings and films reduce the loss of quality attributes by forming a semipermeable safety barrier around fruits. Edible films and coatings can consist of 3 types of biological materials: polysaccharides, lipids, and proteins [3]. Many biopolymers such as alginate, carrageenan, chitosan, pectin, starch, and xanthan gum have been widely used to form edible films and food coatings. Their film-forming properties allow the synthesis of membranes (thickness > 30 μm) and coatings (<30 μm), which are successfully used to preserve foodstuffs.

Edible coatings can also be used as a carrying matrix of antimicrobial agents which can increase its functioning by substituting the microbial spoilage and increasing the shelf life of the product [4]. The edible coating idea helps to increase the use of raw and perishable vegetables and fruits and control the horticulture loss of crops. Edible coating base material is made of polysaccharides, proteins, and lipids. In view of Zaragoza et al. [1] edible coating controls the respiration rate, it also controls the extension of microbes during the preservation of fruits and vegetables. Chitosan is to be used in organic-based coating for stopping food spoil and defile. It has a very impressive capacity for heavy metal adsorption. It is used as edible coatings to extend fruit shelf life by reducing transpiration and respiration rates. TiO_2 nanoparticles have excellent photocatalytic activity, which is very effective for the removal of organic pollutants. Therefore, the integration of TiO_2 and chitosan can complement each other with their own advantages, and the chemical grafting of antioxidant molecules (such as chitosan) directly on the surface of TiO_2 nanoparticles has the best effect on the treatment of wastewater pollutants.

Mostly the traditional packaging is derived from petroleum plastics such as polypropylene, polyethylene, and polystyrene, which later after the product utilization becomes a major worry due to environmental damage they cause regarding their difficult degradation. Nevertheless, serious environmental problems are created due to the non-biodegradability of these materials, thus enlarging the attentiveness of researchers in biodegradable packaging production utilizing natural polymers extracted from renewable sources for application in food packaging. In this sense, many researchers have shown interest in coatings and edible films which represent an environmentally friendly alternative for food packaging. Edible packaging is known as a future alternative to protecting food quality and improving shelf life by slowing down microbial spoilage and providing moisture and gas barrier properties. In 2016, the edible packaging market was valued at $697 million and by the year 2023, it is expected to hit $1097 million increasing at a compound annual growth rate (CGAR) of 6.81% from 2017 to 2023 on an international level.

Nanotechnology works well for food packaging, and edible coatings made of both inorganic and organic nanoparticles are also possible [5]. Inorganic nanoparticles including silver oxide Np, titanium oxide, zinc oxide, silver and are mostly employed in food packaging as a detector, to prevent foodborne illness, and to lengthen shelf life. In 2006, FDA said that nanomaterials are particles with dimensions less than a micrometre scale that exhibit special properties [6]. In recent years, using edible coatings (ECs) to extend the shelf life of fresh foods has shown to be a successful and environmentally beneficial alternative. An edible coating is a thin layer of food that is applied directly on a food surface and has filmogenic qualities. The inclusion of compounds with antibacterial activity inside the polymeric matrix is one of the most fascinating aspects of coating design. The edible coating's non-toxic anti-fungal ingredients may prevent fungal deterioration, which is the principal cause of postharvest losses of fruit and vegetable goods [7].

2. Edible coatings

These are thin layers of edible material applied to a product surface in addition to or instead of natural protective wax coatings and act as a barrier to moisture, oxygen, and solute movement for food [8]. Fruits and vegetables continue to respire even after harvest and use up all the oxygen within the product, which is not replaced as quickly as by edible coating and produces carbon dioxide, which accumulates within the product because it cannot escape as easily through the coating. Therefore, fruits and vegetables stay firm, fresh, and nutritious for longer, and their shelf life is almost doubled. The amount of coating affects the extent to which the internal atmosphere (O_2 and CO_2) is modified and the degree of minimization in weight loss. Since ancient times, edible coatings and films have been used in the food business to protect food goods. This is not a novel method of preservation. The first edible fruit coating was wax. In the twelfth and thirteenth centuries, the Chinese coated lemons and oranges with war [9].

2.1 Traits of edible coating

The edible coating properties mostly depend on molecular structure than chemical constitution and size.

i. The edible coating should be water-resistant so that it remains intact and adequately covers the product when applied

ii. It should not deplete O_2 or build up excess carbon dioxide. At least 1–3% oxygen is needed around the object to avoid the transition from aerobic to anaerobic respiration

iii. It should reduce water vapor permeability

iv. It should improve appearance, maintain structural integrity, improve mechanical handling properties, carry phytochemicals (antioxidants, vitamins, etc.) and contain volatile flavor compounds.

v. It should melt above 40°C without decomposing

vi. It should be easily emulsifiable, not tacky or sticky and should have effective drying performance

vii. It should never interfere with the quality of fresh fruits or vegetables and should not impart undesirable texture

viii. It should have low viscosity and be economical

ix. It should be translucent but not glassy and should be able to withstand slight pressure

2.2 Benefits of edible coatings

1. Improves external appearance by giving extra shine to fruit surface

2. Reduces weight loss and keeps the fruit firm so it can maintain its fresh appearance

3. Reduces respiration rate and ethylene production, thereby delaying aging

4. Prevents fruits from chilling injury and storage disorders

5. Act as a barrier to free gas exchange

6. Provides a carrier for post-harvest chemical treatments

7. Adds nutrients such as aroma compounds, antioxidants, pigments, ions that stop browning reactions, and vitamins

8. In some countries, taxes on packaging material transport can be saved by using edible coatings and films.

3. Nano edible coatings

Presently edible coatings are being developed using organic nanomaterials which are effective in maintaining post-harvest quality and controlling crop loss. The most explored nanoparticles in fruits are zinc oxide, silver, and chitosan, considering their high antimicrobial activity and stability (**Figure 1**). However, other nanoparticles such as Fe, TiO_2, cerium oxide, and Cu have been used in various sectors of the food industry.

A very effective strategy is to elaborate edible coatings consisting of nanoparticles mixed with organic and inorganic materials producing nanocomposites. The organic nano coatings are chitosan, Alginate, nano liposome, colloidosomes, casein micelles,

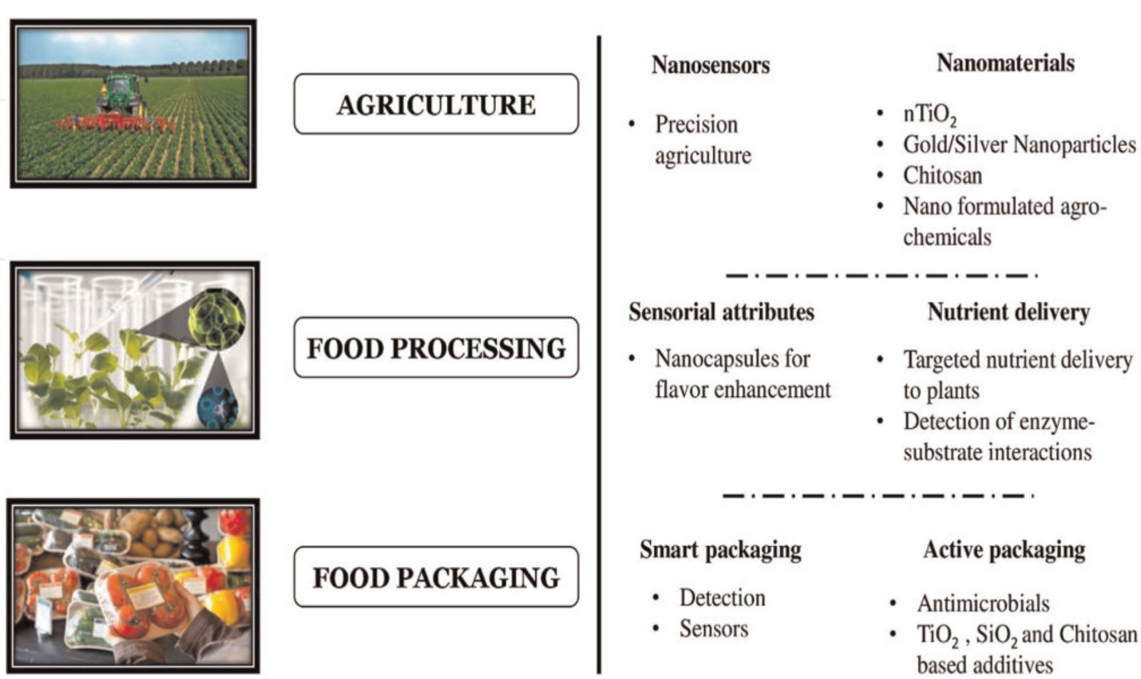

Figure 1.
Applications for nanotechnology in agriculture, food processing, and packaging.

and nano cochleate, however, inorganic coating materials are nano silver, gold, silicon dioxide, TiO_2, nano Fe, ZnO, and carbon nanotube.

3.1 Chitosan and chitin-based coatings and films

Insects, crustaceans, and fungi use the naturally occurring mucopolysaccharide chitin, which is composed of 2-acetamido-2-deoxy-β-D-glucose molecules connected by -bonds, as a structural component (1-4). Chitosan, a concentrated alkali-induced N-deacetylated derivative of chitin, is produced in this environment. Chitosan and chitin are alike to cellulose in their excessive insolubility degree and low chemical reactivity. Solubility of chitosan depends on N-acetylation degree and molecular weight, also it can be dissolved in acid solutions where pH is less than 6.3 even at a concentration above 2% (w/v). Rheological properties, solubility, and appearance, among other properties of chitosan properties, are also dependent on the N-acetylation degree.

Similar to cellulose, chitosan and chitin has a high insolubility degree and minimal chemical reactivity. Chitosan may dissolve in acid solutions with a pH lower than 6.3 at concentrations of more than 2% (w/v), and its solubility is proportional to its N-acetylation degree and molecular weight. Chitosan's N-acetylation level affects not only its rheological qualities but also its solubility and appearance. The potential of chitosan-based films and coatings to act as natural preservatives is widely known.

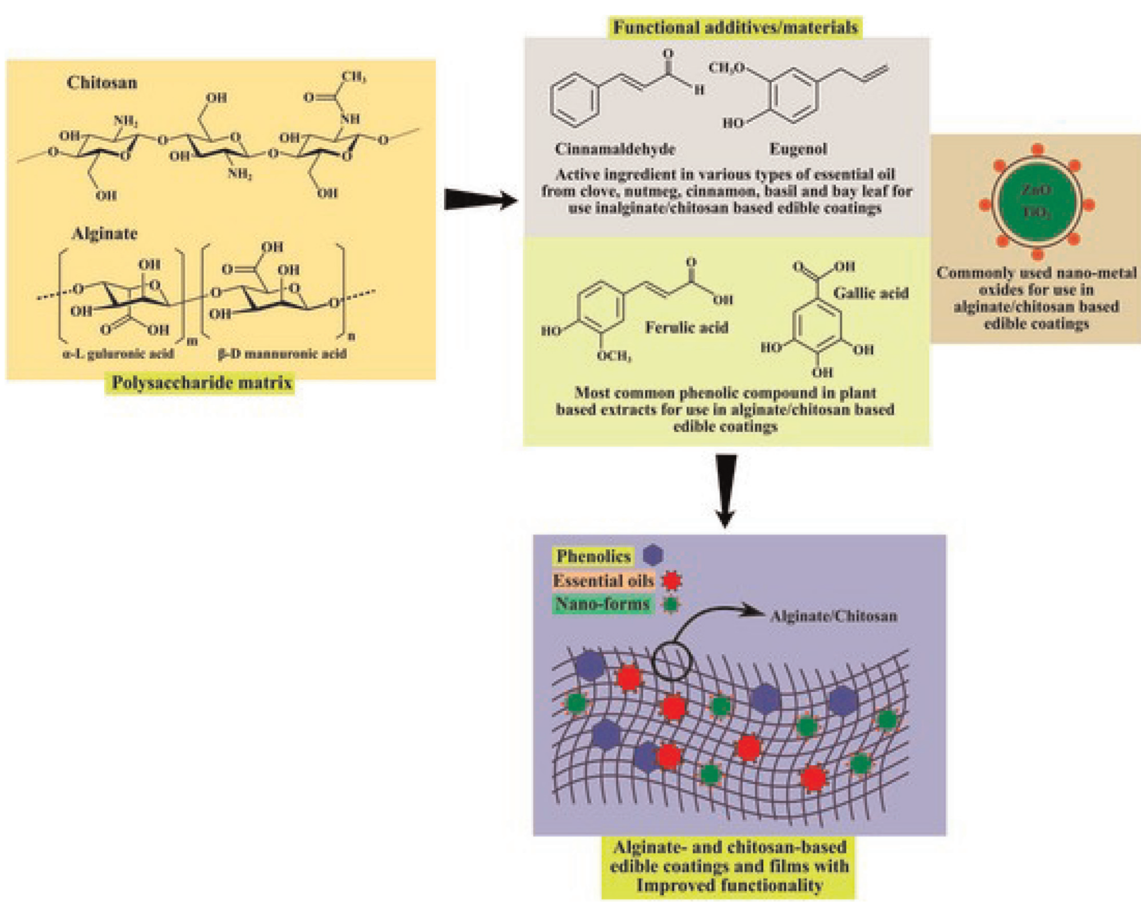

Figure 2.
A diagram representing the various components discussed in the chapter i.e., polysaccharide matrix (chitosan and alginate), functional materials (phenolics, essential oils, and nano-forms), and matrix incorporated with functional materials for improving the overall properties of the edible coatings/films. Here m (α-L guluronic acid) and n (β-D mannuronic acid) (Source: [10]).

Coatings and films made of chitosan are permeable to gases (O_2 and CO_2), have excellent mechanical properties, and also have high permeability to water vapor, which limits their use in humid environments, since controlling moisture transfer is a desirable property. For this main reason, several plans have been made to improve the functional properties of chitosan coatings and films. As can be seen, its functional coating qualities may be improved by adjusting factors such as the degree of solvent, pH, deacetylation, and the addition of surfactants, proteins, lipids, or polysaccharides. Essential oils boost water vapour permeability and give antibacterial and antioxidant benefits. A number of reagents, such as ferulic acid, genipin, glutaraldehyde, formaldehyde, cinnamaldehyde, and sodium trimetaphosphate, are added to the formulation to slow down the dissolving or swelling and enhance the characteristics of chitosan-based coatings. Their main use is in food processing as a functional food and helps in Encapsulation antimicrobial agent and also works as plant growth-promoting agent.

For the effective use of chitosan coating, the chitosan was to be combined with other substances. As seen, the single chitosan coating was oftentimes combined with physical methods that are short heating, short gas fumigation, and modified atmosphere packaging (**Figure 2**) [11].

3.2 Alginate-based films and coatings

Gels or insoluble polymers may be formed from sodium alginate, a well-known polysaccharide, due to its strong reactivity to polyvalent metal cations. Since it may create a semipermeable barrier on fruits and vegetables, it has been widely utilized as an edible covering for preserving foods like apples and peaches [10]. Marine brown algae are a rich natural source of the polysaccharide alginate (Phaeophyceae, majorly Laminaria). Pseudomonas and Azotobacter are two bacterial families that contribute to its development. Alginate is a linear copolymer of (1–4) β-D-mannuronic (M) and α-L-guluronic (G) acid, and it is the salt of alginic acid. These acid residues are located in M or G-residue blocks (also known as MG-blocks) or in MG-residue blocks. M: G residue distribution and percentage differ across algal species. Because nano coating has the potential to extend the shelf life of many food goods, it is seeing rapid growth.

Silver-containing materials are shown to exhibit bactericidal or anti-microbial properties, which led to their strong development in the last few years [12]. Alginates are infamous for their good film-forming properties and performance [13]. Alginates are globally used in edible coatings because of their good availability and regulatory status. The United States Food and Drug Administration (FDA) classifies food-grade sodium alginate as generally regarded as safe to use (**Figure 3**) [14].

3.3 Nano liposome

Its main application is in the Food processing industry and its main use is in specific delivery of nutraceuticals and active and passive delivery of genes, protein & peptides, and also the delivery of pesticides and fertilizers.

3.4 Colloidosomes

Colloidosomes also called Pickering emulsion capsules, have gained a lot of attention for the Encapsulation of hydrophilic and hydrophobic activities [15]. These are microcapsules whose shell comprises tightly packed colloidal particles. Their physical properties like permeability, mechanical strength, and biocompatibility can also be

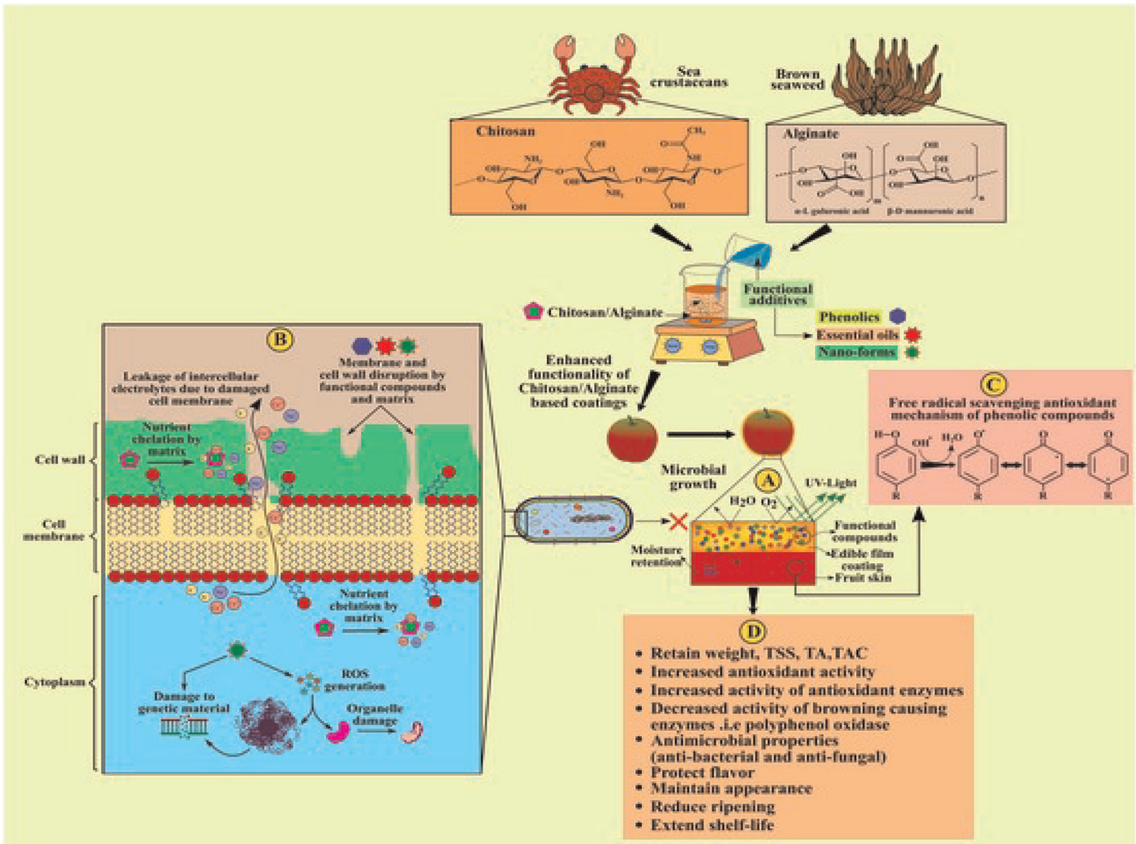

Figure 3.
The role and mechanism of action of functional materials in enhancing the shelf-life of fruits. (A) The matrix of alginate/chitosan along with functional additives acts as a water and O_2 barrier for inhibiting respiration and eventually reactive oxygen species generation. The specialized coating also inhibits the spoilage of fruits by microbes and UV light. (B) Phenolics, essential oils, and nanoparticles destabilize microbial membranes, which can perforate cells and block protein synthesis, causing electrolyte leakage and ultimately cell death. Nano-metallic forms generate (ROS) like hydroxyl radicals, and SOD and result in organelle damage. They further restrict the synthesis of DNA, RNA, and lipids required for the survival of the microbes. (C) These functional materials mainly phenolics act as antioxidants and prevent fruits from being damaged by reactive oxygen species. (D) The synergistic effect of alginate/chitosan-based coatings with functional additives maintains the appearance, flavour, and extends the shelf-life of fruits and vegetables. Here ROS (reactive oxygen species), total soluble solids, titratable acidity, and total ascorbic acid content.

controlled by the proper choice of colloids and preparation conditions for their assembly [16]. Colloidosomes are also used in the Food processing unit and their main application is increasing the nutrient content of food.

3.5 Casein micelles

Casein micelles show hydrophobic and hydrophilic properties that make them ideal for encapsulation of food bioactive [17]. Its main application is as a nutritional supply that helps in the delivery of sensitive products.

3.6 Alginate and chitosan

Alginate and chitosan are used to coat the nanoparticles and make negative and positive charges available on the particles [18]. Their main application is as a target delivery supply that supplies B-carotene, lycopene, vitamins A, D, E, and omega-3-fatty acids.

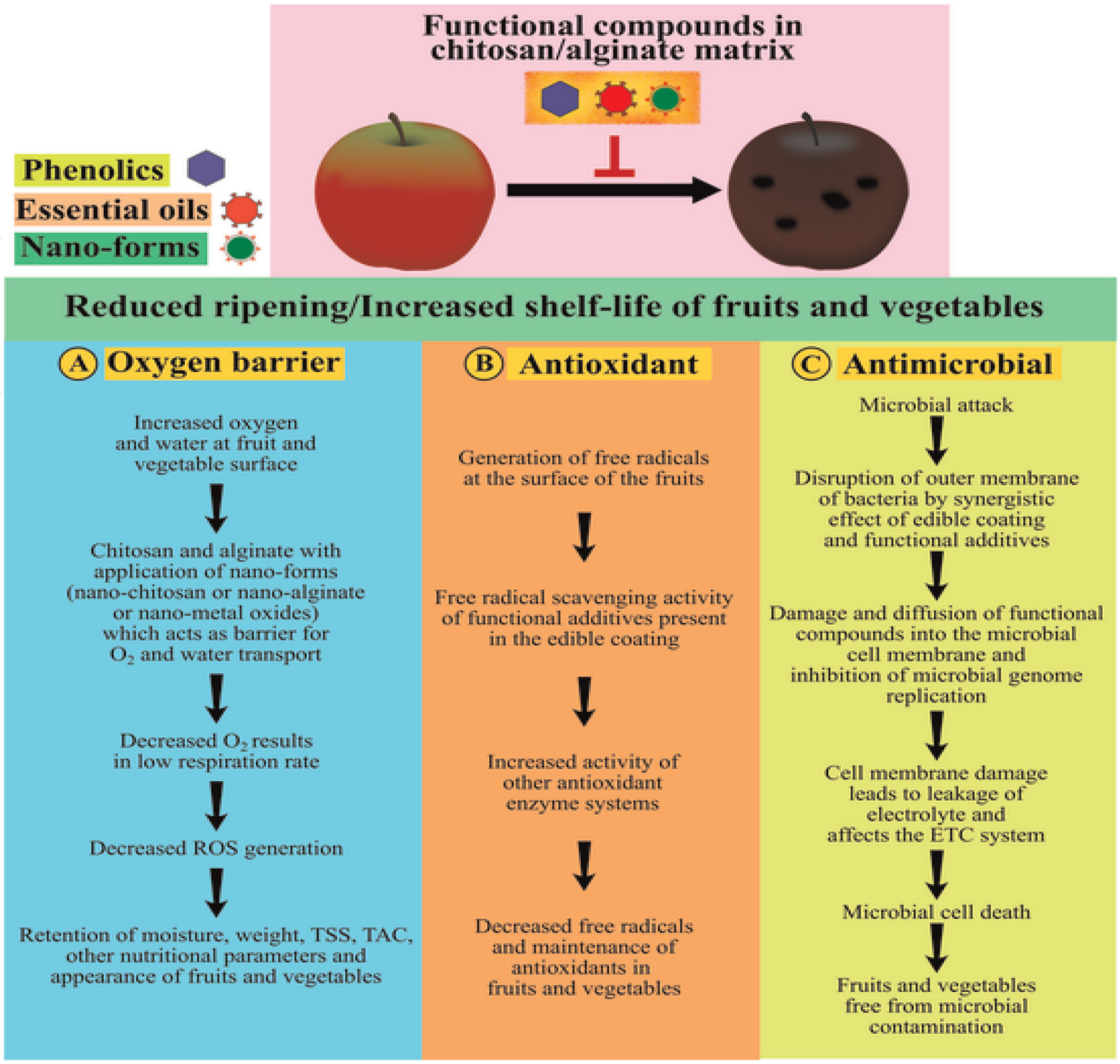

Figure 4.
*Overview of the mechanism of the synergistic effect of alginate/chitosan matrix and functional additives (phenolics, essential oils, nano-forms). (A) Acting as an O_2 barrier. (B) Acting as an antioxidant. (C) Acting as anti-microbial. The overall action of (A), (B), and (C) results in a prolonged shelf-life of fruits and vegetables (source: (**Table 1**) [10]).*

3.7 Nano cochleate

Nano cochleates' main application is in Nutritional supply where Nutrients are efficiently delivered without affecting colour and taste (**Figure 4**) [6].

4. Edible films and coatings for fruit preservation

Fruits are acknowledged as the main sources of vitamins, minerals, antioxidants, and fibre in the diet of consumers. At a similar time, their short shelf life is well known, due to their high percentage of moisture content (75–95%), which is one of the major causes of their fast degradation. Many types of nanocomposite films and edible coatings are used nowadays very much on fresh fruits and vegetables for increasing their shelf life using the same methods as modified atmosphere methods, which have already shown good results for preserving fruits and vegetable quality [23]. Total soluble solids content (°Brix) is a very important maturity index for fruit and vegetables. Edible coatings are

S. no	Nano material	Application and properties	Examples	References
1	Nano silver	It has the property of strong disinfection & storage. It is also rich in 22 essential vitamins and minerals and is also used for sterilization & quality control. Sometimes it acts as an antibacterial agent	Used as nano-silver salad bowl, storage box, daily vitamin boost, nano colloidal silver, nanosilver sol, and also in food packaging	[6, 19]
2	Silicon dioxide	Its main application is as biosensor which prevents UV light and is used as pesticides & herbicides and as edible coating. It can detect food colorant hygroscopic	Acts as a drying agent also used in food packaging of fruits and vegetables	[6]
3	Titanium dioxide	Titania exists as an oxide of titanium and is recognized as NPs of metal oxides comprising unique optical, thermal, electric, and magnetic properties	It works as a biosensor which is used as a whitener in dairy for products like milk and cheese	[20]
4	Nanoclusters iron np 30 nm	Its main application is for the development of functional food	In nano cuticles slim shake vanilla and fortified fruit juice	[6, 19]
5	Zinc oxide	It is used as a Food preservative and as an edible coating having its main properties as an antimicrobial agent.	Improve fruit properties of strawberry, banana, and others	[6]
6	Nano gold	AuNPs are being used in nano packaging industries for their properties like possessing therapeutic and antibacterial characteristics as well as their inert and nontoxic nature	It acts as a pathogen and glucose detector	[21]
7	Carbon nanotube	Carbon nanotubes have recommendable electronic conductivity, vigorous stability, and environmental friendliness	Application is in the food packaging industry e.g., wine and honey-making industry	[22]

Table 1.
Inorganic nano materials.

also very operative in lowering TSS, or we can say in lowering the ripening rates of fruit and vegetable products [24]. Edible coatings and films (ECF) are employed as matrixes for including antimicrobial nanoparticles (NPs), and then they are used on fruits and vegetables to increase their shelf life and enhance quality in storage. The preservation ability of the quality of fruits and vegetables indicates that many ECFs with NPs could be used as the ideal materials for food application. Looking at the introduction to these characteristics, an attempt is made to look out for future trends in this field [25].

5. Future trends of ECF with NPs

In the last few years, nanosized particles as anti-microbial agents incorporated into edible coatings are the subject of many studies. However, additional research including the interactions between coating materials and nanosized particles is very much important. Also, further work about the effect of these nanosized particle's addition on the properties of coating materials should be understood. These investigation results may provide insights regarding upcoming improvements to their physical and antimicrobial properties for practical applications. In order to determine the requirements for its production and application, it is crucial that future research concentrate on improving the uniformity of composite coating qualities and keeping an eye out for its impacts on the storage quality of fruits and vegetables. It's crucial to do further research on economical methods of creating and using ECF [25].

6. Application methods of edible coatings

The application technique will be selected based on the nature of the food to be coated, the surface qualities, the rheological properties of the solution, and the primary purpose of the coating, all of which influence how well the coating will preserve fresh fruits and vegetables. Coatings' ability to stick to food surfaces is crucial to their serving their purpose. Interfacial contact between food surface and coating may be evaluated by measuring wettability. This factor is essential to consider when monitoring the effectiveness of the coating solution on the food's surface. Coating fresh fruits and vegetables with edible substances are often done by dipping, spraying, or hand-coating. Fluidized bed processing and foaming are two more methods; however, they are seldom employed outside of research settings [26]. Edible coatings depend on numerous parameters such as type of coating used, amount, viscosity, and also surface tension. The coating method also affects the efficiency and quality of the coating (**Table 2**) [34].

S. no	Fruit	Edible coatings used	Findings	References
1	Fresh cut apple	Sodium alginate	Nanoemulsion-based edible coatings presented higher *E. coli* inactivation and slower psychrophilic bacteria growth compared to conventional emulsions at the same concentration	[27]
2	Grape berry	Chitosan	The use of the nanoemulsion effectively reduced the initial growth of S. Typhimurium, total aerobic mesophiles, yeasts, and molds, and showed retention of antioxidant capacity	[27]
3	Fresh cut apple	Nopal mucilage	The coatings formed with the nano-emulsion had a significant inhibitory effect on PME and PPO activity, in contrast to conventional emulsions	[27]
4	Guava (*Psidium guajava* L.)	SLN (solid lipid nanoparticles) Candeubawa S wax (carnauba wax and candelilla wax) Poloxamer 407	The potential use of SLNs in edible coatings could be applied easily to minimize the senescence of several products	[27]
5	Guava (*Psidium guajava* L.)	Poloxamer 407	The application of candeuba wax (SLN) helps to conserve the natural maturation process but at a slower rate	[27]

S. no	Fruit	Edible coatings used	Findings	References
6	Apples	Nano-SiO_2	The preparation of edible coating by ultrasonic processing and incorporation into an SPI matrix results in a decreased respiration rate, maintenance of firmness, and extension of shelf life	[28]
7	Fresh-cut papaya, pear	Montmorillonite (MMT)	Adding 15 g/L of montmorillonite at 80°C and essential oil of oregano decreased weight loss and maintained the quality of papaya; moreover, the edible coating helped slow microbial growth	[29]
8	Strawberries	Montmorillonite (MMT)	This edible coating contained 70% WPI, 0.5% potassium sorbate, 3.75% calcium caseinate and 0.375% MMT. It was effective in limiting mold growth for at least 12 days and maintained the quality of the fresh coated strawberries	[27]
9	Ready-to-eat pomegranate	Nano-ZnO_2	Edible coatings with 0.2% ZnO_2 reduced yeast and mould development at 6 and 12 days of storage, although bacterial load increased. CMC and nano-ZnO_2 helped preserve pomegranate bioactive	[30]
10	Citrus fruit	Silver nanoparticles (AgNPs)	AgNPs caused cell deformation, cytoplasmic leakage, and cell death of *P. italicum*. AgNPs also showed significant activity on *E. coli* and *S. aureus* with beneficial effects for citrus fruit preservation	[28]
11	Kinnow (*Citrus reticulata*)	Silver nanoparticles (AgNPs)	Silver nanoparticles were added to a coating emulsion base together with either CMC or guar gum at a ratio of 1:1	[31]
12	Strawberries	Limonene	limonene liposomes showed significantly lower fungal growth as compared to the control on the 14th day of storage	[32]
13	Cantaloupe	Chitosan/nano-silica/ nisin	Their combination was found to be perfect which increased shelf life by maintaining color, Vit-C, and Peroxidase Activity for up to storage time of days	[33]
14	Blueberries	Chitosan/nano-TiO_2	They could maintain the nutrient composition while preserving quality at zero degrees	[25]
15	Blackberry	Chitosan	Showed best antifungal effect over racemosus	[23]
16	Fresh Fruit (Redberry) *Arbutus unedo*	Sodium alginate	AL 1% + Eug 0.20% showed the best results in terms of preservation	[23]
17	Fresh cut pineapples	Sodium alginate	The edible coating containing 0.5% and 1% citral nano-emulsion improved physicochemical attributes and reduced microbial growth	[23]

Table 2.
Use of different nano edible coatings of fruits and its findings.

7. Nanoparticle synthesis techniques

There are two general methods of nanoparticle synthesis:
1. Top-down method and 2. Bottom-up method is shown in (**Figure 5**).

7.1 Top-down method

In this method, larger compounds are broken down into nano-scaled materials by using mechanical and chemical forces. Mechanical milling, lithography, electrospinning, etching, sputtering, and laser ablation are the most common top-down approaches to nanoparticle synthesis.

7.1.1 Mechanical milling

Mechanical milling is a method of placing elements in a high-power mill with or without a medium (wet and dry milling) to reduce the particle size of the element. The rolling ball transfers its kinetic energy to the milled elements, resulting in the size reduction of the elements to nanoscale dimensions [29, 35–41]. This energy transfer depends on various factors such as the type of mill, packing of balls, milling speed, type of milling (wet or dry), duration, and milling temperature. This method is more reliable than traditional methods it can be used for both wet and dry materials and large-scale synthesis of nanomaterials due to their inexpensiveness.

7.1.2 Nanolithography

It is a nanofabrication technique for developing nanopatterns with a size range between 1 and 100 nm. It can be divided into two types:

i. Mask lithography includes soft lithography, nanoimprint lithography, and photolithography—In these masks, molds or templates are used in

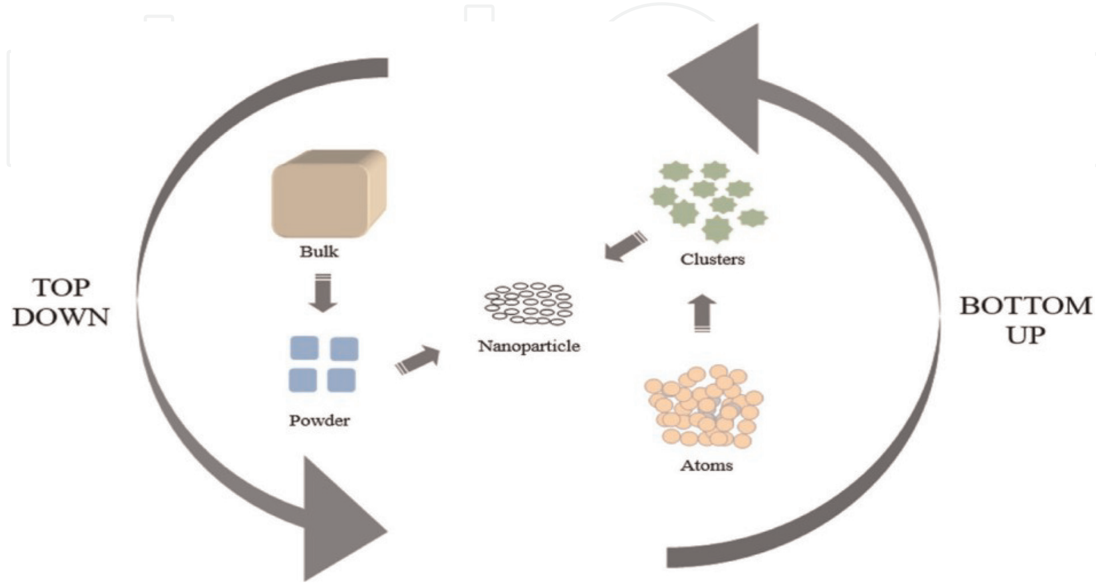

Figure 5.
Schematic diagram of top-down and bottom up method.

nanopattern fabrication, while in maskless lithography nanopatterning is performed without the involvement of masks.

ii. Mask-less lithography including electron beam lithography, focused ion beam lithography, and scanning probe lithography.

7.1.3 Sputtering

The method relies on using a high-energy plasma or gas to generate nanoparticles that travel and strike the surface to form a layer.

This method is based on the use of high-energy plasma or gas to produce nanomaterials that travels and strikes the surface to form the layer. Sputtering is carried out in different ways: DC sputtering, reactive sputtering, RF sputtering, and magnetron sputtering. In this technique, the target surface is bombarded with highly energetic gas ions, resulting in the ejection of surface molecules or small clusters. Sputtering is advantageous because the composition of the deposited nanofilm is the same as the target source.

7.1.4 Laser ablation

This method is a complex process in which a laser beam is used to remove microscopic material from a target source. This is a method used to produce highly refined nanoparticles whose properties such as size and distribution depend on laser focusing parameters, laser pulse parameters, and the medium used. Recently, pulsed laser ablation in liquid is an emerging technique used in the synthesis of monodispersed colloidal nanoparticles without the use of complex chemicals. Laser ablation in liquid is advantageous in reducing the thermal effect on the pattern source, reducing preparation time, and being environmentally friendly.

7.1.5 Electrospinning

This technique is used to develop fibers of metals, ceramics, composites, and polymers of a few microns to the nanoscale range by aligning the fibers, thereby reducing Gibb's free energy. Coaxial electrospinning is used to develop ultrathin fibers up to a length of a few centimeters.

7.1.6 Etching

This method is mainly used in nanotechnology to chemically remove material from a sample surface. The two main types of etching are wet etching (liquid chemicals or etchants are used to remove the layer from the sample surface) and dry etching (etchant gases or plasmas are used to remove the layer from the sample surface). Metal nanoparticles generated after etching the metal surface can be converted into usable material.

7.2 Bottom-up method

The bottom-up method is to synthesize the nanomaterial from atomic or molecular species via various processes. Chemical vapor deposition, sol-gel, solvothermal and hydrothermal methods, and reverse micelle methods are various methods used for nanoparticle preparation.

7.2.1 Chemical vapor deposition (CVD)

It is a widely used bottom-up method to deposit nanomaterials and thin film on a pre-selected substrate. This is a widely used bottom-up method to deposit nanomaterials and thin film on the preselected substrate. In this technique, the chemical reaction takes place between precursor, gas, or vapor and the preselected substrate at high temperatures. This reaction causes the deposition of desired product on the selected surface. This technique provides nanocrystals with high purity, quality, and minimum defects on the substrate but the disadvantage of this technique is its high production cost and the toxicity of gaseous by-products.

7.2.2 Sol-gel method

This method is mainly based on the precursor hydrolysis and polycondensation reactions of the hydrolyzed products resulting in the formation of the polymeric network. The method derives its name from the process by which a liquid precursor in the preparation of nanoparticles is first transformed into a sol and then into a final structural network known as a gel. The sol-gel method is widely used in the preparation of metal oxides such as ZnO, TiO_2, SnO_2, and WO_3 nanoparticles due to their effective control over the shape and size of the nanoparticles.

7.2.3 Solvothermal and hydrothermal method

In this method nanoparticles are obtained by heterogeneous reaction in a solvent in a closed vessel at high temperature and pressure near its critical point. This method is carried out in an aqueous medium, whereas the solvothermal method is carried out in a non-aqueous medium. Solvothermal and hydrothermal methods are very helpful in engineering nanomaterials such as nanosheets, nanorods, nanospheres and nanowires.

7.2.4 Reverse micelle method

In oil-in-water microemulsion, the hydrophilic head region of surfactant molecules orients outwards and hydrophobic tails towards the core trapping the oil droplets while in water-in-oil microemulsion the surfactant inverts its orientation and results in the formation of reverse micelles water droplets. The size of the nanoscale water droplets trapped in the core of reverse micelles, known as the “water-pool”, can be changed by changing the ratio of water to surfactants. The type of surfactant in reverse micelles helps in the variation of nanoparticle properties depending on their size and morphology.

8. Commercially available nanomaterials and companies

S. no	Trade	Company	Type of material	Type of product	Application	Form
1.	Aegis HFX Resin and OXCE Resin	Honeywell International Inc., USA	Nylon 6-nanoclay composite	Beer and flavored alcoholic beverage bottles, PET	O_2 scavenging	Barrier nylon resins

S. no	Trade	Company	Type of material	Type of product	Application	Form
2.	OMAC® Imperm®	Mitsubishi Gas Chemical Inc., Japan	Cerium oxide	Retort product and hot fill of meat and fish products	Oxygen scavenging	Film
3.	Oxy Guard®	Clariant Ltd., Swaziland	Iron oxidation	Fried snacks	Oxygen scavenging	Sachets & Film
4.	ATCOR DE 10S/100 OS/ 200 OS	Emco Packaging Systems, UK		Cooked meat	Oxygen scavenging	Labels
5.	Cryovac® OS Systems	Cryovac Div., Sealed Air Corporation, USA	Polymer oxidation	Strawberries, eggplant	Oxygen scavenging	Tray, Films
6	Ageless®E	Mitsubishi Gas Chemical Inc., Japan	Sodium carbonate/ sodium glycinate	Ham, ready-to-eat meat product	CO_2 Scavenger	Sachets and label
7	UltraZap R Xtenda Pak pads	Paper Pak Industries, Canada	Allyl isothiocyanate (AIT) or scavenging molecular O_2 (Listeria populations)	Meat, poultry, fish, dairy, confectioneries, and baked goods	CO_2 emitter and antimicrobial pad	Tray pads
8	Microspheres	Bernard Technologies, Inc., USA	Chlorine dioxide	Fruits	Microbial Contamination	
9	RipeSense™ Sensor	Ripesense limited, New Zealand	Changing color based on aromatic compounds	Seafood, Oysters	Freshness Indicators	Stickers
10	TimeStrip®	TimeStrip UK Ltd, UK	TTI based on enzyme, lipase, and pH	Dried fruits, cheeses, coffee	Freshness (based on color)	Stickers
11	N-coat	Multifilm Packing	Nanoclay	Fruits Vegetables	Gas barrier	Film
12	Biomaster	Corporation, USA Addmaster Limited, USA	Nanosilver	Fruits Vegetables	Antimicrobial	Bag, Spray
13	Ethysorb ®	Stay Fresh Ltd	PE-Nanoclay composite			
14	Tip Top bread	George Weston Foods	Nanosized self-assembled liquid structure		Ethylene scavenger with nano capsule with tuna fish oil	Bag
15	Carnation Instant food	Carnation Breakfast Essential, Switzerland	Titanium Dioxide (Nanoencapsulation)	Powdered milk-based products	Anticaking	Spray

9. Conclusions

Fruits are a major part of the human diet, supplying essential minerals and vitamins for human health. Acceptability of fruits by consumers depends on quality parameters such as color, texture, absence of decay, and especially the nutritional and health benefit they provide. Edible coatings, driven by their low cost and non-toxic nature, are one of the most well-studied natural polymers and their application has proven promising for fruit preservation. The application of nanoparticles to extend the shelf life of fruits appears most promising in the field of harvest storage. Current materials widely used for coating fruits are zinc oxide, silver, and chitosan nanoparticles because they show good results in preserving post-harvest quality. Another promising area of research is the combination of nanoparticle-enriched edible coatings with the use of current technologies such as low-temperature storage and controlled atmosphere storage. The specifics of the food, the substance to be added, and the intended extension of shelf life all influence the best sub-micron technology to use. As we can see, the ingredients should be non-toxic and be obtained from natural sources, such that the functional nanosystem allows the controlled release of active substances with low solubility. Moreover, the research looked out here, it has become clear that much more work is needed. In particular, we must also understand the behaviour of these materials after consumption, in order to make safe nanosystems that can be used freely in commercial products. Studies on this subject are limited and more information is needed to develop new coating applications with better functionality and higher sensory performance.

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