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Application of Nanochitosan in Food Packaging Sectors

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Abstract

Synthetic polymers generated from petroleum have long dominated the food packaging industry, and, by the year 2050, it is predicted that 500 million tons of plastic would have been used worldwide. Food packaging is designed to protect food products from the environment without compromising their intrinsic properties. In addition to plastics, food packaging has also traditionally included the use of glassware, metals, and paper. However, these traditional materials also have issues with degradability, disposal, and recycling. Due to their total biodegradability in nature, biodegradable materials have the potential to replace conventional polymers. Chitosan works wonders for food preservation. Due to its antibacterial qualities, chitosan is frequently utilized in antimicrobial films, edible protective coatings, dipping, and spraying for food products. Nanoparticles made of chitosan are possible. A variety of foods have been packaged using chitosan films to preserve their quality. Chitosan offers a lot of potential for a variety of applications due to its biodegradability, biocompatibility, antibacterial activity, non-toxicity, and varied chemical and physical properties. The use of nanochitosan in the food packaging industry is described in the current review.

Keywords: Chitosan, food, nanoparticles, nanochitosan, packaging

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8.1 The Evolution of Food Packaging

Glass was first used to store food and drink in Egypt approximately 7000 BC, where food packaging first emerged. China created flexible packaging in the second century BC using mulberry bark treated paper to package food. Wooden barrels were used in ships to transport food and water from 500 to 1500 AD [1]. The British Empire was in full swing with paper production in 1310. The increase in product demand throughout the industrial revolution (1760 to 1840) accelerated the need for high-quality packaging. One of the most often used packaging materials today was invented by Peter Durand in 1810 for iron cans that were covered with tin rather than glass to maintain the quality of food [2].

Sir Malcolm Thornhill created the cardboard box in 1817, although cardboard was first created by the Chinese [3]. Bristol, England, produced the first paper bags used for commerce in 1844 [4]. A paper bag manufacturing machine was then created in 1852. The first carton was inadvertently created by Robert Gair, who was the owner of a paper bag business. Branding, labels, and trademarks were all created for packaging. Smith Brothers formally registered trademarks for their cough medicines in 1866. NABISCO, an American producer of cookies and snacks, created the first branded packaging in 1890 [5]. To deliver their cereals, the Kellogg brothers created the cereal box in 1906 [2]. In 1908, Swiss chemist Jacques E. Brandenberger created cellophane, a material that repels liquids [6]. Aluminum foil containers first appeared on the market in 1910, followed by the aluminum can in 1959 [5].

The first commercially available modern plastics injection molding machine was patented by Eckert and Ziegler in 1926. Polyvinylidene chloride, which was used to package food after World War II, was discovered by Ralph Wiley in 1933. Styrene was first extracted from a balsam tree in 1831, and, after Germany improved the method in 1933 because the results were brittle, Styrofoam became widely available in 1950. The concept of frozen food packing was introduced between 1940 and 1949. Plastic manufacturing sectors started to expand significantly around 1970. Chemical engineer Nathaniel Wyeth received the patent for polyethylene terephthalate bottles in 1973. In 1980, hot foods were packaged in plastic. The Food Standards Act, which had an impact on the food packaging business, was introduced to the House of Commons in 1999 [5, 7, 8].

8.2 Standard Food Packaging

Food packaging is a vital phase in sustaining the safety of food. The primary objectives of food packaging are to avert contamination, minimize spoiling, and improve sensitivity by facilitating the activity of enzymes and curtailing weightiness. In order to facilitate easy food handling and maintain food quality for a longer period of time, conventional packaging for food is used to offer automated support and shield them from external impacts such as germs, light, oxygen, and off-odors [9]. Food spoiling typically happens as a result of microbial contamination, insect stings, endogenous enzyme degradation, or, less frequently, physical and chemical changes.

The majority of the times, microorganisms are what cause the deterioration, and there are numerous ways to stop, delay, or lessen microbiological decomposition [10]. Drying, freezing, fermenting, salting, low-temperature storage, canning, irradiation, changed environment, and the addition of antimicrobial agents are all common methods of food preservation. These methods are used to stop microbial growth [11]. The disadvantages of adopting these conventional materials are their high cost, susceptibility to breakage, and association with other hazardous materials. Each type of packaging requires a variety of materials, including wood, fibers, chemicals, minerals, energy, and water. Heavy metals, particulates, greenhouse gases, and wastewater or sludge containing harmful pollutants are also commonly released during its manufacture [9].

8.3 Types of Food Packaging

When discussing different package types, they are typically broken down into three groups: primary packaging, secondary packaging, and tertiary packaging.

8.3.1 Primary Packaging

This is often referred to as a consumer unit and is the kind of packaging that directly touches the product, for this reason. The major goal of primary packaging is to prevent the final product from contamination while also keeping it confined, preserved, and protected [12].

8.3.2 Secondary Packaging

When referring to a packaging system, secondary packaging refers to the exterior portion of the package that helps to protect the main packaging, and the main product is also known as reusable packaging [13].

8.3.3 Tertiary Packaging

This is also known as bulk or transit packaging. This type of packaging is used to bundle more stock keeping units for transportation from point A to point B. During this phase, products are handled as distribution units. With this kind of packing, large and/or heavy material might also be transported safely and securely. This kind of packing aids in protecting the goods from damage when handling and transporting it [14]. Packaging specifically for food has several different types such as the following:

Aseptic packaging: A paper and aluminum mixture with a polyethylene coating makes up aseptic packaging. It is used to preserve the sterility of products like milk and eggs and beverages with milk as well as liquid eggs.
Trays: The vast majority of this is obvious. Trays can be used to transport beverages, meats, and seeds.
Bags: Much like trays, bags are a common method for packing food. Fruit and bagged snacks are the most well-known options. The food is kept apart from its surroundings, mainly the air, by "bagging."
Boxes: Boxes are used to convey food items because they are the most practical. The most widely used box materials are metal, corrugated fiber board, and wood. Cans, cartons, flexible packaging, pallets, and wrappers are also used for packaging food [5].

8.4 Environmental Impacts of Food Packaging

Problems usually arise throughout the design process of packaging food. Resources like water, petroleum, energy, minerals, wood, textiles, and chemicals are needed to supply all the products and packaging [15]. The designing phase of the production process frequently results in the release of harmful pollutants such wastewater and sludge as well as some airborne particles and greenhouse gases. The role of packaging in preventing and reducing product waste is frequently disregarded, but, in recent years, its significance in waste reduction has started to gain attention [16].

Pollution issues can occasionally be caused by improper package disposal. Even society may perceive garbage to be a problem. More people than ever before are conscious. Others do their living, working, and playing in garbage-filled places. "Source reduction" is the process of creating packaging using less material. Examples of source reduction include lightweight plastic beverage bottles and thin goods like aluminum cans. Environmental factors are crucial to the production of new commodities and should remain so [17].

In the creation of biomimetic materials for nanotechnology, natural polymers are essential. In the field of biomaterials, natural polymers constitute a vital supply. It is anticipated that more cost-effective packaging designs will be recoverable. Throughout its life cycle, sustainable packaging is practical, safe, and economical and satisfies market and health expectations for consumers as well as society [17]. Renewable energy is used in their creation, supply, production, transportation, and recovery. It is made using the best practices and most eco-friendly production processes, and it is meant to have the greatest amount of recyclable or renewable components. It is made of all healthy elements and is physically constructed in accordance with all end of shelf-life scenarios in order to use the most suitable resources and energy efficiently.

Consumer awareness of recycling and "green" packaging is anticipated to increase over the next 10 years, according to the packaging industry. The best or least expensive designs in terms of social, economic, and environmental performance and costs are those that are sustainable. In order to address future human demands, sustainable design must be strategically employed while minimizing environmental risks and design flaws [5].

8.5 Significance of Food Packaging

The primary goal of packaging is to protect and preserve food products from outside elements that could spoil them or otherwise degrade their quality. Depending on preferences and the items being preserved, several materials might be utilized to package food. Most food packaging is made of glass, paper, steel, and plastic [18]. To protect food from contamination, food packaging is essential. The preservation of the product's shelf life is greatly influenced by food packaging. The trademark of the business or the product is often incorporated into food packaging, allowing consumers to recognize and distinguish it from competing goods. Labels on food packaging allow consumers to read information about the ingredients, expiry date, and the nutritional value [19].

8.6 Current Challenges in the Field of Food Packaging and Sustainability

Marketing changes particularly in the extremely vibrant universal food packaging business emphasize geniality, aesthetics, and usability to appeal to customers. Without a thorough and impartial evaluation of their overall environmental benefit, some business practices assert that they are sustainable either in the case of their resources (bio-based) or their shelf life (biodegradable) [20]. The vast majority of these eco-friendly technologies are less eco-friendly than expected, for instance, despite frequent assertions to the contrary, materials vary widely in the amount of renewable resources used during their manufacture and may or may not be readily biodegradable. None of these technologies made any claims to being sustainable for the utilization advantage of reducing food loss [21]. A thriving research and development sector is still necessary to close the critical societal gap of sustainable food consumption. This sector should provide a substantial pool of cutting-edge packaging innovations that will improve the sustainability of packaged foods. A lot of scientific consideration has been paid to the creation of bio-packaging solutions, or packaging made from renewable resources or biodegradable materials. However, overcoming specific technical issues with these bio-packaging materials that are currently preventing their wider market adoption presents a challenge for those working in packaging. These technological issues, particularly unnecessary raw material unpredictability and a too narrow processing window, prevent the scaling up and distribution of these products among package manufacturers when compared to normal oil-based alternatives. Additionally, stakeholders are unable to fully take advantage of the financial, societal, and environmental advantages of these innovations because there are not enough resources to assist users in customizing packaging according to food needs and comprehend the true sustainable development of bio packaging solutions and packaging in general. This is especially true in terms of curtailing food losses [22].

8.7 Current Scenario of Nanotechnology Application in Food Packaging

Numerous industries, including electronics, health, textiles, defense, the food and beverage industry, agriculture, and cosmetics, are investigating the use of nanoparticles. Food safety, processing, packaging, fortification, encapsulation, bioavailability, disease discovery, and other fields of the food sciences are all served by nanotechnology [23]. By improving a number of qualities that effectively convey active materials into biological systems at low prices with reduced environmental impact, such as temperature resistance, improved stability, barrier, flame resistance, recycling, and optical properties, nanotechnology-based food packaging offers many benefits over conventional food packaging resources [24].

8.8 Different Nanoparticles in Food Packaging Applications

8.8.1 Inorganic Nanoparticles in Food Packaging

Nanotechnology can be applied to food packaging to enhance food quality and act as antibacterial agents to prolong the shelf life of foods during storage and distribution. Silver, magnesia, selenium, zinc oxide, gold, copper, and titanium nanoparticles, among others, are glazed on the surfaces. The packaging and processing of food, the manufacture of medical devices, the production of synthetic materials, and water purification are only a few industrial uses for these nano-scale components [25]. Silver nanoparticles are widely employed in the food and healthcare industries, home products, biomedical and environmental applications, as well as other fields due to their specific physiochemical characteristics like thermal, biological, optical, high antimicrobial and electrical capabilities. According to [26], silver has numerous uses in the food system, including anti-inflammatory, antibacterial, anti-cancer, antifungal, anti-angiogenic, and antiviral properties. One of the most popular types of metal oxide nanoparticles used in packaging are zinc oxide nanoparticles due to their, photocatalytic activity, excellent stability and antibacterial action [27]. Compared to other metal oxides, ZnO has a stronger inhibitory effect on bacterial growth such *Listeria monocytogenes E. coli, S. aureus, Salmonella* spp., and *Campylobacter jejuni* [9].

8.8.2 Organic Nanoparticles in Food Packaging

Products made from renewable sources are valued more by consumers in the 21st century. The use of biodegradable materials in packaging and their application to food products to improve security by regulating the exchange of gas and/or moisture transmission is known as "bio-based packaging" [28]. Food is shielded from temperature changes, microbial growth, spoilage, and gas conditions by biodegradable packaging, which creates a hurdle between the materials and the food products. In recent commercial applications, bio-based polymers, which are naturally present in polysaccharides (such as collagen, starch, and chitosan), nucleic acids, and proteins, have become more prevalent [29].

8.8.2.1 *Chitosan*

Chitosan is a naturally occurring linear biopolysaccharide that is produced through alkaline deacetylation of chitin. The most common sources of chitin are the skeletons of crustaceans like lobster, crab, and shrimp. It was also discovered in the skeletons of coral and jellyfish, two types of marine zooplankton [30]. Yeast, mushrooms, and several other fungi also have significant amounts of chitin in their cell walls. Typically, as compared to other fungal classes, zygomycetes have the highest levels of chitin in their cell walls. Due to chitosan's biocompatibility, biodegradability, and safety, research into it has risen over the past few years. It is distinguished by its chelation, adsorption, film-forming, and antibacterial capabilities [31].

8.8.2.2 *Nanochitosan as a Food Packing Material*

Chitosan is a widely used, inexpensive, and a readily available polysaccharide and has disadvantages such as poor mechanical and thermal properties when compared to frequently employed non-biodegradable polymers [32]. Chitosan matrix's functional characteristics will be improved by adding nanoparticles or polymers. Chitosan films are a popular option for packaging materials due to their excellent antibacterial activity against a variety of infections and their capacity to maintain the integrity of food products [33]. Yanjun Tang along with his team, while comparing paper layered with chitosan to blank paper, demonstrated that covering cellulose paper with chitosan/titanium dioxide nanocomposites significantly improved the mechanical attributes and antibacterial activity of the paper. This finding supported the hypothesis that titanium dioxide and chitosan nanoparticles (CSNPs) would improve the coated paper's general qualities, including rip strength, brightness, tensile strength, antibacterial activity, air permeability, and opacity [34].

8.9 Preparation of Chitosan Nanoparticles

8.9.1 Ionic Gelation Method

The interaction of macromolecules with opposing charges can produce CSNPs. Tripolyphosphate (TPP) has frequently been utilized to make CSNPs because it is multivalent, nontoxic, and capable of making use of ionic interactions to form gels. The charge density of TPP and chitosan, which is influenced by the solution's pH, can be used to regulate the interaction [35].

8.9.2 Reverse Micellar Method

This method allows the production of ultrafine polymeric nanoparticles with specific range of sizes. The reverse micelles are produced by dissolving the surfactant in a natural solvent. Chitosan aqueous solution is added while being constantly stirred in order to prevent any turbidity. The aqueous phase is controlled to maintain an optically transparent microemulsion phase throughout the whole combination. Add extra water if larger-sized nanoparticles are to be created [36].

8.9.3 Nano-Based Food Packaging Methods

8.9.3.1 Active Packaging

Active packaging is a creative way to increase or maintain the shelf life of food goods. Furthermore, this will ensure their reliability, excellence, and security [37]. Contrary to normal food packaging, active food packaging acts as a passive barrier and promotes the release of antimicrobials and antioxidants. These will interact with food in a direct way and aid in the removal of particular pollutants like oxygen or water vapor [38]. Systems for packaging food contain antimicrobial ingredients such as bacteriocins, natural extracts, fungicides, enzymes, organic acids, polymers, and nanoparticles. Active packaging made of nanomaterials can interact directly with food or its surroundings to improve protection of the product and serve as an antibacterial agent [39]. Metal and metal oxide (nanocopper oxide, carbon nanotubes, nanotitanium dioxide, nanosilver, and nanomagnesium oxide) are utilized as packaging resources owing to their superior antibacterial properties [40].

8.9.3.2 *Smart Packaging*

Smart packaging is a new nanotechnology designed specifically to track microbiological, chemical, or biochemical changes in food or the environment [41]. To ensure the food's quality and safety, it also reacts to changes in the food's internal and external factors as they occur inside the food or in its surroundings. A variety of nanomaterials are utilized to enhance the functionality of packaging for various sensing events, such as freshness indicators, time and integrity indicators, radiofrequency identification, and temperature indicators [42].

Nanosensors can identify, quantify, and detect decaying materials, proteins that cause allergies, and pathogenic microbes; they can also be used to detect flavors or colors [9]. Nano-biosensors have proven effective for real-time monitoring of food quality, plummeting the need to resolve shelf life, and also retorting to some chemical markers, infections, and toxins present in the food [43].

8.9.3.3 *Intelligent Packaging*

The focus of intelligent packaging is to track the entire food supply chain, whereby a user can learn more about the product by scanning the code embedded inside the goods, QR code, or barcode, with a smartphone or any other type of scanner. It can also check the quality of food by printing thermochromic ink on packaging, which changes color as the temperature changes [9].

8.9.4 Food Application of Chitosan

8.9.4.1 *Edible Coating or Film*

The use of chitosan (CS) as well as its byproducts has extended the shelf life of a variety of foods. Therefore, the antimicrobial/antioxidant capabilities of food packaging materials can be improved by the capability of CSNPs to control the release of diverse bioactive constituents. Electrospray was used to create the gelatin film that included tea polyphenol-loaded CSNPs [18]. In combination with modified atmospheric packaging, fillets of beluga fish (aka Huso huso) coated with edible coatings containing CSNPs laden with fennel essential oils displayed decreased levels of peroxide, total volatile nitrogen, and thio barbituric acid. Additionally, CSNP-coated fillets showed reduced psychotropic and mesophilic *Pseudomonas* spp. and lactic acid bacteria populations than CSNP-uncoated fillets [44].

In a different study, *Carangoides coeruleopinnatus* fillets coated with chitosan and CSNPs at 4°C for 12 days were compared for qualitative attributes. Compared to fillets coated with Chitosan, fillets coated with nanoparticles more effectively slowed down lipid oxidation and the growth of microbes. Recently, it was discovered that soy-bean oil packaged in gelatin film with 30% (w/v) tea polyphenol-loaded CSNPs had the lowest peroxide value on day 14 [18]. In addition to extending the shelf life of different foods, CSNPs also enhanced the physicochemical and mechanical characteristics of films. Bulk CS and CSNPs were incorporated to create tara gum films. In comparison to CS added film, films supplemented with CSNPs displayed higher water solubility, mechanical strength, antibacterial activity, and lower hydrophilicity. Another study found a 42% increase in the solubility of the composite coating of CS-ZnO-NPs.

8.9.4.2 *Bread*

Bread often has a short shelf life due to microbial development and staling [45]. Staling is a term used to describe the gradual degradation of bread's flavor and texture over time. Multiple factors contribute to the complex phenomena of bread staling [46]. There are documented uses of chitosan to prolong the shelf life of bread by suspending starch retrogradation and/or by preventing microbiological progression. The impact of chitosan (493 kDa) coating on the shelf life of baguette was examined by [47]. After molding, the surface of the dough was painted with 0.5%, 1.0%, or 1.5% chitosan in 1.0% acetic acid using a brush. During storage at 25°C for 36 h, baguette coated with chitosan, particularly with 1% chitosan, showed less hardness, weight loss, and retrogradation compared to the control. Chitosan's ability to act as a moisture barrier is probably to blame for this [48]. The chitosan coating may provide a hindrance to prevent moisture from transferring through the surface of the bread, hence averting weight loss, delaying hardness, and retrogradation.

8.9.4.3 *Egg*

Egg storage problems include interior quality decline, weight loss, and microbiological contamination, to name just a few [49]. According to Akarca *et al.* [50], egg quality fluctuations in the yolk and albumen, as well as weight loss, are controlled by the moisture and carbon dioxide that flow from the albumen through the shell. It has been established that chitosan is capable of creating films, which can be utilized as edible coatings [51]. The shelf life of eggs may, therefore, be improved by the protective barrier that chitosan film may provide against gas transfer and moisture from the albumen through the shell.

8.9.4.4 *Vegetables and Fruits*

The primary causes of fruit post-harvest losses include mechanical damage, careless handling, incorrect temperature and relative humidity control, and hygiene problems. Applying edible coatings to the surface of these perishable goods and then storing them in the cold are two potential methods for extending their storageability [52]. Edible coatings could be utilized as a protecting barrier to lower transpiration and respiration rates through the surface of fruits, delay microbiological development, change in color, and enhance the textural feature of fruits [53]. By altering the endogenous O_2, CO_2, and ethylene levels of fruits, semipermeable film has typically been proven to delay fruit ripening [54]. Due to the fact that chitosan films preferentially permit more O_2 than CO_2 to pass through than CO_2, The interior environment may change due to the chitosan covering without causing anaerobic respiration [55]. Therefore, the fungistatic and internal atmosphere-modifying properties of chitosan covering have the prospect to extend fruit storage time and prevent deterioration.

8.9.4.5 *Juice*

Clarifying agents, such as tannins, gelatin, silica sol, bentonite, and polyvinylpyrrolidone, are frequently used in the processing of clarified fruit juices. It has been demonstrated that the partially positive charge on chitosan gives it the ability to bind acids and is useful for assisting in the separation of colloidal and isolated constituent parts from food processing wastes. These characteristics make chitosan a desirable processing service in the preparation of fruit juice [56].

8.9.4.6 *Meat*

Meat and meat products are very prone to lipid oxidation, which causes a rancid or reheated flavor to emerge very quickly. Chitosan has antioxidant and antibacterial properties, which may prevent the growth of spoilage microorganisms and delay the oxidation of lipids in meat during storage. Multiple studies have noted the beneficial effect of chitosan addition on the storage stability of meat. Youn *et al.* [57] reported that, by lowering the overall bacterial cell counts and preventing lipid oxidation during storage at 4°C for 10 days, spiced beef treated with 1.0% of chitosan (120 kDa, DD = 85%) and dissolved in 0.3% of lactic acid was noticeably improved [58].

Chitosan's ability to prevent microbial growth in chilled comminuted pork products was shown by [59] and the effect of chitosan depended on concentration. Chitosan glutamate additions of 0.3% and 0.6% decreased total viable counts, lactic acid bacteria, yeasts, and molds, by 3-log CFU/g at 4°C for 18 days in comparison to the control. According to [60] adding 3% chitosan glutamate (DD = 86%) to turkey or ground beef may lower the likelihood that *Clostridium perfringens* spores will germinate and spread during harsh cooling in 12, 15, or 18 h from 54.4 to 7.2°C [61].

8.9.4.7 *Milk*

There have been several attempts to assess the viability of utilizing chitosan to enhance the shelf life and quality of milk. The impact of water-soluble chitosan having three distinct molecular weights (0.2–3 kDa, 3–10 kDa, and 10–30 kDa) on the sensory and physicochemical characteristics of milk was investigated by [62]. Chitosan concentrations and molecular weights (0.5%, 1.0%, and 1.5%) enhanced the consistency of milk that had chitosan added to it. No protein coagulation occurred during the 15 s of sterilization at 73°C for milk containing 0.5% and 1.0% chitosan, regardless of the molecular weight. Milk's sensory quality of taste, color, and flavor were severely impacted by adding 0.5% water-soluble chitosan [63], which resulted in 0.2- to 3-kDa, 3- to 10-kDa, and 10- to 30-kDa chitosan browning in color and chemical off-flavor, as well as a pungent taste. However, there were no differences in the sensory quality of the chitosan-infused coffee milk compared to the control; this may be because the coffee had a masking effect.

8.9.4.8 *Noodles*

Roy *et al.* (2023) explored at how incorporating chitosan (Mw = 37 kDa) affected the quality and shelf life of wet noodles. Wheat flour was mixed with chitosan that had been dissolved in 1% acetic acid at concentrations of 0.0%, 0.17%, 0.35%, 0.52%, and 0.7%. Regardless of chitosan concentrations, wet noodles' moisture content reduced somewhat over the course of 6 days at 18°C regardless of how long they were stored for. When chitosan concentration was increased from 0% to 0.70%, the amount of viable cells decreased during the course of 6 days at room temperature. Wet noodles with chitosan concentrations of 0.17%, 0.35%, 0.52%, and 0.70% had shelf lives that were 1, 2, 3, and 3 days longer than those of the control, respectively. In comparison to other wet-noodle samples, the wet noodle with 0.35% chitosan had the best sensory qualities. In a different study, wet noodles with chitosan (Mw = 37 kDa, 0.1% or 0.5% dissolved in 1% lactic acid) could be preserved for up to 80 days as opposed to just 7 days for the control [64]. As a result of its antibacterial action, these experiments amply proved that chitosan may be employed as a successful preservative in wet noodles.

8.9.4.9 *Rice Cake*

White rice cake's shelf life was significantly increased after chitosan treatment [65]. Prior to vacuum sealing, these authors coated a white rice cake with alcohol (95%) lactic acid (1%), 1% and/or 2% chitosan (Mw = 37 kDa, dissolved in 1% lactic acid) and left it in for 10 s. The total microbial counts for the untreated control, alcohol-treated, and 1% lactic acid-treated white rice cakes all went over the initial degeneration threshold level of 1×10^6 CFU/g after 6, 27, and 20 days of storage at 4°C. On the other hand, even after 76 days of storage, the white rice cake treated with 1% and 2% chitosan had total microbial counts (3.3×10^5 and 1.4×10^5 CFU/g, respectively) that were lower than the required limit. However, it was discovered that the sensory suitability of the white rice cakes was adversely impacted by the dipping procedure, regardless of the type of solution used. Hadidi et al. [66] also showed how adding chitosan to rice cakes could extend their shelf life. Rice cake was infused with water-soluble chitosan at concentrations of 0%, 0.05%, 0.1%, 0.3%, and 0.50%. As chitosan level increased during storage for 4 weeks at 5°C, the total number of microbes decreased. After 4 weeks of storage, the overall microbial counts of the chitosan-containing rice cakes were 2-log cycles less than that of the control (8.2×10^4 CFU/g).

8.9.4.10 *Sausage*

In Korea, sodium nitrite is typically employed as a curing agent to develop flavor and color for preservation effects. However, nitrosoamine, a potent toxin harmful to humans, is produced when nitrite combines with amine in meat. Numerous studies have looked into the use of chitosan as a curing agent in sausage [67, 68], and it was found that the presence of chitosan could minimize or completely eliminate the usage of sodium nitrite without compromising the preservation action or color development.

8.9.4.11 *Seafoods and Seafood Products*

The fish muscle contains a lot of metal ions and hematin molecules, which accelerate the lipid oxidation of unsaturated fatty acids and is a major cause of quality degradation in seafood products [69]. In addition, autolysis, microbial contamination and development, and protein functional loss all have a noteworthy influence on the quality of seafood [70].

8.9.4.12 *Soybean Curd (Tofu)*

Due to its high moisture level and rich vitamin content, freshly prepared soybean curd has an exceptionally short shelf life, typically only lasting 1 to 2 days even under professional refrigeration [71, 72]. Water soluble chitosan was used as a coagulant or as an immersion solution for the purpose of extending the shelf life of tofu. The shelf life of the tofu was increased by over 7 days at 4°C when combined with the coagulant $CaCl_2$ and compared to that prepared with just $CaCl_2$ [73]. Similar to this, Li and Yu [74] found that using a 0.5% water soluble chitosan solution as an immersion solution increased its shelf life by over 7 days at 4°C. The antibacterial properties of chitosan are what gave tofu an extended shelf life.

8.9.4.13 *Vinegar*

Chitosan's ability to clarify persimmon vinegar was studied by Kang *et al.* [75]. Chitosan of 150 kDa and 37 kDa was dissolved in 1% acetic acid, and concentrations of 100 mg, 200 mg, 300 mg, 400 mg, and 500 mg were added to vinegar. The coagulated solids increased as the chitosan concentrations increased, whereas the contents of browning, turbidity, soluble solids, and tannins decreased. The decrease in turbidity and soluble solids varied a little depending on the molecular weight of chitosan. No matter the molecular weight of the chitosan used, 400 mg/L of it was necessary to produce the best results in clarifying persimmon vinegar. The overall acceptability was lower and this was the outcome of the taste's pronounced astringency when chitosan concentrations (37 kDa and 150 kDa) were increased to 500 mg/L. It was discovered that the quality of persimmon vinegar that had undergone the aforementioned chitosan treatment was more consistent after storage at room temperature for 6 months in contrast to the control (no chitosan treatment) [74].

8.9.5 Other Applications of Chitosan Nanoparticles

8.9.5.1 *Medicine and Pharmaceuticals*

Chitosan NPs have been thoroughly investigated by researchers for use in pharmaceutics and medicine. The substance is biocompatible and enables the chain grafting of the active components and the drug encapsulation. Their use is extremely advantageous in biological imaging, drug administration, diagnosis, and cancer treatment due to notable properties such limiting enzymatic degradation of medicines and minimizing injury to non-targeted tissue or cells [75]. Additionally, it has been claimed that the slow biodegradation of CSNPs ensures continuous and controlled drug release [76]. The stable NPs that convey drugs using different methods in the human body are made possible by the substantially positive surface charge. Two major methods—nanoencapsulation and chemical modification—are typically used to create drug-loaded CSNP variants. According to Rajitha *et al.* [77], nanoencapsulation is the process of creating a nanostructure with an absorbed medication on its surface or inside the nanoparticle.

8.9.5.2 *Wastewater Treatment*

The investigation of bio-based substitutes has been driven by the dearth of an affordable, environmentally friendly, and functional sorbent to replace activated carbon, which is widely used. These nanoparticles are remarkable for the elimination of a variety of contaminants such dyes, heavy metals, and herbicides, because chitosan contains functional amino and hydroxyl groups. Additionally, due to their larger surface area, nanoparticles may have a higher capability than commonly employed micro-sized sorbents [77]. Water treatment has often been advised for derivatives of CSNP with improved magnetic and electrostatic characteristics. Amination is done by grafting substances like hexanediamine, ethylenediamine, or diethylenetriamine, whose NH_2 groups are in charge of the pollutants' electrostatic interactions [78]. Chitosan NPs have been utilized in conjunction with magnetic characteristics to enhance the removal of heavy metals and dangerous dyes.

8.10 Advantages of Nanotechnology in Food Packaging

8.10.1 Nanoparticles Protect Food Quality Decay Caused by Chemicals

The many chemical constituents of food and the environment interact, degrading the quality of the food as a result. Several nanomaterials have been shown in numerous studies to have the capacity to regulate unfavorable responses in food mediums. Nanotechnology can improve the functionality of food by removing chemical contaminants or increasing the availability of nutrients at the nanoscale. Numerous benefits of nano-encapsulating chemicals include continuous administration of various active compounds, pH-triggered release, and shelf-life extension [9]. Edible nano-coatings are used as gas and moisture barriers, as well as to add color, enzymes, flavor, antibacterial protection, anti-browning properties, and antioxidants and to extend the shelf life of manufactured goods in vegetables, fruits, meat, bakery goods, cheese, and fast-food [9]. Few nanomaterials are utilized directly as antibrowning agents, although ZnO nanoparticles were used as coated active packaging to extend the shelf life of fresh-cut apples [53].

8.10.2 Nanoparticles for Enhancing Physical Properties

The physical characteristics of both food and packaging materials will improve with the use of nanoparticles in food packaging. Common applications for nanocomposites include coating and packaging. To make polymer matrices lighter, with lower gas permeability and improved thermal properties, SiO_2, carbon nanotubes, clay and silicate nanoplatelets, starch nanocrystals, graphene, cellulose-based nanofibers, CSNPs, and other inorganic nanoparticles are included [79].

8.10.3 Nanoparticles for the Detection of Food Borne Pathogens

Foodborne pathogens and chemicals that cause food products to degrade and become contaminated are being detected with nano-biosensors [80]. As a nano-biosensing technology, surface enhanced raman scattering can swiftly and precisely identify harmful bacteria. Surface enhanced raman scattering, which uses materials such as plasmonic gold, silver nanocolloids, graphene oxide, silver nanoparticles, carbon nanotubes, and magnetic beads to boost Raman signals, has been used to identify bacteria. *E. coli*, *Salmonella* spp., *S. aureus*, and *S. epidermidis* are only a few of the foodborne pathogens that can be detected using nanoparticles [9].

8.10.4 Nanoparticles for Inhibiting Biofilm Formation

A biofilm is a complexly organized, densely filled mass of bacteria that has the ability to adhere to a variety of surfaces and build a polymeric extracellular matrix that is often made up of polysaccharides, proteins, and DNA, rendering it impenetrable [81]. The circulating bacteria adhere to the surface and cause buildup, biofouling, and biocorrosion issues in the food industry. Concentrations of silver nanoparticles as low as 0.2 ppm can enhance bacterial catabolism and inhibit the formation of several types of bacterial biofilms. This nanoparticles approach has been applied in many industrial settings due to the fact that it reduces the overall density of microbial biofilm without compromising cell proliferation [9].

8.10.5 Eco-Friendly

Several supplies used in contemporary food storing are practically non-biodegradable and pose a huge threat to the environment worldwide. A key strategy for extending the quality and shelf life of food while decreasing packaging waste and even food loss is the use of edible and biodegradable films [20]. However, issues related to performance (such as fragile nature, weak gas or moisture-proofing, and the production process, incorporating low-temperature heat distortion), and cost limit the adoption of edible and degradable polymers. As a biodegradable decomposer, starch, for instance, has drawn a lot of attention.

8.11 Conclusion

Technology has made packaging an essential component of contemporary living. The modern lifestyles of people, their circumstances, their hectic work schedules, their access to and competency in the kitchen, as well as many other variables, have significantly contributed to the rising demand for pre-packaged foods, which has, in turn, raised the entire output of food packaging. The food packaging industry also experiences change as a result of how swiftly technology alters our lives, makes them more active, and impacts each sector in a unique way. The majority of synthetic plastic materials used in the present food packaging system are derived from petroleum. However, this not only places an excessive amount of pressure on the use of non-renewable fossil resources, but also the non-degradability of these polymers makes it extremely difficult to dispose of municipal waste.

Search for alternatives, especially biodegradable ones, to address each of these issues at once. Nanotechnology-based food packaging offers many benefits over conventional food packaging materials by improving a number of properties, including flame resistance, temperature, resistance, barrier, recycling and optical properties, increased durability, processability due to lower viscosity, and successfully delivering active materials into the biological systems, at minimal costs with lessen environmental issue.

Chitin and chitosan, which have emerged as value-added products from the waste generated during the production of seafood, have been the subject of extensive investigation in recent years. Chitosan stands out in comparison to other biopolymeric counterparts because of its many attributes, including antibacterial activity, chelation property, film formation, and reasonable mechanical strength, to show enormous potential as a food packaging material. Chitosan films have so far demonstrated their capacity to increase food shelf life while preserving food quality. Additionally, on a lab scale, the biopolymer has been employed to extend the shelf life of freshly produced fruit, poultry, vegetables, and dairy items without impairing their sensory qualities. Therefore, it is certain that chitosan will eventually displace non-biodegradable polymers and establish itself as a natural substitute.

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