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The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(5): 3361-3365

www.thepharmajournal.com
Received: 02-02-2023
Accepted: 15-03-2023

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Recent advancement of smart nanopackaging enhancing the shelf life

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Abstract
Food spoilage and deterioration have become major global concerns as a result of poor packing technologies. The evolution of food packaging continues in tandem with advances in technology and science, as well as consumer demand. Carbon nanotubes, starch nanocrystals, clay, and silicate nanoplatelets are examples of nanoparticles used in food packaging that have superior barrier and antibacterial qualities. Contrarily, modern polymer nanocomposites, particularly those made of natural biopolymer-layered silicate, show noticeably better packing characteristics because to their dispersion in nanoscale sizes. The active food packaging industry has huge potential for using such biopolymer-based nanocomposite packaging materials with bio-functional characteristics. The use of nanotechnology makes it easier to preserve food, improve nutrition, and deliver micronutrients and bioactive ingredients safely. This paper discusses recent developments in nanotechnology, including its intriguing opportunities and difficulties in 6food processing industry. We address the synthesis of nanomaterials and their application to food industries with regulatory and risk assessment concerns. Although there is great potential for nanotechnology and it has advanced applications in the food sector, detailed study in the nanofood system is still needed. This review focuses on the existing knowledge, recent advancement, concerns, application of nanotechnology, emulsions based methods, LED preservation technology in food packaging sector.

Keywords: Smart nanopackaging enhancing, food packaging, LED

Introduction
The global food industry is under increasing pressure to meet consumer demand for safe, healthy, and fresh food, with updated strict food safety regulations (Wang & Zhang, 2021) [49]. Consumer demand for healthy, fresh and safe food is increasing, and the global food industry is intended to adhere to stricter, more recent food safety regulations (Wang & Zhang, 2021) [49]. Packaging is an important component of the food industry, and the primary drawback of food packaging material is its permeability (Riaz *et al*., 2021) [39]. As a rule, there are no packaging materials currently in use that provide total resistance to water vapors, food and atmospheric gases as well as other packaging materials (Riaz *et al*., 2021) [39]. Nanomaterials exhibit particular and enhanced physicochemical features in comparison to macroscale materials. Nanoparticles have a high surface-to-volume ratio and surface activity due to their small size. When combined with appropriate polymers, nanomaterials improve properties, including electrical conductivity, mechanical strength, thermal stability, and others (Riaz *et al*., 2021) [39]. There are three major types of nanopackaging. (i) Better packaging: These packets contain NPs and are temperature and humidity resistant. (ii) Active packaging: Preservatives, such as inorganic NPs, that can interact directly with food and give antibacterial qualities. (iii) Intelligent/smart packaging: Packaging that is designed to detect biochemical or microbiological changes as well as pathogens in food. Antimicrobial nanomaterials in food packaging chemicals are generally comprised of antibacterial inorganic nanoparticles (NPs). Many studies have demonstrated the biological efficacy of inorganic NPs with high antibacterial activity at low doses (Anwar & Ahari, 2021) [1]. Nanotechnology is used to insert the active ingredient the carrier component can interact with external elements and/or internal in a food packaging material to produce actions that prolong the duration of storage, enhance quality of food, and promote product safety. However, in the case of intelligent packaging systems, incorporation inside the food container is done based on the nanotechnology indicator/sensor(s), which allows them to interact with both internal (food materials and headspace) and external (environmental aspects).

Materials and Methodology

Methods for extending the shelf life of products based on nanotechnology

In general physical, chemical, and biological preservation techniques are included in the traditional techniques for preserving vegetables and fruits (Kadam & Singh, 2021) [12]. Although each preservation strategy places a distinct emphasis on different characteristics, they all manage three essential parameters that are critical for quality preservation: managing the senescence process, which is mostly performed via the control of respirations; regulating microorganisms, which is mostly accomplished through the regulating internal water evaporation and the management of spoilage bacteria, which is mostly performed through the regulation of relative humidity (Rachtanapun *et al*., 2021) [37].

Novel hydrocolloids in nanotechnology

In regulated and technical applications, hydrocolloids are a heterogeneous class of long-chain polymers (such as proteins or polysaccharides) that are used to stabilize and/or thicken formulations (Kalpana & Priyadarshini, 2019) [14]. Polysaccharides are increasingly being used as building blocks in the development of nano-sized functional food delivery systems due to their unique multi-functional groups and physicochemical qualities such as stable structure, low toxicity, biocompatibility and low cost (Rachtanapun *et al*., 2021) [37]. Natural polysaccharides can be found in a range of foods, including animal products (CH, chitin and glycosaminoglycan), Natural polysaccharides and microbial (xanthan gum, dextran, and gellan gum), plant (e.g., cellulose, pectin, and starch) origins include plant (e.g., cellulose, and pectin), animal (chitin, and glycosaminoglycan) and algal origins (e.g., agar, carrageenan and alginate) (Donsı & Marchese, 2015) [7].

Edible coatings based on nanoemulsions on fresh-cut fruits

A heterogeneous system known as a nanoemulsion is made up of at least two immiscible liquids that are dispersed to one another in tiny droplets between the sizes of 10 and 1000 nm (Wan *et al*., 2021) [51]. A typical nanoemulsion is made up of an aqueous phase, an oil phase and an emulsifier. Water is the major constituent of the aqueous phase, but it can also be developed by other polar molecules such like co-solvents (polyols and simple alcohols), carbohydrates, minerals, proteins acids, bases and acids (Zhang & Chen, 2021). Nanoemulsions can be used to deliver important functional compounds such as nutraceuticals, antioxidants, antimicrobials, flavours drugs. Because of their nanosized droplets (10-1000 nm), nanoemulsions have several advantages (Kalpana & Priyadarshini, 2019) [14].

Table 1: Examples of the use of nanomaterials for the preservation of vegetables and fruits.

Fruits/Vegetables	Nano particle	Impact	References
Apple	Nano-ZnO	Apples packed with nanotechnology lasted 6 days longer than samples packed to regular polyvinyl chloride film.	(Li *et al*. 2011) [21]
Chinese yam	Nano-CaCO3	The ripening process could be greatly delayed by new nano-packaging by regulating microbial development, reducing browning, and preserving the action of beneficial compounds.	(Luo *et al*. 2015) [24]
Kiwifruit (Actinidia sp.)	Nano-ZnO	In comparison to the control treatment, the kiwifruit product with nano Zinc Oxide coating had a reduced ethylene concentration, water loss, and texture preservation.	(Meng & Zhang, 2014) [27]
Carrot	Nano-Zno	Nano-ZnO clearly reduced extended the shelf life to almost 40 days while decreasing the overall amount of colonies that formed during storage.	(Luo *et al*. 2015) [24]
Cucumber	Chitosan	Cucumbers coated with chitosan NPs may have higher antioxidant activity and longer storage times.	(Mohammadi & Hashemi, 2016) [30]
Green soy bean	Nano-ZnO	Nano-ZnO has the potential to significantly suppress the development of common microorganisms such as coliforms, bacteria, moulds, and yeast.	(Yu & Zang, 2015) [54]
Pomegranate	Nano-ZnO	A coating made of nanoscales reduce overall weight loss, yeast growth, and mould.	(Saba and Amini 2017) [45]
Strawberry	Nano-ZnO	It is utilized as a food preservative and as an edible covering because of its antibacterial characteristics.	(Yu & Zang, 2015) [54]
Banana	Nano-ZnO	It is an edible coating used for preservation.	(Mohammadi & Hashemi, 2016) [30]
Fresh cut pineapples	Nano-Sodium alginate	The edible coating containing 0.5% and 1%citral nano-emulsion improved physicochemical attributes and reduced microbial growth	(Meng & Zhang, 2014) [27]
Blueberries	Chitosan/nano-TiO_2	They may keep the nutritional composition while maintaining quality at zero degrees.	(Luo *et al*. 2015) [24]
Blackberry	Chitosan	Showed best antifungal effect over racemosus	(Luo *et al*. 2015) [24]
Kinnow	Silver nanoparticles (AgNPs)	At a 1:1 ratio, silver nanoparticles were added to a coating emulsion base together with either CMC or guar gum.	(Li *et al*. 2011) [21]
Melon	Chitosan/nano-silica/nisin	Their combination was discovered to be ideal, which increased shelf life by retaining color, Vit-C, and Peroxidase Activity for up to days of storage.	(Luo *et al*. 2015) [24]
Fresh Fruit (Redberry) Arbutus unedo	Sodium alginate	In terms of preservation, AL 1% + Eug 0.20% produced the best results.	(Mohammadi & Hashemi, 2016) [30]

LED -based preservation technology

A light emitting diode (LED) is a semiconductor device that, when an electric current flows through it, emits light with a very narrow emission spectrum. LEDs provide various advantages over traditional light sources, including decreased energy usage and excellent durability, both of which are crucial for commercial applications. LEDs also have the advantage of being easily integrated into existing systems because of their compact form (Cazón & Antoniewska,2021) [4]. The production of phytochemicals that affect fruit quality, as well as the assessment of mature plant growth metrics, were studied under three different LED light wavelengths (blue, red, and blue plus red) during culture (Cazón & Vázquez, 2020) [3]. Cultivation occurred in two locations: a growth chamber (GC) with LED lights as the primary light source, and a plastic greenhouse (PG) with supplemental LED light in addition to ambient light. It was revealed that plants cultivated in the GC under LED lights had more chlorophyll than plants growing in the PG (Priyadarshi & Sauraj, 2018) [34].

Conclusion

The paper describes the most recent developments in vegetable and fruit shelf-life extension techniques using nanotechnology, including enhanced barrier qualities (carbon nanotubes, starch nano crystals, clay and silicate nanoplatelets), antioxidant film, antibacterial and antimicrobial properties which include chitosan nano particles, silver particles, titanium oxide. Antimicrobial packaging play an important role in the reduction of contamination of pathogen and improving the quality and shelf life of food. Nanomaterials offer active and intelligent packaging methods, as well as improving the mechanical and barrier properties in food packaging. To meet the requirements for successful food packaging, advanced nanomaterial augmented polymers will help to intensify the benefits of existing polymers for the purpose of good, with better safety, in addition to addressing environmental concerns. Moreover, mass production of nano-packaging materials is a complex process that necessitates high-level technological input, as well as the advancement of processing techniques and the upgrading of latest processing technology.

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