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APPLICATIONS OF NANOTECHNOLOGY IN FOOD PROCESSING AND PACKAGING

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ABSTRACT

Nanotechnology is a rising revolution with enormous potential in a variety of professions, including medicine and mechanics, also the food industry, and the definition of this technology is the study of creating and processing substances at nanoscales, where the characteristics vary from those seen at bigger scales such as atomic and molecular levels. In this article, we gathered information about nanoscience from previous reviews and studies. Lately, nanoparticle delivery devices have been discovered where they transport functional substances, food ingredients and additives to specific locations. Although nanotechnology is a promising prospect with advanced applications varying from increasing the mechanical strength of packaging materials to delivering functional substances to food, more efforts are needed to conduct a detailed investigation in the nanofood system and raise consumer understanding. This review aims to shed light on the important applications of nanotechnology in food processing and food packaging including improved, active, and smart packaging.

INTRODUCTION

Nanotechnology is an emerging and quickly growing topic that has made significant achievements in various scientific fields. The manufacture of nanomaterials (with a size less than 100 nanometers) with new characteristics through the manipulation and restriction of matter at the Nano scale level is generally accepted as the definition of nanotechnology (Wahab *et al.*, 2021).

Consumer's worry about food quality is motivating academics and researchers to look for strategies to increase food quality while limiting the impact on the product's nutrient value. Recently, food industry has grown its needs for the nanoparticles due to its content of non-harmful various basic elements, and these materials have shown strong stability in thermal condition and in high pressure (Lugani *et al.*, 2021). These unique and incomparable characteristics of nanoscale substances are due to their high surface - to - volume ratio when comparing to the same materials at the microscale (Grumezescu and Holban, 2018). Institutions, academics, and corporations are developing new nanotechnology-related technologies, methodologies, and products (Nile *et al.*, 2020).

Nanotechnology, like other sectors, is playing an essential role in the food industry as a promising system for tackling challenges through novel solutions related to food safety, food processing, food packaging (Fig. 1), and functional foods (Grumezescu and Holban, 2018; Chaudhry *et al*., 2017).

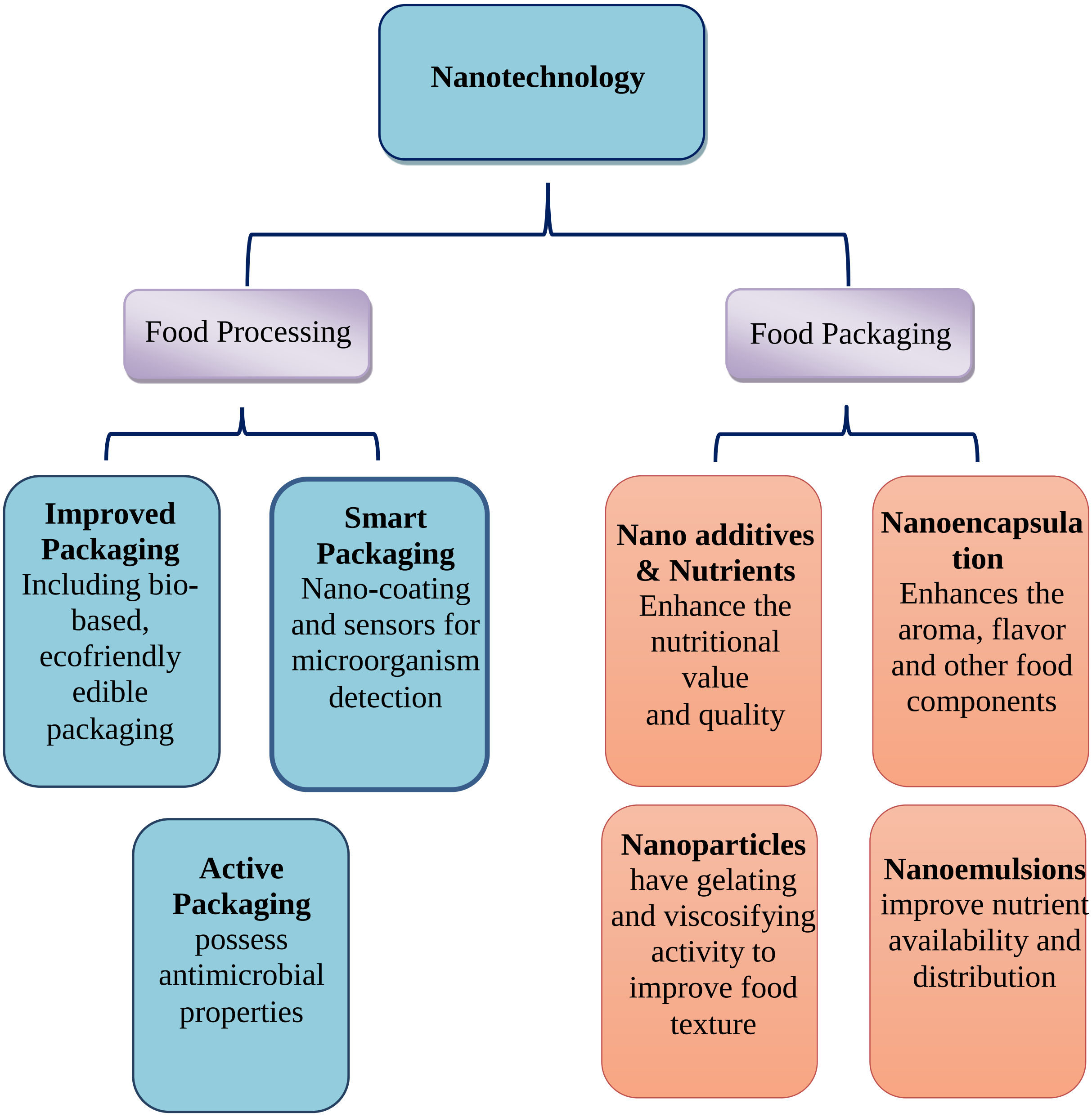

Fig. 1: The implications of nanotechnology on several food industry sectors.

Nanosensors are another food-related application, and have acquired popularity in food manufacturing and packaging industries due to their reliability, speed of detection, and low price (Nile *et al*., 2020).

Nanoparticle classification

Nanoparticles are classed as organic or inorganic based on their materials. Organic nanomaterials consist of polymeric and lipid-based particles (Yu *et al*., 2018). Polymeric are nanoparticles that typically range in size from twenty to one thousand nanometers. It is made up of a polymer combination (e.g., chitosan, alginic acid, and albumin) that forms a matrix that is enclosed by surfactants (e.g., lecithin) (Sahoo *et al*., 2021). Liposomes are lipid-bilayered concentric carrier systems composed of an aqueous core surrounding by surfactant either organic or artificial phospholipids (Fathi et al., 2012). The inorganic nanomaterials are composed of nanoparticles with metallic structure, such as Quantum dots (QDs) (Yu *et al*., 2018), silver, iron, silicon and zinc, in addition to their oxides (He and Hwang, 2016). Quantum dots are semiconductor nanocrystals with narrow, very specific, steady emission spectra, and their sizes range from 2nm to 10nm (Mukherjee and Tiwari, 2020). Organic nanoparticles have a lower toxicity than inorganic particles because they are more easily metabolized in the digestive system (Clements and Xiao, 2017). Table 1 shows some of the various Nanoparticles' applications and their impact on the food industry.

Table (1): Nanoparticles applications in the food industry.

Food applications	Nanomaterials	Positive effects	References
Nano-delivery system	Liposome	Delivery of Vitamin C and B carotene	Liu *et al.*, (2020)
	Albumin Nanoparticles	Delivery of Curcumin	Motevalli *et al.*, (2019)
Preservation and Packing of Food	Zinc Oxide Sensor	UV rays are blocked, which results in less discoloration and flavor loss in food.	Neethirajan and Jayas, (2007)
Pathogen Detection	Soybean Polysaccharide	confirmed antibacterial efficacy towards *Listeria monocytogenes* and *B. subtilis.*	Luo *et al.*, (2020)
	Sulfur nanoparticles (SNP)	demonstrated antibacterial efficacy towards *Coliform bacteria* and *Listeria monocytogenes*	Shankar and Rhim, (2018)
Food quality inspection	Silver and Gold Nanoparticle	Tracking down of food decay.	Paul *et al.*, (2017)
Nutritional supplement	Selenium Nanoparticles	Enhance human health by adding antibacterial and anticancer characteristics.	Skalickova *et al.*, (2017)

Nanotechnology in food processing

To maintain market leadership in food manufacturing sector, it is necessary to apply the latest technologies to manufacture tasty, fresh foods, one of which is nanotechnology (Samal, 2017). Food processing techniques include the use of nanomaterials in their composition, such as nutrients, forming agents, raising viscosity, nutrient delivery, fortification by minerals and vitamins, and Nano-encapsulation of flavors (Pradhan *et al.*, 2015).

Nutrients

Nutritional components like bioactive materials are used in healthy foods to provide additional advantages to the consumer. Nanomaterials are also applied in functional foods as a bio-stimulant (Chau *et al*., 2007). Bioactive compounds can be collected from different sources like carrots which gives Beta carotene, tomatoes give lycopene, oats give beta glucan and salmon oil gives omega-3 (Neethirajan and Jayas, 2011). Minimizing the size of bioactive particles may increase their availability, conductivity, and solubility, and hence its biological activity. The vital activity of bioactive substances is determined by its capacity to pass through the intestinal membranes and into the blood (Shegokar and Muller, 2010).

The ability to produce nutrients at the nanoscale will improve food durability at all stages of processing, which would consider an important way to maximize nutrient's content and consequently customer benefit (Cushen *et al*., 2012).

Nano-encapsulated active substances, such as vitamins and fatty acids, are already commercially available for use in the preparation and conservation of drinks, meat, cheese, and other foods. For instance, commercial sausage and processed meat production demands the incorporation of several additives to accelerate up the manufacturing process, maintain color, and enhance taste. Aquanova, a German company, has created a nanotechnology oriented carrier system employing (30 nm) micelles to encapsulate active compounds such as vitamins C and E and fatty acids, which could be utilized as preservatives (Alfadul and Elneshwy, 2010)

Nano-encapsulation

Nanocapsules are defined as the method of enclosing nanoparticles of solid, liquid, or gaseous materials (the core) inside a secondary substance (the shell) to generate Nanocapsules. The active substance (medicines, vitamins, etc.) is found in the pulp, whereas the peel insulates and protects the pulp from its surroundings. The pulp (active ingredient) is always released by diffusion or in reaction to a signal, like PH or the action of a specific enzyme, allowing the ingredients to reach the target location in specific time and in orderly arrangement (Desai and Park, 2005; Jyothi *et al*., 2010).

A better functional food can be produced using nanocapsules because they prevent active chemicals from reacting with food components and allowing for precise control over their release, all while preserving them from moisture, heat, chemical degradation, and biological deterioration during the manufacturing process. (Ubbink and Kruger, 2006; Weiss *et al*., 2006).

Nano-encapsulation strategies for the creation of nanoparticles can be classified as top-down and bottom-up approaches. The top-down technique incorporates the use of precise instruments that allow for size reduction and structure formation for the desired application of the nanomaterials being generated. particales are created using the bottom-up technique by the self-assembly and self-association of molecules, which are influenced by a variety of factors such as pH, temperature, and ionic power (Tahir *et al.*, 2021).

Nanoemulsions

If one of the two immiscible liquids are scattered as droplets, the resultant solution is known as an emulsion. The nano-emulsion consists of oil droplets ranging in size from 10 to 100 nanometers that are dispersed in a continuous aqueous stage, each surrounded by surfactant molecules. (Silva *et al*., 2011). Nano-emulsifiers are employed in the manufacturing of food such as salad dressings, customized drinks, sweeteners, as well as other treated foods (Garti, 2008).

Nano-emulsions are efficient to a large selection of microorganisms, like Gram-negative pathogens, and can be utilized to decontaminate the surfaces of food processing plants and to reduce surface contamination on poultry skin, and nanoemulsion treatment has prevented *Salmonella typhimurium* colony growth (Sekhon, 2010). Sanguansri and other (2006), reported that nanoemulsions made from nonionic surfactants, soybean oil, and tributyl phosphate prevent bacterial activity.

Nanotechnology applications in food packaging

Packaging is important because it extends the life-span of food by preventing decay, germs, and nutritional loss. The utilization of polymer composites that allow active, improved, and intelligent packaging is one of the future developments of this technology (Aigbogun *et al*., 2017).

Studies and invention in packaging textiles, include films, carbon nanotubes and waxy nano-coatings for specific food products, has been increasingly important lately. Nanoparticles may aid the creation of novel packaging substances with better qualities to improve life-span. (Chaudhary *et al*., 2008; Mihindukulasuriya and Lim, 2014). Aside from antibacterial properties, Nanoparticles can be used to carry antioxidants, flavors, and other substances to increase the lifespan, even if the food product has been unpacking for a while (Cha *et al*., 2004; LaCoste *et al*., 2005).

For functional additives to food packaging, inorganic nanoparticles are used. There are three types of packaging wit nanotechnology: Improved, Active, and Intelligent packaging (Duncan, 2011; Silvestre *et al*., 2011).

Improved packaging

Nanoparticles incorporation into the packaging materials enhances the encapsulating characteristics of the polymer, such as encapsulation barrier qualities, polymer flexibility, and temperature and humidity resistance (Duncan, 2011; Silvestre *et al*., 2011). Several nanocomposites embedded in polymers have already been created to be used in the manufacturing of different beverages and oils, with nanoparticles such as clay nanoparticles reaching 5% (w/w). These nanoparticles increase encapsulation barrier characteristics, like decreasing oxygen and carbon dioxide by 90% (Primoˇziˇc *et al*., 2021).

Active packaging

It considers a new method for increasing the life-span of food by reducing microbiological deterioration, moisture gain, oxidation, and over ageing. To enhance the qualities of the packing polymer, several components like oxygen scavengers, antioxidants, and antibacterial agents are added to the packaging materials or in the empty space of the packaging (Yousuf *et al*., 2018). Antimicrobial drugs prevent bacterial development by either damaging their cytoskeleton or interfering with their metabolic system (Primoˇziˇc *et al*., 2021). Controlled release packaging is one application of active packaging in which nanoparticles can also be employed as delivery devices, assisting in transferring functional additives like minerals and vitamins into food (Graveland-Bikkera and de Kruifa, 2006).

Intelligent/smart packaging

The usage of nano-devices in the polymer matrix helps observe the circumstances of packed food. These containers are designed to determine chemical or microbiological changes in foods by detecting certain bacteria that thrive in food or gases released by food decay. Smart packaging has been improved for as a tracking system to prevent adulteration of food products. (Silvestre *et al*., 2011).

CONCLUSIONS AND RECOMMENDATIONS

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Nanotechnology advancements have benefited the food industry and proved its applicability in food manufacturing, packaging, and safety. Its applications help improve flavor and texture making them tastier, to decrease fat content, or to encapsulate nutrients, like vitamins, and making them healthier. Furthermore, by using appropriate nanoparticles, the mechanical characteristics, advanced barrier, and thermal qualities of the material might be enhanced to increase the life-span. Nanoparticles also demonstrate high antibacterial activity when employed in food packaging materials. Intelligent packaging, combined with nanosensors, could give visual data about the food state inside the packaging. Food spoils or contents' nutritive value can be seen using Sensors. Finally, further investigation is necessary to examine the risks of nanomaterials and their long-term harmful effects on humans, as well as other undesirable outcomes such as allergies, food intolerance, and inadvertent contamination of food due to direct contact with the packaging nanomaterial.

تطبيقات النانوتكنولوجي في معالجة وتعبئة الأغذية

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الخلاصة

تعد تقنية النانو ثورة صاعدة ذات إمكانات هائلة في مجالات عديد منها الميكانيك والطب، بما في ذلك صناعة الأغذية، حيث انها تمثل دراسة تكوين المواد ومعالجتها على المقاييس النانوية، وتختلف هذه الخصائص عن تلك الموجودة في المقاييس الأكبر مثل المستويات الذرية والجزيئية. تتطرق هذه المراجعة الى تطورات تقنية النانو في معالجة الأغذية، والتركيز على تطورات تقنية النانو ونهجها في تغليف المواد الغذائية بما في ذلك التعبئة والتغليف المحسنة والنشطة والذكية. أثبتت العديد من الدراسات قدرة تقنية النانو على التعرف على مسببات الأمراض في التعبئة والتغليف وتحسين النكهة وجودة اللون، وفي الآونة الأخيرة، تم اكتشاف أجهزة توصيل الجسيمات النانوية التى تنقل المواد الوظيفية والمكونات الغذائية والإضافات إلى مواقع محددة. على الرغم من أن تقنية النانو لها أفآق واعده مع تطبيقات متقدمة في صناعة الأغذية تتراوح من زيادة القوة الميكانيكية

لمواد التعبئة والتغليف إلى توصيل المواد الوظيفية للغذاء، إلا أن هناك حاجة إلى مزيد من الجهود لإجراء بحث مكثف في نظام الاغذية المصنعة نانويا وزيادة وعي المستهلك العام.

الكلمات الدالة: حفظ الأغذية، سلامة الاغذية، الجسيمات النانوية، المغذيات.

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