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The Importance and Use of Nano Packing in Food Industry

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ABSTRACT:

Nanotechnology, the science of very small materials, is poised to have a big impact in food and beverage packaging. Due to very large aspect ratios, a relatively low level of nanoparticle is sufficient to change the properties of packaging materials without significant changes in density, transparency and processing characteristics. The addition of certain nanoparticles into shaped objects and films has been shown to render them light, fire-resistant and stronger in terms of mechanical and thermal performance, as well as less permeable to gases. New packaging solutions will focus more on food safety by controlling microbial growth, delaying oxidation, improving tamper visibility, and convenience. Three basic categories of nanotechnology applications and functionalities appear to be in development for food packaging: enhancement of plastic materials' barriers; incorporation of active components that can deliver functional attributes beyond those of conventional active packaging; and sensing and signaling of relevant information. The applications of nanotechnology in the food and beverage sector are only now emerging, but these are predicted to grow rapidly in the coming years.

Keywords: Food packaging, Nutrition, Nanoparticles, Shelflife, Nanoscience, Nanotechnology, Food Processing

Introduction

In order to satisfy the increasing demand for food production which will reach the consumers in a safe condition, and at the same time meet their expectations in terms of quality, the packaging industry has been continually developing and striving to implement new technologies such as nanotechnology. By application of nanoparticles and other nanomaterials of various organic and inorganic compounds in standard packaging materials, the quality of packaging such as polymer-flexibility, gas barrier properties, temperature/moisture/ light stability, thermal and chemical stability and biodegradability has been improved. Moreover, the use of polymer nanotechnology enables constant monitoring of packaging conditions, providing in that way the preservation of fresh food, extension of shelf life of foods and improvement of products quality and safety. The application of nanopackaging on the market is slowed due to lack of data on potential risk to human health and the impact on the environment, as well as to lack of legal regulations. These shortcomings affect public perception of nanotechnology, but when these problems are overcome application of nanopackaging promises to become an irreplaceable part of industrial production of food.

The Food Industry is a global network that provides food items to people worldwide. Various activities are performed in this industry and they include food production, processing, conversion, distribution, preservation and packaging, among other operations. Similarly, since most food products are lost in these procedures, proper storage and distribution of processed foods is essential. Chemical-based preservatives and traditional packaging methods in the food business not only impair the nutritional content of foods and cause health problems, but also cost the company much money.

In the food sector, Nanotechnology (NT) has opened up new paths and benefits for developing novel tastes and sensations, new textures in food components, encapsulation of food additives and nutritional value enhancement. Nano-foods are foods that have improved flavour and bioavailability, owing to the use of nanotechnology in their manufacture, processing, packaging and security. The benefits of Nanotechnology (NT) in various industrial operations connected to the food sector are described in this chapter.

Nanotechnology in Food Processing

Initially, most agricultural products are not consumed as direct food items; instead, they are treated qualitatively before being used, a process known as food processing. Food processing removes germs and extends the shelf life of foods to turn them into edible, safe and valuable food items, among other benefits. Food processing (FP) has three main steps: primary, secondary and tertiary. Agricultural materials are transformed into edible foods in basic food processing. Secondary FP refers to the day-to-day process of making foods from raw materials.

In contrast, tertiary FP refers to the commercial manufacture of edible goods, usually processed foods. Nanotechnology application in food processing has shown considerable promise; it offers various benefits in FP, including improved flavour, physiological availability, shelf-life and uniformity. By changing particle size and distribution in food items, the application of Nanotechnology in FP may also be used to mask bitter flavour, disagreeable order and size. Nano-encapsulation based on nanocapsules is a potential approach in nano-food technology that has gotten much interest. Nano-encapsulation can transport food components to a specific location and keep active molecules there for longer. Nanoparticles have better characteristics for usage, as nanocapsules have been developed, due to the recent breakthroughs in nanoencapsulation. Nanocapsules offer various qualities that can benefit the food business, including the ability to disguise smells and biological degradations. Many bioactive dietary components, such as polyphenols, vitamins and other secondary metabolites are susceptible to acidity and enzymatic activity in the stomach and duodenum. These substances are encapsulated to ensure they are absorbed properly and quickly in the digestive system. Furthermore, the bioactive compound's nanoencapsulation extends the shelf life of food products. Edible nanocoatings on food items not only provide resistance to humidity, heat and gas exchange by extending the shelf life of the food, but also preserve the food's natural colour and flavour.

Nanotechnology in Food Packaging and Security

In terms of food safety, food packaging is another crucial stage in the food sector. Strength, biodegradability and permeability to moisture and other gases are all attributes that must be present in good packing material.

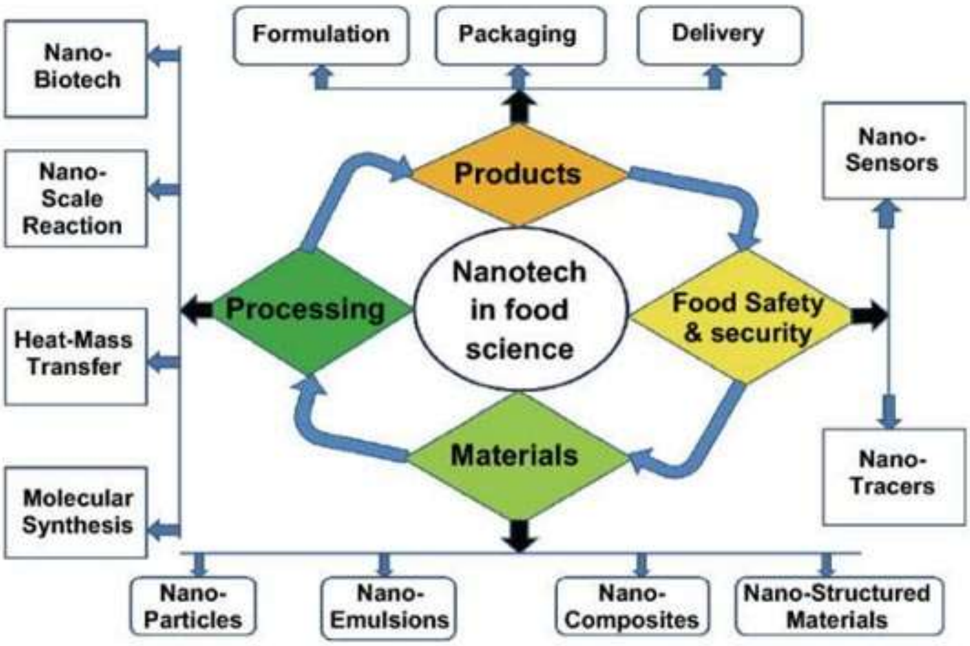

Fig. 1: *Nanotechnology in food science and technology (Nile. S.H.. Baskar. V.. Selvaraj. D. et al. Nanotechnologies in Food Science: Applications, Recent Trends, and Future Perspectives. Nano-MicroLett. 12, 45 (2020) (https://doi.org/10.1007/s40820-020-0383-9)*

Antimicrobial qualities, superior mechanical strength, reduced weight and the ability to warn customers about the food's safety status are all advantages of Nanotechnology (NT-applied) packaging materials over standard packaging materials. The most basic type of nano food packaging is enhanced packaging, which uses nanoparticles (NPS) to create resistance to temperature, humidity and gas. On the other hand, NPS operates as an antibacterial substance in active food packaging and interacts directly with the food products. Pathogens are inactivated by active food packaging, which extends shelf life and improves food safety. Intelligent food packaging is another sort of nano-packaging meant to detect biochemical changes and pathogen growth in food. This packaging keeps track of the packaged food's quality and sees if germs are present.

Active Food Packaging Systems

Food-borne infections cause serious health concerns worldwide and are a significant financial burden on society. Active nanocomposites, utilized to make biodegradable packaging materials are not only environmentally benign, but also extend the shelf life of food. Functional food packaging solutions also control moisture, absorb oxygen, carbon dioxide, ethylene and water vapour and serve as a thermal insulator. Active packaging systems created with NT are primarily used to preserve food products like meat products, which require cold storage and distribution conditions. By establishing essential vacuum pressure by passing gases such as oxygen and carbon dioxide, sophisticated packaging materials extend the shelf life and protect the quality of meat foods, eliminating the requirement for air conditioning for storing and distributing meat food items.

Smart Food Packaging Systems

Innovative packaging solutions combat food packaging environmental conditions by detecting unwanted contaminations and the presence of microorganisms within the food products. Based on the internal molecular exterior environment of packed food products, smart food packaging advises customers about the safety of packed food items. Microbiological and chemical testing is frequently insufficient to determine the safety of packaged foods. Smart food packaging, however, can detect rotting and harmful bacteria in packaged food items almost quickly. Moisture sensors, freshness indicators, temperature indicators, chemical toxin indicators, oxygen, carbon dioxide and pathogen indicators are all included in intelligent food packaging systems. Natural dyes found in vegetables and fruits, such as carotene, curcumin and anthocyanins, as well as curcumin, chlorophyll and carotene, may be employed as a sensor in packaging materials using NPS technology. Nanosensors are nanoparticle-based devices frequently used to detect food pollutants and pathogens in food.

Nanocoating on packaging surfaces

One of the most promising uses of nanotechnology in the food business is nanocoating on food packaging surfaces. The presence of O2 inside packed food items provides ideal circumstances for microorganisms to flourish, jeopardizing the quality and shelf-life of the food. Magnesium oxide (MgO) and polylactic acid (PLA) biopolymer mixed nanocomposites were utilized to create packaging materials that efficiently protect food from the biofilm. The revolutionary prospect of using nanotechnology as a nanocoating on food products to shield them from deterioration has been demonstrated by a recently created coating with zero-valent iron particles having the capacity to scavenge oxygen in food packaging.

Protection from chemical deterioration of foods

Various vital components in food products can react chemically with external conditions, causing food to deteriorate. Less reactive nanomaterials are essential in preventing undesired chemical reactions and carrying antioxidants. Vitamins and flavonoids can be supplied directly in an acidic environment such as the stomach utilizing nano-encapsulation of bioactive substance using polymeric nanoparticles, a novel notion for chemical degradation prevention. The nutritional elements are functional and the core materials are released in a regulated manner in the desired place, thanks to nano-encapsulation. As a result, nano-encapsulated chemicals offer several benefits, including continuous delivery of various active substances, increased shelf life, stability and pH-triggered controlled release.

Improvement of physical properties of food and packaging materials

Various nanomaterials have been created to prevent the texture and other physical qualities of food and packaging materials from deteriorating. Polymer nanocomposite materials containing layered silicate have been made for packaging with several desirable features, including excellent flammability and UV protection. Many NPs have recently been synthesized that can preserve and enhance the physical look of food products, such as colour. TiO_2 NPs have now been authorized as food colouring additives. Aside from TiO_2 NPs, SiO_2 NPs are frequently employed as anticaking materials to keep powdered products flowing and as a carrier of scent in food. Various nanoparticles have been created to prevent food and packaging materials' texture and other physical qualities.

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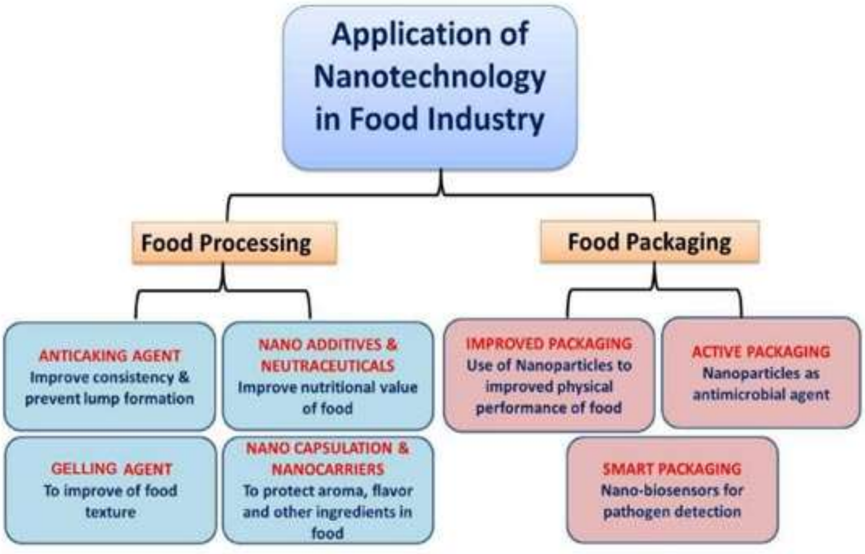

Fig. 2: Application of nanotechnology in Food Industry (Singh, T., Shukla, S., Kumar, P., Wahla, V., Bajpai, V. K., & Rather, I. A. (2017). Application of nanotechnology in food science: perception and overview. Frontiers in microbiology, 8, 1501)

Removal of Heavy Metals

Pb, Zn, Cu, Hg and other heavy metals may enter foods in various ways, including in agriculture polluted water. Because heavy metals may collect and travel up and down the food chain, they may represent a serious hazard to human health. They have the potential to harm the kidneys, lungs, central nervous system and a variety of other essential organs. In addition to posing a direct threat to human health, they are also harmful to the environment, since bacteria cannot decompose them and once they enter the ecosystem, they stay there for years, spreading throughout the food chain. These metals have been linked to cancer and various other life-threatening illnesses. The elimination of these health-hazardous metals from food has piqued the interest of scientists and health professionals worldwide.

Prevention from biofilm formation

Biofilm is defined as a densely packed clump of bacteria that adheres to any surface and forms a polymeric extracellular matrix challenging to break free. Van Der Waals forces can build a biofilm by tightly adhering free-floating microorganisms to the surface of food products. AgNPs boost bacterial metabolism and have been demonstrated to inhibit the production of biofilms. NiONPs with diameters of 10-20nm has been proposed as antibacterial, anti-tumour and anti-biofilm inhibitors. According to researchers, the chlorhexidine conjugated gold nanoparticles have excellent inhibitory effects against the production of biofilm by Klebsiella pneumonia.

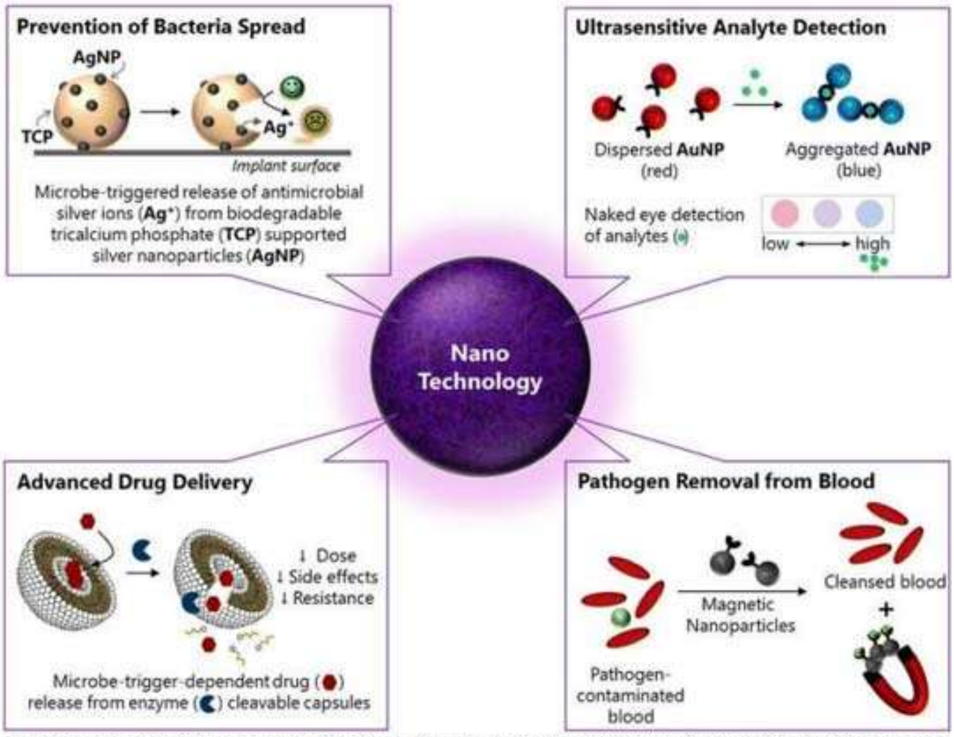

Fig. 3: *Examples of nanotechnology-based solutions for detection and prevention of microbial infections. (I.K. Herrmann, 2015 How nanotechnology-enabled concepts could contribute to the prevention, diagnosis and therapy of bacterial infections. Crit. Care 19, 239)*

Nanosensors in the Food Industry

Food safety and security are critical issues in the food sector because they directly impact human health and economic prosperity. Many ancient and traditional ways have been found and used in the food business to occasionally identify and monitor hazardous microorganisms and poisonous compounds. On the other hand, these technologies are slow, expensive and ineffective in detecting dangerous bacteria and undesirable items in food. As a result, the food sector needs a sophisticated and user-friendly instrument/sensor that can quickly, accurately and affordably identify infections and harmful compounds in food. In recent years, nanotechnology has demonstrated much promise in detecting viruses and toxic compounds in food, which helps to enhance human health and the agricultural and food industries' economic growth. A sensor is a device that detects or measures changes in the environment in the form of physical and chemical qualities for a specific system. Nanosensors have significant advantages in terms of sensitivity and specificity over regular sensors and they may be used successfully in the food business. Nanosensors have been functionalized with chemical and biological molecules like antibodies to enhance their ability to detect changes in physical and chemical processes. Due to the high surface-to-volume ratio of nanoparticles utilized in manufacturing, they have high detection sensitivity. One-dimensional nanomaterials such as nanotubes and nanowires have shown considerable promise in creating nanosensors. Nanosensors have several potential uses in various fields, including medical, agriculture, food technology and research. Nanosensors can accurately detect pressure, temperature, volume, concentration, gravity, velocity and electric and magnetic signals, among other physical changes. Electrochemical, piezoelectric and spectroscopic nanosensors that employ molecularly imprinted polymer fall into three groups. The electrochemical characteristics of sensing materials, such as charge, conductivity, capacitance and electric potential are used to create electrochemical sensors.

Detection of Toxins, Pesticides and Chemicals in Food

Aflatoxin, polytoxins, botulinum and mycotoxin are examples of food toxin elements that contaminate food products and cause a variety of ailments when they enter human bodies. Researchers have created a number of nanosensors based on nanocomposite materials that are highly effective and sensitive in detecting these harmful chemicals. Aflatoxins were detected using gold nanoparticles functionalized with anti-aflatoxins. Palytoxins present in mussel flesh is detected using carbon nanotubes based on electrochemical luminescence sensors. Farmers in the agricultural sector are utilizing excessive pesticides and fertilizers to increase crop and fruit output, which is harmful to human health. Gold nanoparticles have been functionalized as calorimetric and fluorometric sensors to detect organophosphate and carbamate pesticides in food.

Nanosensors for food freshness

The materials used in packaged foods are prone to degradation over time and at different temperatures. The presence of disproportional amounts of oxygen and humidity degrades the freshness of packaged food products and shortens their shelf life. As a result, oxygen oxidizes the food's nutritional vial molecules, favouring the growth of bacteria and other infections. The colour, size and spectral response of nanoparticles have been used to produce time-temperature-based food freshener indicators. A hybrid nanocomposite of methylene blue and titanium dioxide has been produced for use as an oxygen sensor.

Nanoparticles incorporated into plastic packaging make food more valuable by extending shelf life

They noted that a modest one to three-day increase in shelf life is enough to offset the energy investment required to add the nanoparticles. The results suggest that using nano-packaging can lessen the net environmental demand of the overall food supply chain, with the most drastic impact reduction corresponding to the preservation of meat and other expensive, resource-exhaustive commodities.

So could we extend nano packaging technology to materials like metal and glass? The short answer is that it likely wouldn't be a smart use of resources. Aluminum cans and glass bottles are already impervious to gases, so the role of nanoparticles to slow oxygen diffusion is redundant. Likewise, these classic preservation methods have relied on their ability to protect from microbial growth by forming an impermeable barrier between the perishable food and outside contamination with the help of heat and pressure. Metal and glass are recyclable and reliable but expensive to produce and ship. Plastic has its own drawbacks but fills a void in the packaging industry by being flexible, lightweight, and relatively inexpensive. It can also be combined with paper in composite materials such that nano packaging could have potential for applications like milk cartons and instant oatmeal packets.

The investigators note that more research needs to be done to verify the safety of nanoparticles – both to people and the environment – before the use of nano-packaging becomes widespread. In a push for commercialization, several types of nanoparticles for food packaging applications have already been patented.

However, the research on how safe these particles are is lagging behind the commercial implementation. The FDA has made non-binding recommendations on the use of nano packaging but more robust scientific safety studies are crucial as nanomaterials claim increasing presence in the packaging market. One could also argue that continuing to use plastic packaging at all has a negative environmental impact, calling for additional scientific scrutiny over whether nano packaging is indeed a long term solution. The dilemma of how to address both plastic pollution and food waste as we move forward as a society is indeed nuanced and riddled with competing motivations.

Future Remarks and Conclusion:

Nanotechnology has demonstrated the potential to play an essential role in the food sector, including packaging, storage, distribution and improving the quality and flavour of food products. However, data obtained till date on the potential applications of nanotechnology in the food industry indicates that, despite having revolutionized the food industry through nanoprocessing & nanopackaging of various food stuffs and ensuring the safety and quality of food products through the use of advanced nanosensors, the use of NT in the food industry is still in its early stages. Bioactive component nanoencapsulation allows for tailored administration of active chemicals, while extending shelf life of food products.

Nanocoating on food surfaces not only helps to avoid chemical and microbiological degradation, but also helps to restore nutritional content. Heavy metal reduction/removal from food and drinks using NT is an innovative and cost-effective food quality assurance approach. Despite the revolutionary nature of NT applications in the food business, various difficulties must be thoroughly investigated. Other key considerations are the hazardous qualities of specific nanoparticles and their limited availability. The chapter concludes that, if properly controlled and regulated, nanotechnology has the potential to play a critical role in the food business, enhancing food processing, product quality and safety, all of which will benefit people.

Applications in this area already support development of improved tastes, color, flavor, texture and consistency of foodstuffs, increased absorption and bioavailability of nutrients and health supplements, new food packaging materials with improved mechanical, barrier and antimicrobial properties, and nano-sensors for traceability and monitoring the condition of food during transport and storage. The rapid use of nano-based packaging in a wide range of consumer products has also raised a number of safety, environmental, ethical, policy and regulatory issues. The main concerns stem from the lack of knowledge with regard to the interactions of nano-sized materials at the molecular or physiological levels and their potential effects and impacts on consumer health and the environment. Research and development in the field of active and intelligent packaging materials is very dynamic and develops in step with the search for environmentally friendly packaging solutions. In this context, the design of tailor-made packaging is a real challenge, and it implies the use of reverse engineering approaches based on food requirements and not just on the availability of packaging materials any longer.

Packaging plays an important role in extending product lifespan. It provides protection from contaminants, such as moisture and bacteria, and blocks out environmental stressors, like light and oxygen. For example, canning has been a staple in food preservation for generations, allowing people to enjoy their summer harvests late into the winter months. As plastic packaging technology came onto the scene, it again increased the value of food substantially by making it last longer before spoiling, while reducing the high costs associated with the shipping and handling of heavy packaging materials such as glass. This then translated into increased profits for retailers and better food safety for consumers.

Recently, scientists have shown that microscopic pieces of a second material, such as clay or silver, can be integrated into plastic packaging films to enhance their antimicrobial or oxygen-blocking effects even more. These miniature team players are called NANOPARTICLES because their size is on the nanometer scale. For reference, there are 25.4 million nanometers in one inch! Nanoparticles can be made by milling and grinding materials down to ultra-fine sizes or by building them up synthetically from atoms and molecules. Both manufacturing methods require an energy investment since the particles need to be created and then integrated into the main packaging material through additional processing steps.

Researchers at Purdue University were curious to know if the increase in food shelf life resulting from the incorporation of nanoparticles into plastic packaging would offset the added energy and resources required to add the particles into the package design. They compared the relative energy costs of plastic packages with and without nanoparticles over their entire lifespan from creation to being thrown in the trash. Important to note is that they assumed the addition of the nanoparticles would not require any more or less plastic than the non-supplemented plastic packaging it would be replacing; essentially, an increase or decrease of plastic use was not considered in this analysis. Although NANO PACKAGING is already used in limited capacities for food packaging applications, with poly-nano composite materials available commercially through companies like AdvanSix, this was the first life cycle analysis of plastic food packaging enhanced with nanoparticles.

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