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# Applications of Nanotechnology in Food Industry

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**Abstract**

New innovations and discoveries of nanomaterials in food industry is an emerging field in Nanotechnology. It has transformed number of scientific and industrial areas in food sectors. Nanotechnology is playing vital role in food industries and has wide applications which is provides the scientist to invent new things in field of food industries. Different applications of nanotechnology has increased the need of nanoparticles in different fields of food microbiology, food science, food processing, food packaging, food safety, increase in shelf-life of food, detection of food borne pathogens and functional food development. This review summarizes the types of nanoparticles in food industries and potential of nanoparticles to provide consumers a safe food. We have also discussed on risk assessment of nanotechnology and its regulation in food industry. Different applications of nanoparticles in food industry are explained in brief which makes a path to nanotechnology, an emerging field in food industry.

**Keywords-** Nanotechnology; Food industry; Types of nanoparticles; Role of nanotechnology; Risk assessments; Regulations of nanotechnology in food industries.

## Introduction

From past decades, Nanotechnology is considered to be an attractive technology as it has revolutionized the food industries [1]. This technology is based on the nanometre scale that deals with size of atoms, molecules and macromolecules that ranges from approximately from 1-100 nm. This material has novel properties like colour, strength, toxicity, solubility, thermodynamics, etc [2]. The immense



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development in nanotechnology is attracting more investors to invest in this technology. There is wide range of scope and opportunities for development of material, system and structures with novel properties which is useful in field of agriculture, food, medicines, etc.

Now-a-days, consumer is more concern about the food quality and health benefits. Due to this, many researchers are engaged into finding new ways that can enhance the food quality without disturbing the nutritional values of the food. The demands of the nanoparticles are increasing day by day due to its non-toxic and stable property at different temperature and pressure. Nanotechnology is playing vital role in food industry by offering complete food solutions from manufacturing, processing and packaging. It is observed that nanomaterials not only bring great difference in food quality but also plays significant role in health benefits that food delivers. There is increase in research in field of nanotechnology by finding novel techniques, methods, products that have direct application in food industry. Nanotechnology has diverse applications in food industries like nanostructures can be used as food additives, antimicrobial agents, anti-caking agents, carriers for smart delivery of nutrients, increasing mechanical and durability of packaging materials, etc [3,4].

Food nanotechnology has its history from Pasteurization process developed by Pasteur which kills the spoilage bacteria. This was the first step in food processing and quality of food. Later on, the invention of carbon nanotubes called 'Buckyball fullerene' which is of size 1nm led to the new era of nanoscience. In this review, we have mentioned the different types of nanoparticles, its synthesis and the wide range of application in food industry.

## Types of Nanoparticles in Food industry

Nanoparticles are classified into various types on bases of size, morphology, physical and chemical properties. Mainly nanoparticles are divided into two types: Organic and Inorganic particles.

**a) Inorganic nanoparticles-** In food industry, many inorganic materials such as iron oxide, zinc oxide and silver are commonly observed. These are amorphous or crystalline in nature at ambient temperature which leads to different surface characteristics and size[5,6]. **Silver nanoparticles**

Silver (Ag) nanoparticles have wide application in food industry. It is used as antimicrobial agent in foods packaging. It is used in the packaging container which protects the food from damage of food pathogen It also increases the shell life of the food Along with the advantages there are some disadvantages by using silver particles like it causes lymphocyte infiltration, discharge of mucus granules, pigmentation of villi and abnormal mucus composition of the intestine [7,8].

## Zinc oxide nanoparticles

Zinc oxide (ZnO) can be used in supplementation and functional foods as it is found that it is an essential trace element needed to maintain in human body. It can be used in food packaging as an antimicrobial agent to prevent food spoilage by microorganisms. In recent studies it was found that zinc oxide nanoparticles has ability to penetrate into human cells which



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generates ROS that has ability to damage cellular components which results into cytotoxicity [9,10].

**Iron oxide nanoparticles**

Iron oxide particles can be used as colouring agent or source of bioavailable iron. It comes in different forms like size, shape which may change its toxicity. It also has ability to produce ROS which leads to damage of cellular components.

**Organic nanoparticles**- They are basically made up of lipids, carbohydrates, proteins. The morphology of these substances tends to be liquid, semi-solid or solid at ambient conditions. They are generally spherical in shape and can vary in their behaviour in different areas of human gastrointestinal tract. They can aggregate, dissolve, precipitate or can also be digested in mouth, stomach, small intestine depending upon the structure and composition of the nanoparticle. It is found that organic nanoparticles are safer due to less toxicity and easy digestion of particles in human body as compared to inorganic nanoparticle.

**Lipid nanoparticles**

The major advantage of using these particles is to increase the bioavailability and functional performance of encapsulated components. It increases the physical stability of the product . Food contains different lipid nanoparticles which vary in composition, structure and dimensions. The lipid nanoparticles rapidly hydrolyze in gastrointestinal tract because of their high specific surface area .

**Protein nanoparticles**

These nanoparticles are found in food in form of casein in milk and are widely consumed by humans thus has a less potential toxicity. In recent studies, protein nanoparticles are being developed to form delivery systems to protect, deliver bioactive agents, encapsulate such as flavours, colour, minerals, vitamins and nutrients. There are different structures of protein which decides the gastrointestinal fate of the protein particles. They vary in size and get digested in upper gastrointestinal tract.

**Carbohydrate nanoparticles**

Carbohydrate nanoparticles are of two types digestible and indigestible. E.g. - starch, cellulose, alginate, pectin and xanthan. These nanoparticles are spherical or non spherical depending upon the origin. They can be digested in upper gastrointestinal tract. They do not exhibit any toxicity as they produce same digestion products like simple sugars. But undigested carbohydrate may be fatal to human and can affect the human health.

Organic nanoparticles have less toxicity effect so they can be used in food industry. But proper design and suitable analytical tool has to be developed as some undigested lipids, proteins and carbohydrate nanoparticles may prove to be fatal for humans.[11]

**Characteristics of food nanoparticles**

The physiochemical and structural properties of nanoparticles plays important role. These nanoparticles have characteristics features like they have different morphology, composition, electrical charge and dimensions. These features determine the properties of nanoparticles which can be used in food industry.



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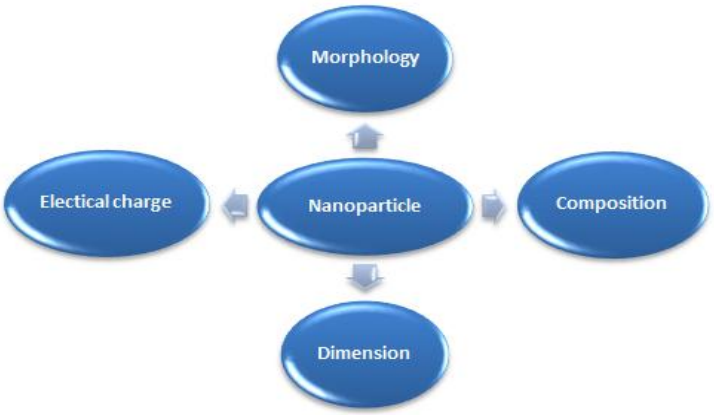


## Role of Nanotechnology in Food Industry

### A) Nanotechnology and Food Processing

Now a day's various agro-food industries are searching for new and cheap methods to enhance the food productivity and quality and also to preserve foods. Nanotechnology is one of the important field in food processing area. In agro-food industries, nanotechnology cover various aspects including enhance functionality of products, food safety, nutrient delivery systems through bioactive nanoencapsulation, packaging materials, bioavailability, pathogen detection, improve shelf-life, minimize food spoilage, etc. According to Tiju J. and Morrison, nanofood is the food which is processed, formed and packaged by using various nanotechnology tools. Sometimes the nanostructure materials (NSM) are also being used in many food industries as a nanosensor, new packaging materials and Nano encapsulated food component.

### B) Bioactive nanoencapsulation

Usually pest control can be done using pesticides, which are applied in higher concentrations for adequate period for control of the pathogens. However, these chemicals compounds causes potential hazards to human health such as eyes pain, abdominal pain, respiratory illness, paralysis. The bioactive nanoencapsulation of any agro-chemical could minimize the chance of damage to other plant tissue and it reduces the amount of chemicals which are released into the environment. This bioactive nanoencapsulation system is mainly used for nutrient or pesticide delivery in food sector [12].

Nanoencapsulation is incorporation of small vesicles or materials with the nano sizes. In this system the surface of nanoparticles are mainly modified by coating or encapsulation with nanoparticles and then it is used in food processing. These nanoencapsulation system, protect the food/plants from immediate degradation and target the delivery point. By encapsulating nano- poly D, L lactic acid with specific drugs can improved the site specific drug delivery and it has been studied. His experiment indicated that drug loaded, encapsulated nanoparticles of poly-D L lactic acid in polyethylene glycol was protected from absorption by human monocytes cells. This experiment concluded that nano encapsulation will avoid



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phagocytic absorption in human and hence it enhances circulation of food and drug nanoparticles.

The bioactive encapsulation ensures the food preservation by entrapping odour and other unwanted components in food and then delivers the nutrients to the target. These nanocapsule have a ability to carry the nutrient components through the gut that ensures the component bioavailability. This nano encapsulation system is used for delivery of health supplements, mineral and vitamin and enhancing the nutrients of the food. By using this technique, we can achieve the protection of bioactive compounds such as protein, vitamins, lipids, carbohydrates and antioxidants for production of foods with increasing functionality and stability of food product. Nanoencapsulation have a significant application in formulation, as it can reduces the amount of ingredients needed for formulation of product.

Other important advantages of this bioactive nanoencapsulation is that it can be improved the stability of bioactive compounds. Example, encapsulation of nitric oxide in nanomaterial increased its stability and shelf-life. The nanoencapsulation technique also used to developed the probiotic bacterial preparations. When probiotic preparation delivered to gastrointestinal (GI) tract they interact with their specific receptor and may act as a de novo vaccine, with the ability of modulating the immune response. As described above, all these objectives can be achieved by using number of potential delivery system such as colloids, nanoemulsion, biopolymeric nanoparticles, nanofibres, nanotubes, nanocapsule, etc.

### C) Various Technologies in Food Nanopackaging

In food sector, one problem is more likely observed that is the physical and chemical stability of food and its microbial contamination during the food storage. Food packaging is one of the most essential step in food safety. Nanotechnology plays a crucial role in food packaging, hence it is considered as largest application in food processing. Use of nanotechnology in food packaging reduced the environmental pollution by employing biodegradable nano material for the packaging. Mainly packaging provides the physical protection to foods and keeping food products from microorganisms, moisture, temperature, light, oxygen and other gases that may lead to spoilage of food product .

#### (i) Edible thin film packaging

By using edible thin film, food deterioration can be easily delayed by improving the shelf life and enhancing the food quality. Gelatin, starch, alginate, polylactic acid, polyhydroxy buyrate, polycaprolactone, polyglycolic acid are some materials which are used in edible thin film packaging. This edible thin film mostly used to protect the fruits, chocolates, chickens, spinach, beverages, cheese, candies, etc, because this thin film can act as a active packaging carriage and preventing gases from damaging the food content and preserving the flavour and texture of the food.

The edible thin film packages are prepared from edible nanolaminates and it protected the food from gases, odour, off flavour, moisture, lipids. Protein and polysaccharide are mostly good barriers against oxygen, carbon dioxide and hence they are used for



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preparation of edible nanolaminates. It is also possible to add colloidal particles to this thin film as nanolaminates that could include functional agents such as anti-microbial, anti-browning, anti-oxidant agents, enzymes, colours and flavours.

**(ii) Nano Based Antimicrobial Packaging**

The use of different nanoparticles with their antimicrobial activity has protected the food products from foodborne pathogen due to the consumption of spoiled packaged food. Compared with conventional food packaging, the antimicrobial compound through direct interaction with food and this interaction with food mainly improved the food stability.

There are various nanomaterials are used for antimicrobial packaging, the most common antimicrobial film are based on silver nanoparticles but zinc oxide and chlorine dioxide also used. The use is silver nanoparticles are well known for its strong toxicity to wide range of organisms with very high temperature stability. Silver nanoparticles efficiently releases the silver ions which have a bactericidal property due to the inhibition of wide range of microorganism and these nanoparticles have very low toxic effects in human.

In food industry, polyvinyl alcohol (PVA) is used as an eco-friendly antimicrobial food packaging material. The PVA antimicrobial film has antimicrobial effect against the Methicillin Resistance *Staphylococcus aureus* (MRSA) and DH5 alpha *E. coli*. Nanosilver particles also inhibit the growth of yeasts and molds. The nano based antimicrobial film can be used in the package of orange juice, poultry meat, asparagus, beef meat, etc. Zinc oxide nanoparticles are used to decrease the activity of Lactobacillus plantarum, Salmonella and yeast and keep improving the quality of fruit juices. There are also various other materials have been used as antimicrobial films are chitosan, carbon nanotubes, titanium dioxide, zinc oxide, silver oxide, etc.

**(iii) Nanocomposites**

The purpose of nanoparticles is not only limited to antimicrobial packaging but the use of nanocomposites in food packaging also provide a barrier to external thermal and mechanical shock and extending the shelf life of any food product. In this way, it offers good food quality with much longer shelf-life and it generally considered as eco-friendly because it reduces the need of plastics as packaging materials. Bionanocomposites are also made up of nanostructured materials with thermal, mechanical and gas barriers property. In recent year, nanocomposites which are based on starch and reinforced with tunicin whiskers or clay nanocomposites, silicate nanoplatelets have been developed. To achieve improved polymer composites, many organic and inorganic nanoparticles are being used. The incorporation of the nanoparticles in composite polymers has allowed to develope more resist packaging with cost effectiveness. Nanocomposites such as clay, silicate nanoplatelets, silica, chitosan has various advantages such as stronger, lighter, fire resistance and has better thermal property.

**D) Nanosensors for Pathogen Detection**

Nanoparticles play an important role in food packaging and presentation. The another main potential use of nanotechnology is the development of nanosensors for the



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detection of pathogens and contaminant in food sector, for example, thousands of an array of nanoparticles designed to fluoresce when they contact with the food pathogen. In nanosensor construction, the use of nanomaterials offers high sensitivity and some other novel attributes . Basically these nanosensor act as a indicator, that immediately respond to changes in food conditions such as temperature or humidity in storage rooms, product degradation, microbial contamination, food deterioration, etc. During the food packaging, nanosensors are incorporated into food products that might be useful in tracking any chemical, physical or biological modification.

In food processing, nanosensors are mainly constructed for controlling the external and internal food condition. External conditions: detection of atmospheric changes in food package and internal conditions: detection of inner atmospheric changes like high level of oxygen or other gases in package and chemical detection, microbial contamination, etc. Various nanosensors have been designed for the detection of foodborne pathogens such as *Salmonella* nontyphoidal, *Clostridium perfringes*, *Staphylococcus aureus, Campylobacter* spp., Norovirus, etc. These are the five main pathogens that contributing to acquire food borne illness [1].

The main aim of these nanosensors is to reduce the time for microbial detection. The nanosensors are directly placed into the packaging nanomaterial, where they would act as 'electronic noses' by detecting the toxins or chemical which are released during the food spoilage. These electronic noses were potentially used for the detection of fungal contamination of cereal, for food spoilage detection and for the presence of Ganoderma boninense on trunks of palm oil tree. Nanosensors are based on various nanomaterials such as carbon nanotubes, nanofibres, nanocantilevers, etc and are being used for detection of pesticides in food.

Bioconjugated nanoparticles ($SiO_2$) are used for detection of *E. coli* and the detection is 1000-fold more effective. For the development of nanosensors, carbon nanotubes are also used as electronic bridges and signal amplifiers. Carbon nanotubes have superior electrical conductivity, biocompatibility, high electro-chemical catalytic activity and non-toxicity and hence it has been extensively useful for designing the nanosensor. By using magnetic nanogold- immunosensor, the toxin such as aflatoxin which is produced from *Aspergillus parasitics* and *A. flavus* that mainly contaminants the food could be effectively detected.

Gold immunochromatographic assay can also be used for the rapid detection and quantification of pesticides in food. The polypyrrole nanowire immunosensor is highly sensitive and specific for detection of viruses. It was useful for phage detection that resulting in potential health care with special food safety. In food processing, there are various advantages of nanosensors are known including freshness preservation, increased shelf-life, improved food properties and quality, improved the nutritional supplements,etc.

**Risk assessment of Nanotechnology in Food**

Now a day's, nanotechnology already provoked public concern and debate. In nanotechnology,



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there are various nanomaterials are known to exhibit different properties which are mostly not found at macroscale which could be result in unpredicted safety problems and risk. For example, aluminum oxide which is used in dentistry because of its inertness and at nanoscale it can spontaneously explode and then it is tested as a potential rocket fuel. There are number of routes are known such as dermal exposure, ingestion, inhalation, etc for nanoparticles to enter into the body and the impact of this nanoparticles on body i.e. nanotoxicity mostly depended on properties of nanoparticles such as particles size, surface properties, mass, chemical composition and how individual nanoparticles are aggregating together. In March 2006, laboratory based studies investigates and reported that more than 70 people were suffered from the respiratory illness after the using nanotechnology bathroom cleaner.

Nanoparticles can enter into the cells and lungs whereas some nanoparticles of 30nm can even pass through the brain and blood barriers. These nanoparticles then could translocated from the respiratory system to blood system and distributed throughout the body and then further translocated into liver, speen, bone marrow, heart, brain, etc. Inhalation of nanoparticle such as titanium dioxide (20nm) of low intrinsic toxicity showed significant pulmonary inflammatory responses. In recent year, due to the consumption of different cosmetics and sunscreens, skin can act as a potential route of absorption for various nanoparticles. These nanoparticles, penetrate through the outer layer of skin but there's little information on hazard. By using Nanoliposomes, we will increase the effectiveness and cellular uptake of capsulated material. Nanoliposomes have various aspects such as currently it has been used in preparation method of food processing[10].

The main priority of any food industry is the quality and safety of food product, so in these area health risk assessment are more essential. In nanotechnology field, researchers should pay attention to the gastrointestinal (GI) absorption and the possible side effects of nanoparticles. When nanoparticles accumulate in higher concentrations in tissue, it can cause various serious effects on health. Therefore it is necessary to standardize the protocols for the risk assessment.

Besides this, majority of people prefer natural foods while healthfulness of natural and artificial food was specified to be equivalent. Hence number of foods containing nano-scale substances is still lower in market. A number of international and national advisory committees have recommended new strategies for nanomaterial risk assessment. Although there is no comprehensive guidance developed for the safety assessment of nanomaterials in food because of the lack of efficient data and information regarding the potential hazards of nanomaterials.

**Regulation of Nanotechnology in Food**

Recently the use of nanotechnology in food and agricultural sector is quite limited because of toxicological and regulatory concerns. Nanotechnology is usually used to get good quality and safety of food throughout the protection of antimicrobials and encapsulation that are very unstable in food. At the present time, there are no distinctive regulations known for use of



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nanotechnology in foods in the United States and European Union. The U.S Food and Drug Administration (FDA) has regulates on product by product basic and point out many products that contain nanosize materials. In the United Kingdom, the Institute of Food Science and Technology (IFST) is independent qualifying body for food technologists and scientists- suggested that when nanoparticles used as food additives, the conventional E- numbering system for labelling used along with 'n' subscript [12-14]

Government of United Kingdom also agreed to this suggestion that, these nanoparticles

materials be subjected to safety assessment before using them in consumer food products. TA- Swiss, the Swiss center for technology assessment, has analyzed the food additives that have been used in Switzerland. Although TA- Swiss study showed that there are no indications at this time that nanoparticles are dangerous to human health. In most cases no specific tests have been performed to clarify new risks depending on particle size. If food has been tested and confirmed as a positive list, identify by an E- number then it is used in certain foods according to the standard practices [2].

The European Union (EU) for food packaging and food product has suggested that for introduction of new technology, testing procedure, specific safety standards are required. In the U.S. most of the food packaging and nano-foods are mainly regulated by the U.S Food and Drug Administration (U.S. FDA), whereas in case of Australia, nano-foods and nano-food stabilizers are mostly regulated by Food Standards Australia and New Zealand (FSANZ) under the Food Standards Code. Beside this in many countries, insufficient food safety regulations are established due to poor information about availability, exposure and toxicity to human. In fact there is urgent need for international and national regulating system for the use of nanoparticles.

## Conclusion

The use of nanotechnology in the field of food and their related industries improved the flavour, taste, colour, texture and foodstuffs reliability, enhanced the bioavailability of nutrients and increases the product's shelf-life. In many countries, nanotechnology have been employed numerous application in food systems and processing which includes Nano encapsulation, Nano packaging, Nano sensors, Nano based delivery systems, medicine, Nano coating, Nano frying. Nanosensor could play main role in food processing as it is work both in external and internal conditions for controlling the pathogen detection. Nanomaterials has various applications in agro-food sector aim to enhancing the food quality and quantity moreover there are different nanomaterials used for coating the internal surface to avoiding the microbial infection and improving hygienic conditions and reduces the cost.

Besides the applications, nanotechnology also has certain limitations for which it is not used in food sectors till date. These limitations include facilities availability, cost factor, efficient production and acceptability of nano-food products in market. In the end regulatory considerations including the safety, environmental impact, economics and consumer acceptance will ultimately



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demand its success in food applications. Before the incorporation of nanomaterials into the food and dairy packaging there is an urgent need for the regulations of these nanomaterials. It must not causes health risk for consumers and therefore more research studies are required to understand these nanomaterials. Safety issues and environmental impact should be the first priority while dealing with the nanotechnology in food systems and hence testing of nano-foods is compulsory before they are released into the market.

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