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THE POWER OF NANOENCAPSULATION IN REVOLUTIONIZING FOOD PRESERVATION- A SCOPING REVIEW

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Abstract

It looks at how nanoencapsulation changes the safety and quality of food in this study. There are many good things about bioactive drugs that are nanoencapsulated in nanoscale carriers. It is more stable, absorbs more, and dissolves better, among other things. The study tries to find out how to make nanoparticles from natural materials, how they could be used to package things, and how they could make food taste, feel, and be healthier. The study looks at nanoencapsulation from both the top down and the bottom up. Scientists are looking into how these technologies can be used to make medicines, make food taste better, and keep it fresh. Nanotechnology is being looked at in the food industry because it poses a lot of legal issues and security risks. The article comes to the opinion that more studies are needed to find out if nanoencapsulation is safe, works, and could change the food business.

Keywords: Nanoencapsulation, Food, Technology, Quality, Safety issues, Industry, Busin

Introduction

Nanotechnology is growing very quickly in the field of food because nanomaterials have special properties and hold a lot of promise in food science and packaging technology. In the near future, new developments that improve food's quality, safety, and health effects are likely to appear (Chelliah et al., 2019). Twelve papers and three reviews from researchers and technologists in many fields were included in this special issue. They give an interesting and cross-disciplinary look at the topics that were covered.

By including nanoparticles with at least one dimension in the nanoscale range, nanocomposites offer an alternative to traditional methods for enhancing the passive properties of biopolymers, which is useful for food packaging. Being the most prevalent renewable biopolymer created by nature, cellulose is also a fibrous, stiff, and water-insoluble substance, making it an ideal option for usage as a reinforcing nanomaterial. Nonetheless, cellulose can be extracted from microorganisms (such as bacteria) in addition to vegetables (such as plants and certain types of algae). The fermented fibers that make up so-called bacterial cellulose (BC) are made of pure cellulose, unlike plant fibers that contain lignin and hemicellulose. Because of this, they have better qualities, such as being biocompatible, having a low density, being able to hold a lot of water, and having an ultrafine fibre structure.

Pateiro et al. (2021) came up with a quick, effective, and safe way to prepare BC so that cellulose nanocrystals (CNCs) could be extracted. This method had two steps and was used to make bacterial cellulose nanocrystals (BC-NCs) that look like nanocrystalline cellulose that is sold in stores. Ultrasonic irradiation was used to partly depolymerize BC as the first step (Ozdemir & Kemerli, 2016). In the second step, microwaves were used to separate the solid areas with the help of manganese (II) chloride (MnCl2)-catalyzed hydrolysis. Researchers (BRATOVCIC & SULJAGIC,2019) used a simple method to make all-cellulose nanocomposites that could be used for biodegradable food packing. They dissolved cellulose in a solution of 2:1 trifluoroacetic acid to trifluoroacetic anhydride.

Then, different cellulose nanofibers (CNFs) that were mixed in chloroform were added. It was found that nanofiber ratios between 5 and 9 weight percent gave the best results in terms of clarity, mechanical properties, and lowering water permeability while still maintaining good clarity. But more information about the environmental health and safety plan and a life cycle risk assessment of the possible dangers of inhalation must be given before the safe commercialization of cellulose nanomaterials can move forward.

In order to do this, (Shafique et al., 2022) looked at the available research on the risk of breathing in cellulose nanomaterials and judged the quality of the studies to figure out the risk.

The researchers came to the conclusion that, like other low-toxicity dusts that are poorly soluble, cellulose nanoparticles could cause temporary inflammation after short-term exposure. A quantitative evaluation of the possible health risks requires knowledge of the consequences of long-term and low-dose exposures that reflect realistic workplace settings; nevertheless, there are currently many data gaps in this area.

Uses and Developments in Nanotechnology for the Food Sector

The food and healthcare industries have recently shown a great deal of interest in nanotechnology owing to the many advantages it provides (Torres-Giner et al., 2020). In addition to the benefits already mentioned, such as increased bioavailability and decreased BAC levels, the ability to target specific tissues or organs for the administration of bioactive compounds is also strengthened. Nanostructured materials have remarkable qualities and can be used in the food business because of their large surface area and small particle size. Despite this, nanotechnology in food science has only just started to tackle applications that potentially offer significant societal benefits, especially when compared to other sectors. Texture modification, edible ingredient encapsulation, novel taste elaboration, and dietary component bioaccessibility/bioavailability enhancement have all been major areas of concentration for food product innovation. Packaging, Food manufacturing, safety and quality, nutraceuticals, and functional foods are the five main topics that nanotechnology studies in the food sector are now focusing on, according to (Bazana et al., 2019).

Nanotechnology has several uses in the food industry, but some of the most notable include : (1) BACs are made more stable and have a longer shelf life, protecting them from degradation in processing, distribution, and storage. (2) The mechanical and thermal properties are improved. (3) Food additives and functional raw materials, such as ʊ- 3 fatty acids, are integrated. (4) Unwanted tastes are masked (Das et al., 2020). (5) Nutraceuticals are protected from low gastric pH and their release during digestion is optimized. (6) Functional constituents are made more soluble, which strengthens their dietary value. (7)

Obtain higher activity levels of the encapsulated ingredients, which includes antioxidants, antimicrobials, probiotics, and so on. (8) Food components' flavor and texture can be changed. 9. Develop optically transparent beverages, which are nanoemulsions with oil droplets smaller than 100 nm.

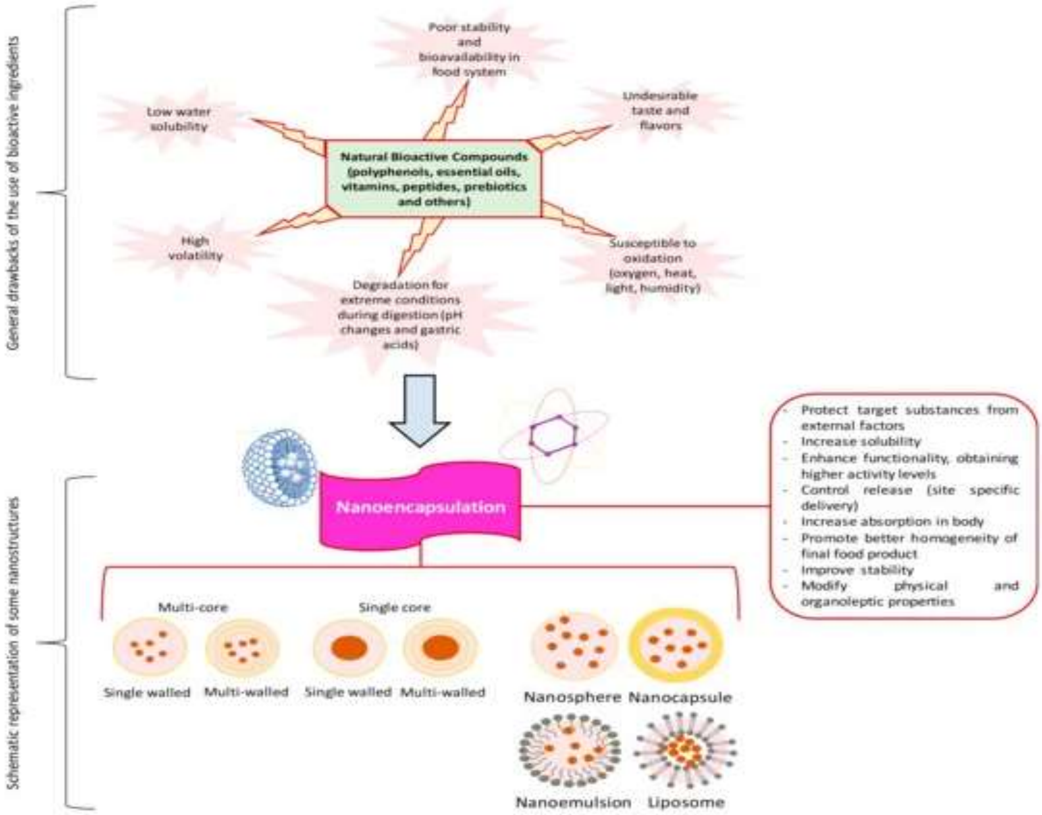

Figure 1 Bioactive compounds' (BACs) restricted use in food production

Nanoencapsulation of Bioactive Compounds and Food Ingredients

The human diet is vital to the health and well-being of consumers, and there are several BACs and other nutrients that are hydrophobic or poorly water-soluble (Zanetti et al., 2018). This class includes things like insoluble vitamins, phenolic compounds, carotenoids, and vital fatty acids. Figure 2 shows that improving the solubility and bioavailability of these compounds was the main obstacle to their use in pharmaceuticals and foods.

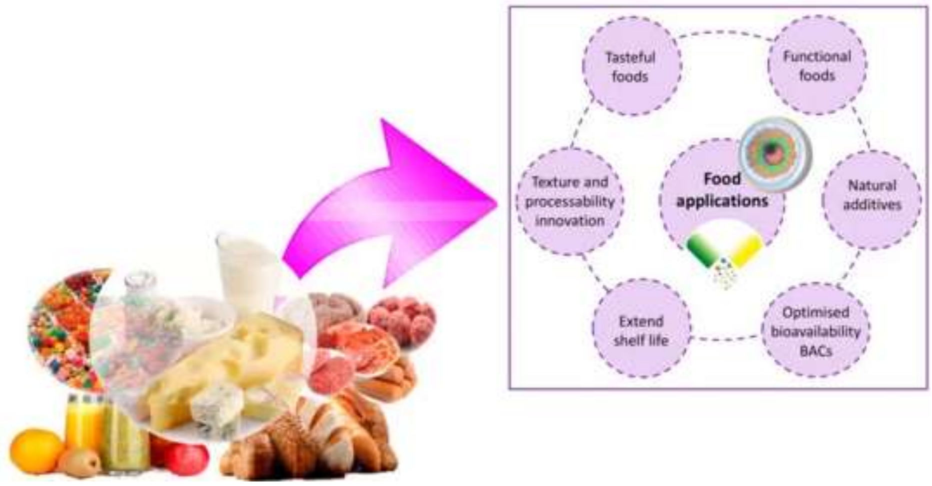

Figure 2 Nanoencapsulation of Bioactive Compounds and Food Ingredients

Therefore, nanoencapsulation may be a promising strategy for protecting numerous food components from specific physiological conditions or degradation while simultaneously disguising some kinds of undesirable flavors and aromas. It is hypothesized that BACs' functional activity, bioavailability, solubility, and delivery may be improved if their particle size was reduced. Nanotechnology has actually been utilized to dissolve and distribute lipophilic components (such as carotenoids, phytosterols, and antioxidants) in water and fruit drinks (Gupta& Variyar, 2016). Furthermore, nanoencapsulation has the ability to enhance the properties of the end food product while controlling the release of active components. These components can include phenolic compounds, proteins, enzymes, vitamins, minerals, and more. In their discussion on health-promoting foods, (Thiruvengadam et al., 2018) covered the primary BACs such as antioxidants, antimicrobials, vitamins, probiotics, prebiotics, minerals, enzymes, and flavoring compounds, among others.

Methods by Which Nanoencapsulated NA in Foods Act as Antimicrobials

Some of the papers we used for our research looked at how nNA works. Damage to the cell membrane by cell components and subsequent release of lysate constitute the principal action mechanism in these investigations (Paredes et al., 2016). Components like nucleic acids and proteins can be discharged if the cell membrane is irreparably damaged. Fungi cause damage to the plasma membrane, which inhibits methylglyoxal, ergosterol concentration, and cell leakage of ions, proteins, and nucleic acids. One explanation for the inhibitory action of mycotoxins is a decrease in carbohydrate catabolism when EO is present (Ranjan et al., 2014). Previous research has demonstrated that D-limonene, thymol, methyl, cinnamate, and encapsulated linalool can cause cell membrane disruption and the leakage of cell components.

Overarchingly, EO's antimicrobial effect is linked to its ability to penetrate cell membranes and mitochondria, where it increases cellular permeability by penetrating several layers of lipids, polysaccharides, and phospholipids (Palit et al., 2020). The cellular contents and ions are leaked, the ATP pool is reduced, and macromolecules are lost, ultimately leading to cell lysis, as a result of this disruption of the membrane potential. There is evidence linking the mechanism and action of EO to cytoplasmic coagulation and enzyme reserve, which impact energy directive and also the structural component production.

(Pasupuleti,2022) bacteriocins are more effectual beside Gram-positive bacteria than Gram-negative ones. The widely recognized concept for how nisin works in cells states that it forms holes in the cytoplasmic membrane of target cells, which allows the outflow of minor critical components from the cytoplasm, including ATP, potassium ions, amino acids, and the pH gradient of the bacterium. Figure 3 shows the primary action mechanisms of natural antimicrobials.

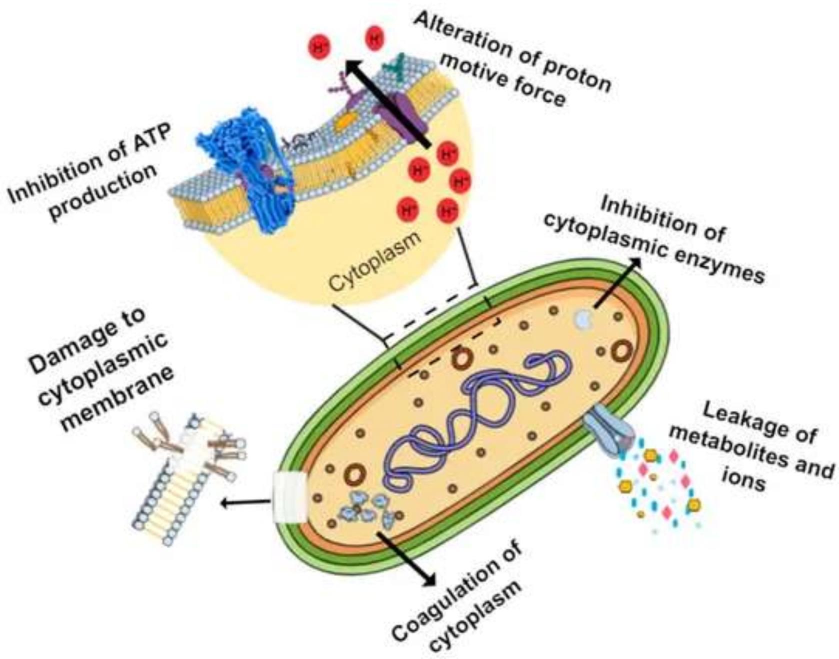

Figure 3 The primary action mechanisms of natural antimicrobials

It is clear that natural antimicrobials work in a similar way to nanoencapsulated antimicrobials, inducing a number of cellular consequences. Why, in most cases, does nanoencapsulation enhance the antibacterial activity of natural antimicrobials if the processes are identical? Their antibacterial activity is cumulative since their release is gradual and protracted in nNA. Natural antimicrobials can be rendered ineffective against microbes in food by encasing them in nanoparticles. Nanoscale structures may be able to bypass microbial cells and disrupt their essential cellular functions. Nanostructure wall materials can interact with microbial cell surfaces in a variety of ways, including inter-membrane transfer, release contact, absorption, fusion, and phagocytosis, to form pores that enhance antimicrobial action and cell permeability while enabling continuous diffusion of antimicrobial compounds across cell membranes (Nile et al., 2020). Furthermore, nanoemulsions and other nanomaterials can facilitate NA administration by penetrating the bacterial outer membrane's porous proteins. Due to the negative charge that bacteria naturally possess, the charge that is generated by the nanostructures will impact how the bacteria's membrane is electrostatically interacted with.

An increase in the solubility of NA is associated with the nanoencapsulation process. Because of the NA coating's increased polarity, the interfacial tension is reduced, leading to immiscibility in water-based systems, which are typical of most meals. More readily available and uniform NA distribution in the meal results from this. Additionally, NAs can be shielded against potential degradation by heat, light, oxygen, and moisture through nanoencapsulation. Low temperatures, organic acid stress, and osmotic stress are only a few examples of the environmental obstacles that microbes face, and they can all affect the microbial inhibition by NA (Singh et al., 2017).

Classification of Nanoencapsulation Systems/Techniques

The "top-down" and "bottom-up" methods of making nanomaterials in the area of nanoencapsulation technologies have been known for a long time. With the "top-down" method, precise tools are used to gather particles and squeeze them together to make them smaller. The "bottom-up" method, on the other hand, makes the particles bigger. Emulsification is a top-down method, Examples of bottom-up approaches include molecular self-assembly and self-organization, supercritical fluids, coacervation, inclusion complexation, and nanoprecipitation (Rostamabadi et al., 2021). When you use both ways together, you might get the best results. Nanoencapsulated systems are usually put into three groups: solid-solid, liquid-liquid, and solid-solid-liquid. However, these groups are not being used right now.

(Ashraf et al., 2021) say that the oil-water (O/W) emulsion-based method is the main liquid-liquid method used for solubilization.

Nutraceuticals and food-based BACs have been the subject of numerous nanoencapsulation procedures in recent years. Examples of such approaches include micelles composed of polysaccharides and/or proteins, biopolymer nanoparticles (NPs), nanoliposomes, nanoemulsions, nanosuspensions, and nanoliposomes. In their description of methods that are suitable for nanoencapsulation, (Pal et al., 2020) listed the following: electrochemical-based techniques (electrospinning and electrospraying), ionotropic gelation, coacervation, emulsification-solvent evaporation, ionotropic processes, and liquid-based processes (nanoprecipitation).

These nanodelivery systems can be used in a variety of solid foods and beverages since their effects are dependent on how well the NPs' characteristics match those of the BACs and the intended application. Considerations such as pH, organic solvent choice, processing time, polymer type, presence of surfactants, ratio of target compounds to polymers, and drying method(s) are crucial for successful NP preparations (Sun-Waterhouse& Waterhouse,2016). The absorption, distribution, metabolism, and excretion of NPs are influenced by their size, shape, mechanical characteristics, and composition, which might vary depending on the encapsulation method.

The functional qualities of the nanoencapsulated substance are mostly determined by the particle size. Not only did the concentration of polymers and double-walled NPs increase, but so did the size and shape of the particles themselves. Because the surface area to volume ratio of NPs increases with decreasing particle size, improved dissolving behavior is seen. Another crucial metric for size distribution is the polydispersity index (PDI) (Rashidinejad& Jafari,2020). A number of less than 0.3 is thought to suggest monodispersity, whereas a value more than 0.6 is seen to indicate polydispersity. Hence, this parameter may reveal whether the size distribution of NPs in suspensions was uniform or not.

One important parameter for NP stability is the zeta potential (ZP), which measures the difference in potential between the immobilized and dynamic ionic layers of charged particles. Nematicites with ZP values more than +30 mV or less than −30 mV are able to create more stable complexes, as stated by Ezhilarasi et al., 2013. Several factors can account for variations in complex ZPs. These factors include, but are not limited to, ionic strength, pH, coating material type and concentration, and the ratio of these two (de Jesus Freitas et al., 2022).

Bioactive components including enzymes, vitamins, β-carotene, soy isoflavones, or ϋ-3 fatty acids can have their solubility increased by using micelles. Bioactive compounds can be encapsulated by a German business called Aquanova using a carrier system based on nanotechnology that contains 30 nm micelles. The target compounds are made more bioavailable and effective by using the nanoscale carrier technology known as NovaSol® (Anandharamakrishnan et al., 2014). Meanwhile, food scientists have found nanoliposome research intriguing because of the promising prospects it presents in several domains, including encapsulation, controlled release, enhanced stability, and bioavailability. Nanoliposomes are used to add flavour to food, but they are also being looked into as a way to add nutrients, antioxidants, nutraceuticals, enzymes, enhancers, and antimicrobials to food.

Ionic gelation is a gentle, easy, and solvent-free method that can also be used to make nanosized objects consistently. Polymers that are positively charged, like chitosan, and polyanions work together in this other way. This process of making cross-links between and within molecules happens naturally, without the need for harsh chemicals or very high temperatures. There are some problems with NPs and microparticles made through ionic gelation, which used to be known as ion-induced gelation (Rezaei et al., 2019). These include a surface form that isn't right, an index of dispersibility that is too high, a particle mechanism that is easily broken, and a lack of good surface modification areas that could connect functional moieties.

But because they work well, can be used in a variety of situations, and are still fairly new, electrospinning methods have gotten a lot of attention in food science lately. Electrospun nanofibers have many structural and functional benefits, including a high surface-to-volume ratio (SVR) because they are porous, high encapsulation efficiency (EE) (EE without thermal energy), and better stability of the parts they hold (Oliveira et al., 2022). Another novel and easy method that relies on controlling the high electrostatic potential is electrohydrodynamic atomization, often known as electrospraying. The nonthermal character of electrospraying makes it an attractive option for encapsulating heat-sensitive food components, according to reports.

Finally, (Pisoschi et al., 2018) A comprehensive inventory of nanostructure and nanoencapsulation techniques suitable for antioxidants and antimicrobials has been compiled. These techniques include: (1) nanoencapsulation via association micelles; (2) nanoencapsulation via lipids (including solid lipid NP incorporation, nanoemulsions, and nanoliposomes); and (3) encapsulation utilizing both biologically-derived and non-biological polymeric nanocarriers (via coacervation, ionic gelation, electrostatic complexation, and layer-by-layer deposited nanoNPs) (Figure 4).

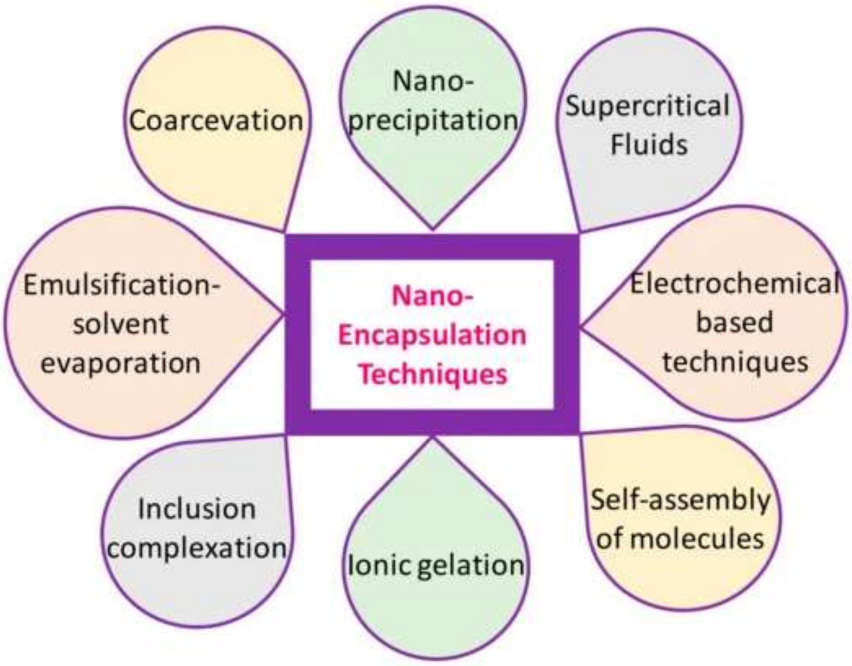

Figure 4 Techniques for nanoencapsulation of food bioactives

Incorporation of Nanoencapsulated Oils into the Food Market and Patent Application

The present state of food incorporates micro and nanoscale structures, as stated by the (Guía-García et al., 2022). While plant-based nanomaterials make up fruit juice, nanoemulsions averaging 190 nm in size were found in Bailey's Irish Cream. The water droplets in margarine were less than 10 µm in diameter and contained even tiny crystals of fat. There was a wide spectrum of naturally occurring nanomaterials in foods and drinks, from tiny particles less than 100 nm in beverages like tea, beer, and coffee to bigger oil particles about 800 nm in foods like milk and protein structures about 300 nm in eggs and soy. The nanoscale nature of all food, both fresh and processed, forced the body to adapt to these new substances.

Incorporating nanotechnology into trade has received little academic attention . Additionally, there were no products available that utilized oil nanoencapsulation. Nonetheless, a publication emphasizes the fact that there are a plethora of oil microencapsulation products available for trade (Ferreira& Nunes,2019). One possible explanation for this discovery is that nanotechnology is still in its infancy and is notoriously difficult to implement. Nonetheless, there are certain shared features between the techniques employed in micro and nanoencapsulation of oils. A number of concerns regarding nanotechnology's commercial application have arisen due to the absence of adequate regulation in this area.

Multiple European Union (EU) research initiatives are currently under way to address nanosafety from every angle, including toxicology, ecotoxicology, risk assessment, exposure assessment, interaction mechanisms, and standards, with a focus on nanotechnology regulation. The NanoLyse project and the NanoReTox project are two examples of ongoing EU initiatives that are concerned with the potential negative effects of engineered nanoparticles on human and environmental health and the environment, respectively (Awuchi et al., 2022). Nonetheless, organizations responsible for overseeing regulations have begun to address the concerns raised by nanoparticles. These include the US Food and Drug Administration and the Environmental Protection Agency, as well as the EU's Health and Consumer Protection Directorate. There is currently no specific legislation in place concerning the manufacturing, processing, or labeling of engineered nanoparticles or the products and materials that contain them.

Some patent documents pertaining to the food sector have been filed in many nations, even if there is no particular rule regarding nanoparticles. The subject of the Argentine patent application WO2018029626 was an edible nanoemulsion containing chia oil. The ingredient list for the chia oil nanoemulsion was as follows: water, 10–20% chia oil (Rao& Naidu,2016), 2–5% polysorbate, 0.5–5% non-polysorbate emulsifier, 0.05–0.2% antioxidant, and so on. Recipes for edible chia oil nanoemulsions that may be added to clear desserts and drinks like juices and jellies were shared. Cinnamon oil nanoemulsions as a means to halt the proliferation of harmful food-borne microbes were the subject of a Korean patent application (KR20160005182).

Moreover, the cosmetics and pharmaceutical industries could also find use for this innovation, in addition to the food industry (as additives, packaging materials, preservatives, etc.). To prevent the volatile oil from mustard oil from evaporating and its potential use in food and medicine as a germicide, a Chinese patent (CN103315956) was produced to reduce the oil's strong odor (Rostamabadi et al., 2021). In his Chinese patent application (CN103750050), Wang Weichun Feng Wei detailed a palm oil nanoemulsion that addressed issues with current young animal feeds, such as high equipment investments, long production periods, large granularity, poor stability, low oil content, low absorption rates, and high production costs. To make the palm oil nanoemulsion, an emulsifier was mixed with the oil, then the combination was chopped and emulsified. Finally, cell breaking was done in the mixture using ultrasound. The created nanoemulsion had a high oil content, small dispersion granularity, excellent stability, and enhanced digestion by cattle. The procedure was simple, the reaction was easily controllable, the production time was short, and the equipment investment and costs were low (Bahrami et al., 2019).

Green Nanoparticles in Meat Industry

Recent developments in the food industry's use of nanotechnology have been driven by NPs' exceptional mechanical, electrical, optical, and surface energy capabilities compared to their parent molecules. The creation of "smart foods" is just one of many fields that are making use of NPs (Figure 5). For use as colorants, flavor enhancers, preservatives, or carriers of nutraceuticals, food processors create inorganic and organic NPs, such as nanoemulsion and nanofiber. The primary applications of inorganic and organic NPs in food packaging are antibacterial properties and the incorporation of nanosensors into films or coating solutions (Pisoschi et al., 2018). Using nanotechnology at every stage of the manufacturing chain—from processing and preservation to packaging—is a new way to increase the shelf life of meat and meat products.

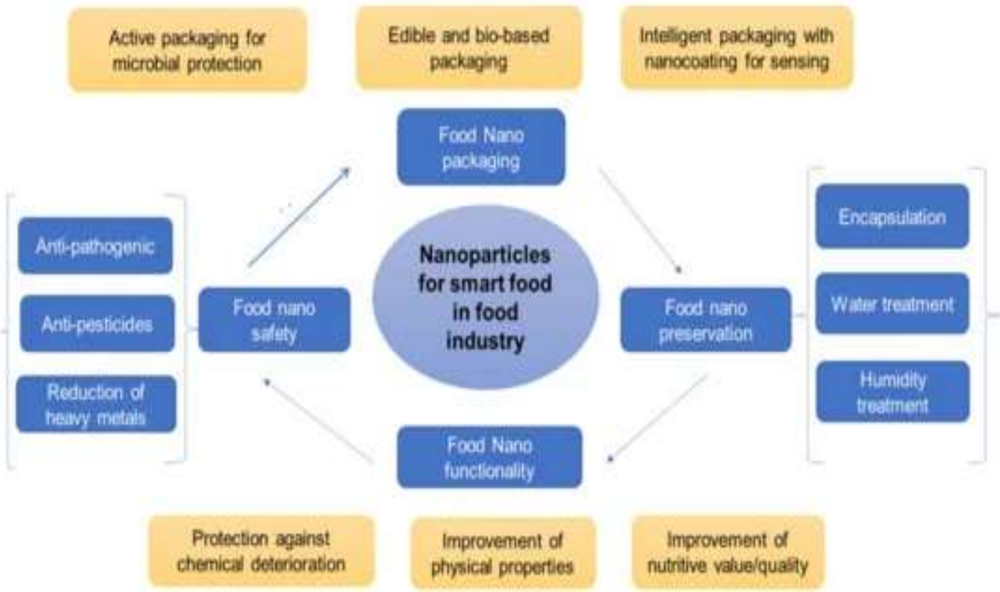

Figure 5 some applications of nanoparticles for developing smart food

Safety Issues in Food Nanotechnology

There have been several new scientific and industrial fields that have emerged thanks to advancements in nanotechnology, and the market for products that contain nanomaterials is growing at a constant rate. Although there are many benefits to using nanotechnology in food technology, there are also many concerns about public safety, the environment, ethics, legislation, and regulations that have arisen due to its fast expansion (Jafarzadeh et al., 2022). Unpredictable dangers may result from nanomaterials' unknown physicochemical and biological characteristics, which may differ significantly from their conventional form.

Despite the significant research on nanoencapsulation technology for bioactive substances in the food business, the potential danger of nanoparticles coming into direct contact with humans through oral intake remains a cause for worry. Whether nanocarriers are hydrolyzed by digestive enzymes or not depends on the circumstances in the gastrointestinal tract (GIT) and the nature of the nanocarriers themselves (Bagheri Darvish et al., 2021). The bioaccumulation of foreign substance in human blood, cells, and tissues may be accelerated due to the fact that unbound nanocarriers may usually pass intestinal/cellular barriers.

The produce of nanocarriers involves the considerable employment of organic solvents and emulsifiers, which can pose hazards due to their toxicity. Although evaporation is necessary for the removal of organic solvents, it is possible for the finished product to contain undesired amounts of solvents that could pose safety risks if their concentration is not understood. Authorities such as the FDA, the WHO, and the EFSA have established safe usage levels for volatile, emulsifying substances, which are known to be harmful.

Actually, very little is known about the possible dangers that nanotechnology poses to human health and safety. Further risk evaluation is necessary to determine whether nanoparticles are safe and whether they pose any dangers. Nanomaterials' potential interactions with biological systems, their activity within the gastrointestinal tract (GIT), and their biological fate after digestion are all aspects of human health that need further investigation into the potential direct and indirect consequences of nanomaterials. To further safeguard the public from nanotechnology's possible negative impacts, regulatory measures must be developed (Delshadi et al., 2021).

Many concerns pertaining to consumer health are regulated by modern food regulation, which, with the assistance of many international organizations, may be extended to nanotechnology and nanomaterials utilized in food (Huang et al., 2022). It is clear that there have been substantial advancements in the application and regulation of innovative nanotechnology in the food sector, despite the present absence of dedicated regulation and risk management for nanotechnology. There is a way to guarantee that nanoparticles used in food are safe: adhere to current food rules, be open and transparent with information, and be prepared to share information with the public.

Legislative Aspects Concerning the Use of Nanoparticles in Food Products

Several areas of the food industry make use of food nanotechnology, including packaging, additives, and preservation, as was demonstrated in the preceding section. On the nanoscale scale, you can find several common chemicals used in food additives and packaging. One example is the presence of TiO2 nanoparticles in food-grade products, which can reach concentrations of up to 40% in the nanometer range (Brandelli& Taylor,2015). Nanomaterials such as TiO2 nanoparticles are known to be rather harmless under typical circumstances, but prolonged contact with them could lead to harmful effects. Most laws and regulations pertaining to nanotechnology in food come from either the European Commission (EC) or the Food and Drug Administration (FDA) in the US. The risk evaluation of chemicals in food products based on conventional particle size was summarized in a recent literature study (Assadpour et al., 2020). The advent of nanotechnology in the culinary sector, however, is not to blame. The physical and chemical properties of nanomaterials, as well as their absorption, biodistribution, metabolism, and bodily excretion, can be carefully evaluated in order to mitigate the impacts of nanotoxicity before they are used in the food industry.

Conclusion

Overall, nanoencapsulation could change the food business by making products safer, healthier, and better in terms of quality. By putting bioactive substances inside nanoscale carriers, food ingredients become easier to dissolve, more bioavailable, and last longer. These are just a few of the many benefits of encapsulation. This piece talks about nanomaterials that come from sustainable sources, nanocomposites that are used to package food, and nanoencapsulation that is used to deliver nutrients and keep food fresh. Even though worries have gone down since nanotechnology is being used in food, more study and rules are needed to protect consumers. With the help of nanoencapsulation, the food business might be able to stop food from going bad, losing nutrients, and spreading diseases. Nanoencapsulation technology makes it possible to create new foods that taste better, have more nutrients, and last longer as well. To fully utilize nanoencapsulation in food science, researchers from academic institutions, business participants, and regulatory authorities must work together and share their findings. Setting clear limits on nanoparticles in food should be the main focus of more study. Also, more study needs to be done on how nanoparticles affect health, the environment, and new technologies for enclosing nanoparticles. Nanoencapsulation can be used to make food items that are safer, healthier, and better for the environment. This choice will be good for the earth, businesses, and customers.

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