CURRENT USE OF NANOPROTEIN AND APPLICATION IN THE DEVELOPMENT OF FOOD PRODUCTS FOR FUNCTIONAL AND NUTRITIONAL BENEFITS

Shalini Biswas¹, Samadrita Sengupta²

Address(es): Dr. Samadrita Sengupta,
¹West Bengal State University, Post Graduate Student, Department of Food and Nutrition, Berunanpukhuria, Barasat, Kolkata-126, West Bengal, India.
²West Bengal State University, Assistant Professor, Department of Food and Nutrition, Berunanpukhuria, Barasat, Kolkata-126, West Bengal, India, (+91)9903780850.

*Corresponding author: senguptasamadrita3625@gmail.com https://doi.org/10.55251/jmbfs.1737

Keywords: Nanoparticle; nanotechnology; nutrition; nutraceutical; functional food

ARTICLE INFO

Regular article

Received 27. 5. 2019
Revised 20. 11. 2021
Accepted 8. 12. 2021
Published 1. 4. 2022

ABSTRACT

In the last few decades, there has been a growing interest in the production of Nano protein particles from food protein. The term Nanotechnology refers to the formation of materials, devices, and systems by manipulating their matter into a length scale of ~1-100 nm. Nanoparticles can be formed from various types of materials like metals, polysaccharides, and proteins. Biological protein-based nanoparticles made from whey, soy, corn zein are advantageous for health and possess relatively low cost. For the production of Nano protein, the physical and chemical properties of proteins can be modified for specific food and make the protein applicable for biotechnological purposes. Specific structure and number of functional groups in protein that are responsible for the physicochemical properties are selectively modified during the preparation of Nano protein. Nano protein particles are used in a wide range of settings and it replaces many particles which are not biocompatible and exerts a negative effect on the environment. In the food industry Nano protein is a revolutionary fact to maintain the color, flavor, and nutritive value of food. Various types of natural and synthetic nanoparticles are available in the food and pharmaceutical industry but among them, protein-based nanoparticles are widely used because of their size and relatively easy method of preparation. These nanoparticles are used in the loading and delivery of physiologically active compounds like nutraceuticals. Nano protein formation is also helped to combat global food security challenges which are related to the increased global population, unstable world economy, and climate changes.

INTRODUCTION

Protein-based nanoparticles are widely used in the development of functional food. Recent nanoparticles show a promising effect in the field of the food industry. Nano protein is widely used due to its high nutritional value, availability, and acceptability. In the current year, food protein is used to prepare nanoparticles which are further used in the formation of the innovative functional food product. The most important fact is to control the size of nanoparticles for determining the taste, flavor, texture, appearance, and rate of release of bioactive compounds in the biological system (Chen et al., 2006).

Nanomaterials permit improved encapsulation and release efficiency of the active food ingredients related to traditional encapsulating agents, and the development of nano-emulsions, liposomes, micelles, and biopolymer complexes have directed to improved properties for bioactive compounds protection, organized delivery systems, food matrix assimilation, and masking undesired flavors. Nanotechnology also has the prospective to improve food processes that use enzymes to confer nutrition and health benefits. Nano protein hydrolysate is easily developed with anti-nutritive components and hence surges the bio-availability of minerals and vitamins. Nanomaterials create a major interest for the development of advanced packaging systems, by improving mechanical and barriers properties of food packages. In the food industry, nanomaterials are used to improve the mechanical strength, electrical conductivity, and thermal stability of food materials (Sharma et al., 2017). Over the next few decades, proteins-based nanomaterials will play a major role in developing the efficacy of functional food. Nanomaterials are also used to stabilize fragile nutraceuticals and the formation of site-specific carrier targeting. At present the more knowledge and information about protein-protein and protein-nutraceutical interaction is required to develop the design of nutraceuticals carriers for use in the food industry (Chen et al., 2006).

Nanoprotein in food processing

In recent few decades’ nanotechnologies and nanoscience implies a new and innovative application in the food industry. The term Nanotechnology refers to the formation of materials, devices, and systems by manipulating their matter into a length scale of ~1-100 nm. Nanotechnology has been considered a most attractive and revolutionary method in the food sector. Nanotechnology offers a wide range of advantages in food processing technology, food packaging material, and the formation of nanomaterials for use in foods without affecting nutritive value and protection from adverse health effects. Nanotechnology is also applied for the improvement of tastes, color, and texture, consistency of foodstuff, increased bioavailability, and absorption of food material. The application of nanotechnology is new in the food sector but, predictably, this technology is growing rapidly in the coming years (Srinivas et al., 2010; Chaudhary et al., 2008; Singh et al., 2017).

Nowadays Nanocarriers are used as a delivery agent to deliver active food components and food additives in food. In the food industry nanotechnology is applied for the formation of emulsion, encapsulation, simple solution, and association colloids which offers efficient delivery systems (Singh et al., 2017). Nano emulsion is widely used to encapsulate various lipophilic components such as lycopene, lutein, capsaicin, astaxanthin, beta-carotene, lemon oil, D-limonene, vitamin E, and omega-3 oil. Studies revealed that the incorporation of coenzyme Q 10 into nano emulsion increases the bioavailability of coenzyme. Anti-inflammatory activity, stability, and oral bioavailability of polyphenols of curcumin and epigallocatechin gallate are enhanced by incorporation into nanoemulsion. The bioavailability of heptadecanoic acid is increased when it is encapsulated indigestible oil droplets with the smallest size (Yalcinoz et al., 2018). Nano emulsion is used to formulate smart food in the food industry for example nano emulsion is prepared with beta-carotene. Beta-carotene is a water-soluble pigment and has an effective health benefit. This emulsion is stabilized by β-lactoglobulin which is a biocompatible emulsifier. The bioavailability of these emulsions is high (Gupta, 2016). Nanoencapsulation is one of the most effective parts of the food processing industry in which solid, liquid, and gaseous materials are packed into different carriers such as capsules. Many nutraceuticals, functional food components including protein, vitamins, fat, and minerals are encapsulated in a perfect delivery system and exert their functional properties. Nanoencapsulation of the bioactive peptide is most challenging concept and this process increased the bioavailability of bioactive peptides by using a nano delivery system. Many bioactive ingredients are prone to react with other food and loss their bioavailability, as a result, the encapsulation process is very helpful to protect bioactive components without
affecting their functional properties, color, and flavor (Burcu et al., 2014; Mohan et al., 2015). The food industry also continues its investigation with this technology to face the growing demand for the functional ingredient of food (Mohan et al., 2015).

**Nano protein in food preservation and shelf life**

Many bioactive ingredients are prone to react with other food and lose their bioavailability as a result of encapsulation is very helpful to protect the bioactive component from degradation without affecting their functional properties, color, and flavor (Burcu et al., 2014). Edible nano-coatings on various food material are effective because they hinder the exchange of moisture and gas and retain color, antioxidants, enzymes, anti-browning agent. This technology helps to increase the shelf-life of manufactured food even after the opening of the packet. Encapsulation of functional components slows down the chemical degradation process by modifying the properties of the interfacial layer which are surrounding them. Curcumin is a bioactive compound of turmeric and least stable in normal conditions. The stability of curcumin is increased by pasteurization and at different ion strengths upon encapsulation (Singh et al., 2018). Microorganisms are the leading cause of food spoilage. The addition of antimicrobial agents in food packaging material prevents the growth of microbes and increases the shelf-life of food. When antimicrobial agents are incorporated into the packaging film, they can be dispersed onto the food surface through migration, evaporation, or diffusion abilities. Recently a bio-nano composite film has been developed from fish skin gelatin and silver-copper bimetallic nanoparticle. This biofilm is active against the growth of Listeria monocytogenes and Salmonella enteric.

In recent years, an intelligent type of nano-coating film has been developed by few researchers which can indicate the presence of any contamination in food material that has occurred during storage. Other methods such as Gas content and non-invasive detection methods exert the great ability to detect and monitor the gas content, excess moisture, and oxygen content of a package-headspace. Thus, biofilm provides an effective measure to evaluate the quality and safety of food even after the production process has been done. The presence of oxygen inside the packaging can cause shelf-life threatening of food due to the ability of oxygen to create a healthy environment for microbial growth (Bajpai et al., 2018).

**Nano protein in food packaging**

Now day’s global food industry deals with consumer demand for safe, healthy, and fresh food. Besides this, they have to meet the condition of food safety regulations. To supply safe food products, foods manufacturers, traders, and food regulatory authorities are looking for a novel, cost-effective, fast, and consistent measure. The application of nanotechnology in food packaging brings three major possibilities and those are direct incorporation into food products, incorporation in food packaging material, and application in food processing (Sharma et al., 2016). The demand for effective food packaging can be meet by nanomaterial augmented polymers which help to enhance safety and also addressed environmental concerns. The packaging material should have to reduce any interaction between food material and packaging, adverse effect on consumer’s health and amount of waste materials. Nanomaterials are also used for encapsulation of biologically active peptides which are very sensitive to the acidic environment of the stomach. These peptides are very important and have to be protected from inactivation. However, nanomaterials enhanced food preservation by reducing the effects of microorganisms. The use of silver as nanoparticles possesses a less environmentally toxic manufacturing method when it is to be utilized on a commercial scale (Sankaria et al., 2012).

**Animal and Vegetable sources of nano protein and their application in the food industry**

**Soy protein**

Soy proteins are a significant source of food proteins. In the past few decades, soy protein has been used in the formulation of several foods. It is used in a wide spectrum due to its good nutritional value, functionality, acceptability, and availability and it also exerts potential health benefits. Amino acid composition of soy proteins helps to protect against bacterial infection (Peles et al., 2013). Soy protein isolates are the enriched form of soya protein (SPI). Soy protein isolates possess a balanced composition of nonpolar, polar, and charged amino acids, which can be incorporated into drugs or protein-based delivery system with its all-functional groups. The major components present in SPI are glycinin. These components exist as globular molecules in an aqueous environment and consist of a hydrophilic shell and hydrophobic kernel, which together form water-soluble aggregates. SPI molecules continue to and form structures like microspheres, hydrogels, and polymer blends when dissolved or crosslinking agents are added. For evaluating the encapsulating property of SPI curcumin was selected as a model drug. During the commercial production of SPI, the globulins in SPI are easily denatured, as a result, most of the globulin is found in aggregated form. Aggregated proteins in SPI exhibit good surface-active properties due to their insoluble nature. This protein helps in the formation of effective Pickering and Pickering stabilizers (Liu et al., 2013; Brandenburg et al., 1993).

When nanotechnology is applied, it is easily digested and biodegradable. Soy protein isolate (SPI) of defatted soy flour is used for soya protein nanoparticle (SPNs) production. Soy yogurt developed from SPNs and rice bran oil is considered a functional food product because of its valuable physiological functions (Sengupta, Goswami, Basu and Bhowal, 2019; Sengupta, Bhattacharyya, and Bhowal, 2018; Sengupta, Koley, Dutta, and Bhowal, 2019a; Sengupta, Koley, Dutta, and Bhowal, 2019b). Soy protein is used in tissue engineering for wound healing and transdermal drug delivery in the form of films, scaffolds, and hydrogels (Tansuz, 2016).

**Corn zein**

Corn zein is present within the cytoplasm of corn cell endosperm. It has a low molecular weight (20kDa). Corn zein is insoluble in water and becomes soluble in the presence of alcohol, urea, alkali, and anionic detergents. The structure of zein is helical wheel-shaped with nine homologous units arranged in a parallel way with hydrogen bonds. This helical shape provides a globular structure to corn zein which makes it similar to insulin and ribonuclease (DeFrates et al., 2018). The nanoparticle of zein has been used as carriers of non-polar drugs as it protects encapsulated compounds from the acidic environment of the stomach. Zein nanoparticles improved their properties by combining the natural polymer with other substances. Sodium caseinate is incorporated with zein nanoparticles to improve the stability of particles in water (DeFrates et al., 2018; Anderson and Lamsal, 2011). Zein is commonly used in chewing gum and as a preservative coating for some food and pharmaceutical products. Corn zein nanoparticle is useful for controlled release of fat components such as alpha-tocopherol (Anderson and Lamsal, 2011).

**Whey protein**

Milk protein is an important source of whey. Whey protein constituent approx. 20% milk protein. Beta-lactoglobulin, alpha—lactalbumin, serum albumin, immunoglobulin are the most important whey protein. These biologically active peptide fractions can be obtained from hydrolysis and used in the production of functional food (Kinsella et al., 1989). Bioactive peptides are inactivated in the parent protein molecule and can be activated by hydrolysis of the protein molecule. There are different types of hydrolysis procedures but the most common procedure is acid hydrolysis. However, the use of the neutral hydrolysis process is beneficial as it retains nutritional properties unaffected. Hydrolysate’s enzymes improved stability at heat treatment, provide peptides specific for special diet and improve functional properties such as gelation, foaming, and emulsifying capacity. Various treatments including heating, high pressure, sulfidation, and changing the polarity of the environment make the protein susceptible to hydrolysis. Physico-chemical changes occur due to physical and chemical treatment which influence the state and stability of the native protein (Burcu et al., 2014; Schmidt and Markwijk, 1993). Hydrolysed whey protein-based formulas are beneficial for children. Proteins are broken down into peptides and free amino acids during hydrolysis. Through this hydrolysis process formulation of the biologically active nutritional component from whey protein provides health-promoting opportunities for the use of dairy ingredients. Manipulation of molecular size of biologically active peptides is an essential step in the development of protein hydrolysate for dietary use. (Burcu et al., 2014).

The technology of production of nano protein from the different protein-rich source material

In recent years Plant protein-based nano-delivery systems are gaining attention in the food industries because of consumer demand for vegetable diets. To improve the functional properties of plant proteins several physical and chemical methods are required. Soy protein nano-aggregates have been produced by using a combined method of pH-shifting and nano-thermo-sonication (MTS). In this method, Soy-protein, isolate (SPI) is treated with pH-shifting at pH 12 or in combination with MTS and high-pressure homogenization (HPH). The resulted from SPI aggregates are spherical with the smallest size, 27 ± 1 nm. Soy protein nano-aggregates have improved properties of highest protein solubility, lowest turbidity, free sulfhydryl and disulphide bonds, surface hydrophobicity, antioxidative activity, and rheological and emulsifying properties than the other samples (1). The SPI nano-aggregates have good stabilizing power as a result these
are used to prepare oil-in-water nano emulsions with canola oil and provide stability over 21 days at 4°C (Yildiz et al., 2017). Zhang et al. (2014) has been developed a study to investigate the influences of nano-bacterial cellulose (Nano-BC)/soy protein isolate (SPI) complex gel on the textural, rheological, and sensory properties of the ice cream model. Nano-bacterial cellulose (Nano-BC)/soy protein isolates (SPI) mixtures with different ratios (Nano-BC: SPI, 1:20, 1:15, 1:10, and 1:5 w/w) are prepared with constant total solid content (16%). The result showed that the thermal stability, textural, rheological, and emulsifying properties of nano-BC/SPI mixtures are improved than pure SPI. Some properties such as low calorizing, melting resistance, and good textural properties of ice cream are developed When 20% of nano-BC/SPI (1:20) mixture was added into ice cream as the cream substitute (Guo et al., 2018).

Nanoparticles are produced from soy protein by using dispersion, dissolution, drug incorporation, cross-linking, and evaporation process. Particle size, size distribution, and zeta potential play important role in the production of nanoparticles. Curcumin is used as model drug and encapsulated in into nanoparticles. In this process, the average size of the curcumin loaded nanoparticles was 220.1 to 286.7 nm, and their zeta potential was around -36mV (Teng et al., 2012).

Nanoparticles are produced from soy protein by using dispersion, dissolution, drug incorporation, cross-linking, and evaporation process. Particle size, size distribution, and zeta potential play important role in the production of nanoparticles. Curcumin is used as model drug and encapsulated in into nanoparticles. In this process, the average size of the curcumin loaded nanoparticles was 220.1 to 286.7 nm, and their zeta potential was around -36mV (Teng et al., 2012).

Sensory properties of nano protein-based food product

In recent years Nanotechnology is widely used to improve the functional properties, taste, flavor, texture, and shelf life of food products by modifying their physical, chemical, and biological properties. Ingredients in food products that are subjected to form nanostructure increase the bioavailability of nutrients and improve the sensory properties of food (Singh et al., 2016). Chitosan is a useful nutrient and has microbical activity, protective film formation ability, binding action, and antioxidant activity. Chitosan nanoparticles are used as an edible coating material for fishery products such as fish fingers, fish balls, etc. to increase the microbiological quality and shelf life of fish products. Chitosan nanoparticle coating prevents lipid oxidation on the fish finger and enhances the shelf life of fish products during storage conditions (Abdou et al., 2012).

Food grade nanoparticles have been used to stabilize novel Pickering emulsions, due to their compatibility with food and good stabilizing power concerning coalescence. These types of emulsions imply good functional performance that can be used as an effective delivery system and development of novel functional food. Soy protein nanoparticles are used as Pickering stabilizers due to their functional, nutritional properties, and availability. The emulsion prepared with Soy protein nanoparticles achieved steric stabilization (Liu and Tang, 2013). Nanopilosome is produced by applying high energy to phospholipid in an aqueous solution and used in the food industry as a delivery system. Ingredients encapsulated by nanopilosomes are protected from chemical and environmental factors, enzymatic changes, unwanted odor, or taste. Like nano emulsion, nanopilosomes increases the stability, and ionic strength of food products. Nanopilosome is mainly used as a colloidal delivery system to deliver hydrophobic bioactive and functional agents. Nanopilosome is produced by inputting high energy to phospholipid in an aqueous solution and used in the food industry as a delivery system. Ingredients encapsulated by nanopilosomes are protected from chemical and environmental factors, enzymatic changes, unwanted odor, or taste. Like nano emulsion, nanopilosomes increases the stability, and ionic strength of food products. Nanopilosome is mainly used as a colloidal delivery system to deliver hydrophobic bioactive and functional agents. Nanopilosome is produced by inputting high energy to phospholipid in an aqueous solution and used in the food industry as a delivery system. Ingredients encapsulated by nanopilosomes are protected from chemical and environmental factors, enzymatic changes, unwanted odor, or taste.

Table 1 Different Method of Nano protein Production

| Methods | Materials | Use | Citation |
|---------|-----------|-----|----------|
| pH-shifting and nano-thermosonication (MTS) | Soy protein | Oil-in-water nano emulsion with canola oil | (Güdük et al., 2017) |
| Nano-BC: SPI, 1:20, 1:15, 1:10, and 1:5 w/w | Nano-bacterial cellulose/soy protein isolate | ice cream as the cream substitute | (Zhang et al., 2018) |
| High-throughput encapsulation | whey and soy protein hydrogels | bioactive delivery systems | (Echeugoyen et al., 2016) |
| Dispersion, desolvation, drug incorporation, cross-linking, and evaporation | Soy protein | Nutraceutical Encapsulation | (Teng et al., 2012) |
| Nano encapsulated | pectin-whey protein nano-complexes | carriers of orange peel oil | (Ghasemi, 2017) |
| High intensity ultrasound | lutein encapsulated whey protein nano-emulsion | food and beverage industries and dietary supplements | (Zhao, 2018) |
| Nanoparticle protein corona (NP-PC) by gel electrophoresis. Chemical fabrication of the NP | Nanoparticles and protein | Modify transfer of protein, promote translocation of NP across cellular barriers. | (Saptarshi, 2013) |
| Novel polyphenol encapsulation by high speed and high pressure homogenized oil-in-water emulsion. | Water insoluble compound of curcumin, Dibenzo methane. | Anti-inflammatory activity | (Huang et al., 2008) |
| Nano emulsion. High energy and low energy approaches | Solvents- n-hexene, sunflower oil, MCTs, Emulsifiers- lipids, flavors, antioxidants, antimicrobial drugs. | Improve bioavailability and stability of active compound. | (Silva et al., 2012) |

Like nano emulsion, nanopilosomes increases the stability, and ionic strength of food products. Nanopilosome is mainly used as a colloidal delivery system to deliver hydrophobic bioactive and functional agents (Mehmani et al., 2019). When resveratrol was encapsulated in soy protein Isolates exhibited higher low energy and high-energy methods. Low energy method used to prepare oil/water nano emulsion. Commonly used low energy techniques are phase inversion temperature (PIT), phase inversion composition (PIC), and spontaneous emulsion (SE). High-energy methods are the most appropriate for the preparation of nano emulsions in food industries because of the utilization of non-tox/natural emulsifiers at lower concentration levels. High energy methods are mechanical procedures where mechanical equipment is used to separate the dispersed phase into droplets inside the continuous phase and generate highly disruptive forces. High-energy methods include rotor-stator emulsification (RSE), high-pressure homogenization (HPH), high-pressure microfluidic homogenization (HPMH), and ultrasonic homogenization (USH) (Liu et al., 2019). Different method of nano protein production from various protein source is shown on Tab 1.

Correlations between the properties of different crystal ranges of nanoparticle and their suitability in food applications

No single technique can provide information about the properties of different crystal ranges of nanoparticles as result different types of analytical methods are required to determine the size distribution and properties of nanoparticles. Analytical tools used are ranging from electron microscopy to dynamic light scattering to field-flow fractionation techniques. Particle size affects the texture of nanoparticles. Small particle size is desirable than large particles for sensory properties and functional performance. The size distribution of nanoparticles is an important factor for their functionality. The size distribution of nanoparticles is an important factor for their functionality. The size distribution of nanoparticles is an important factor for their functionality.
encapsulated in soy protein-based nano emulsion and is stable against pH 2.0 and pH 12.0. Lactoferrin which is an antimicrobial component of whey protein when encapsulated in liposome nanoparticles is more stable at 37°C for 4 h in the stomach (Cabuk et al., 2014).

In the food industry, the demands and applications of nanomaterials are higher than microscale materials. Nanomaterials are more suitable to develop food products because of their higher exposure per unit mass, different routes of exposure, wide distribution to tissue due to their small size. Another important property of nano-scale material is that it can alter absorption, digestion, metabolism, or excretion in the body (Srinivas et al., 2010).

Correlations between various physical properties, antioxidant activity, and crystal size of the nanoparticle

Antioxidant molecules interact with free radicals, prevent chain reactions and protect the human body from the harmful effect of oxidative stress (Lobo et al., 2010). Antioxidants may be obtained from endogenous sources such as glutathione or exogenous sources, which are generally present in our diet. Recently nanomaterials antioxidant and nano encapsulated antioxidant have been developed from inorganics or biological sources. Melamin nanoparticles act as a potential antioxidant (Liu et al., 2017). Au, Ag, Pt are used to develop metal nanoparticles due to their antioxidant activity (Yusof and Ismail, 2015). Nanoparticles protect antioxidants from environmental factors, increase the bioavailability of antioxidants and deliver them to the target site. An antioxidant can be formed from redox inactive nanomaterial by grafting low molecular weight antioxidants on them. Natural antioxidant conjugated with nanoparticles has shown increase chemical stability, intact molecular form, slow and continuous release of bioactive component (Chakraborty and Jana, 2017). The antioxidant activity of gallic acid referenced by encapsulated into zein nanofibers. Zein nanofibers are produced by using the electrospinning method (Martins et al., 2018). Another study investigated the reactive oxygen species (ROS) generating capacity of TiO2 nanoparticles with varying crystal sizes but the same crystal phase. The result has been shown that the highest ROS generation per unit area occurs for 30 nm particles and it is constant above 30 nm. The ROS generating activity was decreased as the crystal size decreased from 30nm-10nm and constant for 10nm particle size (Jiang et al., 2008).

Nutritional properties of nanoparticles concerning crystal size and physiological problem.

Nanoparticles act as a vehicle to deliver the nutritional and bioactive component to the target cell, the main aim of this method is to improve Nutrition, health and reduce the risk of disease. Nutrients that are used to apply nanotechnology include fat-soluble vitamins eg. A, D, E, water-soluble vitamins c, B12, iron, amino acid, folic acid, zinc, and calcium (Kulkarni et al., 2016). When nutrient or other bioactive compounds are encapsulated in a suitable nanocarrier, they are released after consumption of the food and utilized based on nutritional properties. Structural lipids have been used as carriers of a healthy component to inhibit the transport of cholesterol from the digestive system to the bloodstream. The phthalates are used as biological precursors for the formation of bioactive compounds and is deposited in all regions. Protein with a diameter <10nm is deposited in the tracheobronchial region whereas nano protein with 10-20 nm diameter deposits in the alveolar. Deposition of nano protein in the respiratory tract for a prolonged period leads to increased translocation to the pulmonary interstitium which enhances the impairment of the function of alveolar macrophage (Gatto et al., 2014).

Effect in Respiratory tract

Studies related to toxicology reported that nano protein with a diameter less than 100 nm affects respiratory organs. Nanoparticles of different sizes are deposited in the respiratory tract by inhalation. It has been observed that different size of nano protein is distributed differently in various part of the respiratory tract. Ultrafine particle less than 100nm is deposited in all regions. Protein with a diameter <10nm is deposited in the tracheobronchial region whereas nano protein with 10-20 nm diameter deposits in the alveolar. Deposition of nano protein in the respiratory tract for a prolonged period leads to increased translocation to the pulmonary interstitium which enhances the impairment of the function of alveolar macrophage (Gatto et al., 2014).

Effect in Renal system

Nanoparticle is also deposited into renal tissue and they can escape from normal phagocytosis defences which lead to toxicity. Gelatine nano protein is also used as an immunological adjuvant to influence cellular response against a foreign antigen. Protein like ovalbumin and serum albumin is used to deliver many therapeutic drugs and endogenous molecules due to its biodegradable, easy synthesis, well-controlled size, and easy modification of its functional group on its molecular surface. The other advantage is that drug released from albumin nanoparticles is easily digested by protease enzyme. Albumin carries hydrophobic molecules and reduces the effect of solvent-based toxicity for bodies (Cheng et al., 2016). Several studies have shown that the activity of the bioactive compound is increased when it is in denatured conformation than that of its native state. Conformational changes in protein occur during immobilization and adsorption. This plays a significant role in the design of protein-based nanoparticle. To increase the adsorption of protein on the nanoparticle surface, nanoparticle protein corona (NP-PC) a nanoparticle complex is formed NP-PC influences the activity of protein particle food (Cedervall et al., 2007; Saptarsi et al., 2013). Nano emulsion is useful to treat infection of the reticuloendothelial system (RES). It is also applied for enzyme replacement therapy in the liver, treatment of cancer, and vaccination (Jaiswal et al., 2015).

Physicochemical properties of nanoparticles

Physico-chemical properties are the most important concern for the production of a nanoparticle. The development and effective function of nano protein mostly depend upon pH, size of the particle, and thermal stability.
pH

Several physical properties of nanomaterials make it suitable to apply in different fields like tribology, surface engineering, nanofabrication, and nonmanufacturing. The electric charge on the surface of nano emulsion plays an important role to stabilize it. Studies reported a negligible influence of pH on the particle size of nano emulsion. When pH increases from 7 to 10 the PI value decreases about 0.3 which indicates an effective monodispersity of the nano emulsion. (He et al., 2011; Khan and Saeed, 2017). Nano complex is formed by the electrostatic interaction between components of nano complexes, pH is an important parameter for the formation of nano complexes by determining the degree of ionization of protein. The net charge of the protein is zero at the pi, which leads to pH-related instability of protein nanoparticles. The pH-induced instability of the coacervate nanocomplex is used in drug delivery systems as stimuli-responsive drug released particles. A high protein charge increases the stability of protein micelles and makes the micelles resistant to heat and dehydration (Saptarshi et al., 2013).  

Particle size

Particle size plays a major role in the activity of nanomaterials in biological systems. Generally, the size of nanoparticles ranges from 1-100 nanometres. The size of nanoparticles can vary and it depends upon the molecular weight of the protein-polymer used in the production of the nanoparticle. Nanoparticle size is controlled by preventing the aggregation process. The prevention of aggregation is done by reducing the disulphide bond or by altering the charge of the polymer. Nanoparticle size also depends on the technique which is used to produce those (Saptarshi et al., 2013). When the size of the nanoparticle is decreased, its surface area is increased and the nanoparticle becomes more active. Studies have been shown that particle size affects various biological systems such as endocytosis, cellular uptake. The pharmacological used size of Nanoparticle determines the behaviour of drugs. Nanoparticles smaller than 50nm when administered intravenously, reach rapidly to every tissue and exert a toxic effect in various tissue (Gatoo et al., 2014). Nano emulsions have a droplet size of about 100 nm. Sometimes nano emulsions are transparent in appearance because their droplet size is smaller than the wavelength of visible light. The appearance of nano emulsion102 is altered by controlling the size of the droplet (Gupta et al., 2016).

Table 2 Role of Nano protein in Nutrition and Food science

| Area | Nano particle | Beneficial effect | Author |
|------|---------------|-------------------|--------|
| Macro and micronutrient | Encapsulation of protein vitamin, fat and antioxidant. | Increase bioavailability, retain nutritional value, controlled release of bioactive compound. | (Sonkaria, Khare, Ahn, 2012) |
| Probiotic | Nanoencapsulation of beneficial microorganism | Functions and properties of probiotics are not affected, resistant from degradation. | (Chung, 2010) |
| Pigments (anthocyanin) | Cyanidin 3 O glycoside is encapsulated within inner cavity of soybean seeds. | Thermal stability of anthocyanin is improved. | (Zhang et al., 2014) |
| Flavonoids | Encapsulation of rutin with homogenous soybean seed ferritin. | Protect rutin from UV-radiation and decrease degradation. | (Yang et al., 2015) |
| Nutraceuticals | Formation of nano emulsion by using food ingredient. | Increased bioavailability, effective for drug delivery system. | (Remendetto, 2006) |
| Metalloxide | Encapsulation of SiO2 | Improve flavor and fragrance of food material. | (Remendetto, 2006) |

Macro and micronutrient

In the aspect of food and nutrition, nanotechnology confers a wide range of opportunities to improve the quality of the food and enhancement of food taste. Nutritional products produced by using nanotechnology are available in the market. Retention of flavor, color, and nutritive value of food material is the most important concern for the food industry. In this order, nanotechnology is used as a delivery agent to deliver nutritional supplements such as protein, vitamins, fats, and antioxidants. Several biological compounds with low bioavailability are affected by solubility and stability which may result in decreased absorption of the nutrient in the body. This problem is solved by using nanotechnology. To increase the bioavailability of nutrients susceptible to degradation novel nanoencapsulation methods have been developed. This method offers an effective route to maintain nutritional value, stability, and controlled release of bioactive components (Srinivas et al., 2010; Sankaria et al., 2012). Nanoparticles may alter the absorption, digestion, metabolism, and excretion in the body due to its several beneficial properties such as higher exposure of per unit mass, small size, large surface area, different route of exposure, different distribution to tissues because of their different size, surface coating or particle charge (Srinivas et al., 2010).

Antioxidant

Zhang et al., (2014) developed the process of encapsulation of anthocyanin, a major group of water-soluble plant pigment. Anthocyanin is a potential antioxidant, anticancer, anti-inflammatory, anti-diabetic, and antiaging and cardioprotective agent. But the main problems are oxonion ions present in anthocyanin makes it vulnerable to nuclophile attack by various antioxidants and difficulties in the storage of anthocyanin due to its instability by heat, oxygen, light, and some enzymes. To avoid these major problems Cyanidin 3-O-glucoside (C3G) molecules are encapsulated in the inner cavity of apo recombinant soybean seed, as a result, the thermal stability of anthocyanin is improved. The study conducted by Yang et al., (2015) describe that encapsulation of hydrophobic rutin molecule is possible. Through this method, the thermal and UV radiation stability of rutin trapped within ferritin is increased. The antioxidant activity of FRNs was also retained as compared to free rutin.

Probiotic

In recent year’s nanotechnology play a vital role in the delivery of probiotics that protect our body from diseases and provide nourishment through a biological process. Nanoencapsulation of beneficial microorganisms such as L. salivarius, L. acidophilus, and Saccharomyces spp. Thermophiles and Bifidobacterium confer health benefit effects by improving digestion of food, increase energy storage, fermentation of sugar, preventing the formation of tumours, stimulating the release of antibiotics, and inhibit the development of the pathogenic condition. Probiotic bacteria coated with nanoparticles are resistant to degradation by gastric acid. Encapsulated probiotics are beneficial to human as their functions and properties are not affected during processing and they can reach target locations in the body without degradation (Chung et al., 2010) A protective coating for lactic acid bacteria have been developed which is resistant to heat, acid, and bile and has increased stability (Sankaria et al., 2012).

Nutraceutical

The delivery of lipid-soluble bioactive compounds is done by using nano emulsion which can be prepared by natural food ingredients and designed in such a way that it can enhance water dispersion and bioavailability of food ingredients (Singh et al., 2018). Nanoparticles improve the bioavailability of nutraceutical compounds due to their subcellular size beneficial for higher drug bioavailability. To improve the bioavailability of nutraceutical compounds, the food industry trying to increase the circulation time of nanocarriers in the GI tract, by surface coating with a protein. SiO2 nanoparticles are used in food to improve the fragrance or flavor of food products. The major life-supportive bioactive compound such as lipids, proteins, fat, and carbohydrate are sensitive to high acidic environments and enzymatic activity of the stomach. Nanoencapsulation of this compound protect them from any adverse condition and helps to assimilate easily in food products in


terms of improved digestibility of those bioactive compounds, which is hard to achieve in case of non-capulated form because of their low water solubility. Polymetric nanoparticles are effective for the encapsulation of bioactive compounds such as flavonoids and vitamins to protect and transport them to the target cells (Chen et al., 2006).

CONCLUSION

In recent few decades, nano protein and nanotechnology give a promising effect in the food industry. It is used in food processing and food packaging technology. Nano proteins preserve food and enhance shelf life which ensures the health aspect of the consumer. It can retain the color, flavor, texture, and appearance of the bioactive compound as a result it is considered an effective vehicle system to deliver micronutrients, antioxidants, nutraceuticals to the target tissue. The methods of formation of nano protein from different sources are under investigation. The use of nano protein in various aspects is increased day by day.

Conflict of Interest: The authors are unanimous in publishing this paper. There is also nobody to contradict this manuscript.

Acknowledgements: The authors would like to express their deep gratitude to the West Bengal State University, Barasat for giving permission to conduct this study. We are also indebted to the teachers of Dept. of Food and Nutrition, WBSU, Barasat for their kind assistance during review.

REFERENCES

Arora, A., & Padua, G.W. (2010). Review: Nano composite in food packaging. Journal of Food Science, 75(1), 43–49. https://doi.org/10.1111/j.1570-8480.2009.01556.x

Abdou, E.S., Osheba, A.S., & Sorour, M.A. (2012). Effect of chitosan and chitosan-nanoparticles as an active coating on microbiological characteristics of fish fingers. International Journal of Applied Science and Technology, 2, 158–166.

Anderson, T.J., & Lamsal, P.B. (2011). REVIEW: Zein Extraction from Corn, Corn Products, and Coproducts and Modifications for Various Application. Cereal Chemistry, 88, 159–173. https://doi.org/10.1094/CCHEM-06-10-0091

Burcu, C., Burcu, O., Nicoleta, S., & Harsa, S. (2014). Nanoencapsulation biologically active peptides whey protein. Journal of Nutritional Health & Food Science, 5(6), 062001. https://doi.org/10.15226/jnhs.2014.00126

Brandenburg, A., Weller, C.L., & Testin, R.F. (1993). Edible films and coating from soya protein. Journal of food science, 58(5),1365-2621.

Bajpai, V.K., Kamble, M., Shukla, S., Mahato, D.K., Chandra, P., & Hwang, S.K. (2018). Prospects of using nanotechnology for food preservation, safety, and security. Journal of Food and Drug Analysis, 26(4), 1201-1204. https://doi.org/10.1016/j.jfda.2018.06.011

Chaudhury, Q., Scotter, M., Blackburn, J., Ross, B., Boxail, A., Castle, L., Aitken, J., & Laurent, B. (2015). REVIEW: Zein Extraction from Corn, Corn Products, and Coproducts and Modifications for Various Application. Journal of Food Science & Technology, 49, https://doi.org/10.3920/jfst.2015.04008

Chen, L., Remondetto, G.E., & Subradi, M. (2006). Food protein-based materials as nutraceutical delivery systems. Journal of Food Science & Technology, 17(5), 272–283. https://doi.org/10.1007/s11694-006-1211-1

Chung, M.J., Kim, D.M., & Lee, G.S.A. (2010). Method of preparing triple coating based materials for oil in water emulsions. Korean J. Pharmacognosy reviews. 4(8), 118–126. https://doi.org/10.3390/kjpr.4.2011.7402996

Dawson, K. (2011). Presence and risks of nanosilica in food applications in food packaging. Food Hydrocolloids, 24(23), 1-6. https://doi.org/10.1016/j.foodhyd.2017.04.027

Dekkers, S., Krystek, P., Peters, R.J., Lankveld, P.K., Bokkers, B.G., & Arentzen, V.H. (2011). Presence and risks of nanosilica in food products. Nanotoxicology, 5(3), 393–405. https://doi.org/10.1080/19345309.2010.519036

DeFrates, K., Markiewicz, T., Gallo, P., Rack, A., Weyhmiller, A., Jarmusik, B., & Hu, X. (2018). Protein Polymer-Based Nanoparticles: Fabrication and Medical Applications. International Journal of Molecular Science, 19(6), (1717). https://doi.org/10.3390/ijms19061717

Gatto, M.A., Naseem, S., Arfat, M.Y., Dar, M.A., Qasim, K., & Zubair, S. (2014). Physical and Chemical Properties of Nanomaterial: Implication in Associated Toxic Manifestations. Biomed Research International, 2014, 1-8. https://doi.org/10.1155/2014/498420

Guo, Y., Zhang, X., Hao, W., Xie, Y., Chen, L., Zhu, B., Li, Z., & Feng, X. (2018). Nano-bacterial cellulose/seoy protein isolate complex gel as fat substitutes in ice cream model. PloS One, 13, 1-20. https://doi.org/10.1371/journal.pone.0198536

Gupta, A., Eral, B.H., Hatton, A.T., & Doyle, S.P. (2016). Nanoemulsions: formation, properties, and applications. Royal Society of Chemistry, 2016, 12, 2826-2841. https://doi.org/10.1039/C5SM02958A

Ghasemi, S., Jafri, S.M., Assadpour, E., & Khomeiri, M. (2017). Production of pectin-whey protein nano-composites as carriers of orange peel oil. Carbohydrate polymers, 177 (2017), 369–377. https://doi.org/10.1016/j.carbpol.2017.09.009

He, W., Tan, Y., Tan, Z., Chen, L., & Wu, W. (2011). Food protein-stabilized nanoemulsions as potential delivery systems for poorly water-soluble drugs: preparation, in vitro characterization, and pharmacokinetics in rats; International Journal of Nanomedicine, 116(6), 521–533. https://doi.org/10.1214/AIHP140172824 Taiswal, M., Dudhe, R., & Sharma, P.K. (2015). Nanoemulsion: an advanced drug delivery system. Biotechnology, 5, 123–127.

Jiang, J., Oberdorster, G., Elder, A., Gelein, R., Mercer, E. & Biswas, P. (2008). Does Nanoparticle Activity Depend Upon Size and Crystal Phase? Nanotoxicology, 2(1), 33–42. https://doi.org/10.1080/175089920819708247

Kinsella, J.E., Whitehead, D.M., & Brady, J. (1989). Milk proteins: Possible relationships of structure and function. Developments in Dairy Chemistry, 4, 131-172.

Kulkarni, A.S., Ghugre, P.S., & Udipi, S.A. (2016). 15 - Applications of nanotechnology in nutrition; potential and safety issues. Novel Approaches of Nanotechnology in Food, 1, 509-554. https://doi.org/10.1016/B978-0-08-104380-0.00015-7

Liu, Q., Huang, H., Chen, H., Lin, J., & Wang, Q. (2019). Food-Grade Nanoemulsions: Preparation, Stability, and Application in Encapsulation of Bioactive Molecules. Molecules, 24(23), 1-14. https://doi.org/10.3390/molecules24234242

Liu, F., & Tang, C.H. (2013). Soy protein nanoparticles at Pickering stabilizers for oil in water emulsions. Journal of Agricultural and food industry, 61, 37, 8888–8898. https://doi.org/10.1016/j.jafia.2013.02.006

Lobo, V., Pattil, A., Phatak, A., & Chandra, N. (2010). Free radicals, antioxidants, and functional foods: Impacts on human health. Pharmacognosy reviews. 4(8), 118–126. https://doi.org/10.3923/pr.2014.793.7402

Liu, Y., Ai, K., J., Xi, Askhatova, D., Du, R., Lu, L., & Shi, J. (2017). Comprehensive insights into the multi-antioxidative mechanisms of melanin nanoparticles and their application to protect the brain from injury in ischemic stroke. Journal of American Chemical Society, 139(2), 856–862. https://doi.org/10.1021/jacs.6b01103

Moham, A., Rajendra, S.R.C.K., & Laurent, B. (2015). Encapsulation of food protein hydrolysate and peptide. RSC Advance, 5, 79270-79278. https://doi.org/10.1039/C5RA13419F

Mohan, A., Rajendra, S.R.C.K., & Laurent, B. (2015). Encapsulation of food protein hydrolysate and peptide. RSC Advance, 5, 79270-79278. https://doi.org/10.1039/C5RA13419F

Peles, Z., Binderman, I., Berdicevsky, I., & Zilberman, M. (2013). Soy protein film wound healing application. Journal of Tissue Engineering and Regenerative Medicine, 7(5), 401-412. https://doi.org/10.1002/term.536

Srinivas, P.R., Philibert, M., Vu, T.Q., Huang, Q., Kokini, J.L., Saos, E., & Ross, A. S. (2010). Nanotechnology research: Application in nutrition science. Journal of Nutrition, 140, 119-124. https://doi.org/10.3945/jn.109.115048
Singh, T., Shukla, S., Kumar, P., Wahla, V. & Bajpai V.K. (2017). Application of nanotechnology in food science: perception and overview. Frontiers in Microbiology, 8(1501), 1-8. https://doi.org/10.3389/fmicb.2017.01501

Sharma, C., Dhiman, R., Rokana, R., & Panwar, H. (2017). Nanotechnology: an untapped resource for food packaging. Frontiers in Microbiology, 8(1735), 1-22. https://doi.org/10.3389/fmicb.2017.01735

Sankarta, S., Ahn, S.H., Khare, V. (2012). Nanotechnology and its impact on food and nutrition: a review. Recent Patents on Food, Nutrition & Agriculture, 4(1), 8-18. https://doi.org/10.2174/2212798411204010008

Saptarshi, S.R., Duschi, A., Lopata, A.L. (2013). Interaction of nanoparticles with proteins: relation to bio-reactivity of the nanoparticle. Journal of Nanobiotechnology, 11(26), 1-12. http://www.jnanobiotecnology.com/content/11/1/26

Schmidt, D.G., & Markwijk, B.W. (1993). Enzymatic hydrolysis of whey proteins. Influence of heat-treatment of α-lactalbumin and β-lactoglobulin on their proteolysis by pepsin and papaain. Netherland Milk Dairy Journal, 47, 15-22.

Singh, P.K., Jarath, G., & Ahlawat,S.(2016). Nanotechnology: a future tool to improve quality and safety in the meat industry. Journal Food Science and Technology, 53(4), 1739–1749. https://doi.org/10.1007/s13197-015-2090-y

Srimvas, P.R, Philbert, M., Vu, T.Q., Huang, Q., Kokini, J.L., & Saos, E. (2010). Nanotechnology research: Application in nutrition science. Journal of nutrition, 140, 119-124. https://doi.org/10.3945/jn.109.115048

Shipgelman, A., Cohen, Y., & Livney, Y.D. (2012). Thermally-induced β-lactoglobulin-EGCG nano vehicles: loading, stability, sensory and digestive release study. Food Hydrocolloids, 29, 57–67. https://doi.org/10.1016/j.foodhyd.2012.01.016

Sengupta, S., Bhattacharyya, D.K., Goswami, R., Bhowal, J. (2019). Emulsions stabilized by soy protein nanoparticles as potential functional non-dairy yogurts. Journal of the Science of Food and Agriculture, 99 (13), 5808-5818. https://doi.org/10.1002/jsfa.9851

Sengupta, S., Bhattacharyya, D.K., & Bhowal, J.(2018). Improved Quality Attributes in Soy Yoghurts Prepared From DAG Enriched Edible Oils and Edible Deoiled Soy Flour. European Journal of Lipid Science and Technology, 120(8), 1-10. https://doi.org/10.1002/ejlt.201800033

Sengupta, S., Koley, H., Dutta, S., & Bhowal, J. (2019a). Hepatoprotective effects of synthetic soy yogurt on mice fed on high cholesterol diet. Nutrition,63-64, 36-44. https://doi.org/10.1016/j.nut.2019.01.009

Sengupta, S., Koley, H., Dutta, S., & Bhowal, J. (2019b). Antioxidant and hypocholesterolemic properties of functional soy yogurts fortified with α-3 and α-6 polyunsaturated fatty acids in Balb/c mice. European Journal of Lipid Science and Technology, 1800397, 1-12. https://doi.org/10.1002/ejlt.201800397

Tansaz, S. (2016). Biomedical application of soy protein. Journal of biomedical natural resource, 104(2), 553-569. https://doi.org/10.1002/jbnr.a.35569

Teng, Z., Luo, Y., & Wang, Q. (2012). Nanoparticles Synthesized from Soy Protein: Preparation, Characterization, and Application for Nutraceutical Encapsulation. Journal of Agriculture and Food Chemistry, 60(10), 2712–2720. https://doi.org/10.1021/jf205238x

Yusof, F., & Ismail, N.A.S. (2015). Antioxidants effects of platinum nanoparticles: A potential alternative treatment to lung diseases. Journal of Applied Pharmaceutical Science, 5, 140–145. https://doi.org/10.17341/japs.2015.50722

Yalcinsoz, S., & Ercelebi, E. (2018). Potential application of nanomulsion in the food system. Materials Research Express, 5, 062001.https://doi.org/10.1088/2053-5336/aa3b91

Yang, R., Zhou, Z., Sun, G., Gao, Y., Xu, J., Struppe, P. & Ding, X. (2015). Synthesis of homogeneous protein-stabilized rutin nanodispersions by the reversible assembly of soybean (Glycine max) seed ferritin. RSC Advances. 5, 31533–31540. https://doi.org/10.1039/C5RA03542B

Yin, B., Deng, W., Xu, K., Huang, L., & Yao, P. (2012). Stable nano-sized emulsions produced from soy protein and soy polysaccharide complexes. Journal of Colloid and Interface Science, 380, 51–59. https://doi.org/10.1016/j.jcis.2012.04.075

Yildiz, G., Andrade, J., Engeseth, E.N, & Feng, H. (2017). Functionalizing soy protein nano-aggregates with pH shifting and nano-thermo-sonication. Journal of colloid and interface science, 505, 836-846. https://doi.org/10.1016/j.jcis.2017.06.088

Yi, J., Lam, T. I., Yokoyama, W., Cheng, L. W., & Zhong, F. (2015). Beta-carotene encapsulated in food protein nanoparticles reduces peroxyl radical oxidation in Caco-2 cells. Food Hydrocolloids. 43, 31–40. https://doi.org/10.1016/j.foodhyd.2014.04.028

Zhang, T., Lv, C., Chen, L., Bai, G., Zhao, G., & Xu, C. (2014). Encapsulation of anthocyanin molecules within a ferritin nanocage increases their stability and cell uptake efficiency. Food Research International. 62, 183–192. https://doi.org/10.1016/j.foodres.2014.02.041

Zhao, C., Shen, X., & Guo, M. (2018). Stability of Lutein Encapsulated Whey Protein Nano-Emulsion During Storage. PLoS ONE 13(2),1-10. https://doi.org/10.1371/journal.pone.0192511