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DIETARY NANO PARTICLE—THE FOOD SAFETY PERSPECTIVES

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Nanotechnology have immense applications in diverse fields of science including electronics, communication, energy production, medicine and the food sector. It is considered that nanotechnology has the substantial potential to revolutionize agriculture and food systems. In food industry nanoparticle has got immense use. It is used to incorporate nutraceuticals in nanocapsules to enhance its bioavailability. Processed nanostructured or nanotextured food claims to have the advantage of less use of fat and emulsifiers but better taste. Beside food supplements they are also used as animal feed. Nanometerials can range from adding food colors, preservatives, flavorings agents to nutritional supplements and antimicrobials Surface-functionalized nanomaterials. A range of inorganic additives silver, iron, silica, titanium dioxide, selenium, calcium, magnesium, platinum is also available for supplements, nutraceuticals, and food and feed applications. Nanotechnology has also applications in food and beverages. Although some uses of nanotechnology in agriculture and food industry are mainly still in research and waiting approval yet to occur on the market including novel nanosensors, new packaging materials with improved mechanical and barrier properties, and efficient and targeted nutrient delivery systems. In this review we will see how scientists have provided insights into the potential benefits of nanotechnology in food processing and consumer safety.

Keywords: Nanoengineered food, Dietary nanosensors, Nutrition, Packaging, Regulations

WHY NANOTECHNOLOGY IS IMPORTANT IN FOOD INDUSTRY

Nanofood has been developed using different nanotechnology methods or tools in which either nanoparticles directly incorporated or engineered to be in contact with food materials (1-3). Many natural food structures contains nanoscale components (4, 5). The purpose of nanofood is to improve food safety(6-8), enhance nutrition and flavor (5), increase stability(9) and cut costs (10) by increasing its availability (8, 9, 11-14). Nanoparticles in food are now becoming important as a carrier of antimicrobial polypeptides to prevent microbial deterioration of food during processing and storage (8).

Nanotechnology is a fast growing and promising innovation. Roughly there are six major areas of application of nanotechnology in food (3, 4). They are packaging, food additives for flavour and colour enhancers, food fortification, increasing preservation life, microbial sensor system and sensor for possible adulterants (5, 9). In a first group, nanotechnology is applied as a production tool, without the addition of nanoparticles to the food (15-17). In the consequent groups, nanoparticles are introduced into the food as a whole (16). Examples are the use of nanoparticles, nanotubes and nanosieves to filter out bacteria and nanosensors for the detection of contaminants or micro-organisms (18). These sensors can also be incorporated in food packaging materials to detect food deterioration (18-20). In food storage, silver along with silica, magnesium and zinc oxide are frequently used (21). This may lead to direct exposure of the consumers to the

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nanoparticles through consumption of food (11). Nanotechnology may revolutionize the food system and has the potential to influence the science of food in a positive way, as it could generate innovation in food texture, taste, processability, and stability during shelf life (22-25). Although scientists are of the opinion that nanomaterials are fundamentally different substances that create new and unique risks to human health and the environment and require new forms of safety monitoring (13).

INORGANIC NANOMATERIALS IN FOOD INDUSTRY

Inorganic nanomaterials can be used as building blocks to create novel structures and introduce new functionalities into foods (26-28). They have found application as component of packaging material of different food products and natural or organic nanoparticles used to incorporate various food additives like color flavour and preserving components (27, 29, 30).

For storage include ENMs of transition metals, such as silver, iron, alkaline earth metals, such as calcium and magnesium; and non-metals, such as selenium and silicates are used (28). Other ENMs that can potentially be used in food applications include titanium dioxide (30, 31). Food packaging is the major area of application of metal oxide ENMs (9, 31). Some of them can also be used as health supplements like Nanocalcium and nanomagnesium and other like silver as antimicrobial agent (22, 23).

Amorphous nanosilica is known to be used in food contact surfaces and food packaging applications. Nanoselenium is being marketed as an additive to a green tea product (30, 32), resulting from enhanced uptake of selenium (26, 32). Soluble nano salt enable consumers to cut down their salt intake (3, 30).

EDIBLE FORM OF NANO PARTICLE DERIVED FROM NATURAL SOURCES

Nature derived nanoparticles has got potential applications in the area of functional food. Dietary fibres can play vital role in developing the nanoparticles (33, 34). The naturally occurring edible biological molecules made up of dietary fibres opening up a whole new area of research and development (6, 7). When the macromolecules are functionally engineered into nano materials they are found to behave differently from those in nature (14). Now the question is, what are the potential health benefits of Natural dietary fibres if used as nano carriers.

Naturally occurring nanostructures in foods can be easily designed to improve the functional behavior of the food (35). Many foods contain natural nanoscale components which have been consumed safely for generations (33). During processing of food important raw materials like proteins, starches, and fats under different processing condition can undergo structural changes to form nano and micro scale products (35-37).

Casein micelles may be useful as nanovehicles for entrapment, protection and delivery of sensitive hydrophobic nutraceuticals within other food products (33). It is a potential new carrier for nanoencapsulation of nutrients, supplements, and pharmaceuticals, native beta-lactoglobulins (35, 36), can undergo denaturation via pressure, heat, pH, etc. (15) and the denatured components reassemble to form larger structures, like fibrils or aggregates, which in turn can be assembled to form even larger gel like networks (37). Similar structure has been observed in yogurt (36). Self-assembled nanotubes from hydrolyzed milk protein α-lactalbumin, the isolated vesicle–α-LA at low pH, where protein rapidly inserts into the bilayer generating an idea to use it as an important component for nanocarriers of various food components (33). Protein-polysaccharide mixed solutions can spontaneously separate into a phase with nano- or microsized droplets can be dispersed in a continuous phase (37). Starch granules expand when heated and hydrated releasing biopolymers that can be recrystallized into nanosized structures, e.g., dextrins and other degradation (38). In the case of fats, monoglycerides, for example, can selfassemble into many morphologies at the nanoscale level, and hierarchically structured into tryglicerides and rearrange into large clusters, then flocs, and finally, fat crystal networks (38).

The nanostructured food ingredients are being developed with the claims that they offer improved taste, texture and consistency (30). For example, low-fat nanostructured mayonnaise spreads and ice creams containing nanosized imulsifiers obtained from non hygdrogenated vegetable oils claim to be as "creamy" offer a healthier option to the consumer (33). In fact, dairy products contains nanoparticle is not just a microtechnology but also a nanotechnology, and it has existed for a long time (20).

DIETARY FIBRE AND CELLULOSE BASED NANOPARTICLES

Indigestable Dietary fiber or roughage is derived from plants. They are of two types, i.e., soluble and insoluble.

Both are important in developing food grade nano particles.

Prebiotic viscous or Soluble fibers are those which dissolves in water, and get readily fermented in the colon to form into gases and physiologically active by products (37). Insoluble fiber, which does not dissolve in water, is metabolically inert and provides bulking (38). The fibres can be viscous, insoluble and easily dispersible or they can be gelatinous in nature on water absorption (39). Lignin, arabinoxylans, cellulose are major dietary insoluble fiber sources, may alter the rate and metabolism of soluble fibrous nonostructures (27). It has got an important modifying role in lipid metabolism (37). Some but not all soluble plant fibers block intestinal mucosal adherence and translocation of potentially pathogenic bacteria and may therefore modulate intestinal processes by contrabiotic effect (38).

Many other plant components such as dextrins, inulin, chitins, pectins, beta-glucans, and oligosaccharides can also be used as the potential nanocarriers (27, 28). The US Department of Agriculture has adopted a novel idea to isolate functional fibers that may be included in the diet in the form of nanoparticles (36).

Modified celluloses such as ethyl and carboxymethyl derivatives, widely used in the nanofood industry (31). In the nanoparticle form their substituent groups disrupt the hydrogen bonding and the resulting compounds become more soluble. Cellulose is found in abundance in nature in all plant tissues and is therefore a common component of our diet (39). It is gaining popularity because of its remarkable physical properties, special surface chemistry and excellent biological properties biocompatibility, biodegradability and low toxicity (14, 40). Three different types of nanocellulose, viz. cellulose nanocrystals (CNC), cellulose nanofibrils (CNF) and bacterial cellulose (BC) (29), have been introduced for nutraceutical delivery; and immobilization and recognition of enzyme/protein/amino acid (38, 40).

CNF is mainly extracted from wood (27, 29). It can be extracted from natural resources such as fruit pomace, flax, hemp, grass, sorghum, barley, sugar cane, pineapple leaf fibers, banana rachis, soy hulls, algae, potato pulp, rice straw, chardonnay grape-skins, cacti stem, coconut husk, bamboo, pea-hull fiber, cotton and industrial bioresidues. Another type of nanocellulose is bacterial cellulose (BC) (23), which is produced as an extracellular primary metabolite by bacteria belonging to the genera *Acetobacter*, *Gluconacetobacter*, *Agrobacterium*, *Acanthamoeba*, *Aerobacter*, *Azotobacter*, *Rhizobium*, *Escherichia*, *Pseudomonas* and *Alcaligenes* (19).

Cellulose is the most abundant, renewable, and sustainable biopolymer on earth (32). One of the commercially available product is Greenshaft, that contain blends of normal starches and these nanostructured novel starches (37).

APPLICATION-NANOENCAPSULATION OF PROBIOTICS AND MICRONUTRIENTS

Probiotics are live mixtures of bacterial species and can be incorporated in foods in the form of yoghurts and yoghurt-type fermented milk, cheese, puddings and fruit based drinks or can be consumed as nutraceuticals (39). One such example is Dr Kim's probiotic nanofood which is a calcium containing probiotic was developed for the patients suffering from the risk of osteoporosis. Nanoencapsulated designer probiotic bacterial preparations may act as *de novo* vaccines, with the capability of modulating immune responses (40). A wide range of organic nanomaterials are also available incorporating nutraceuticals, like food additives, e.g., benzoic acid, citric acid, ascorbic acid and supplements like vitamins, isoflavones, carotenoids, lutein, omega-fatty acids, coenzyme-Q and lycopene (41). The health benefits of curcumin, epigallocatechin, gallatecan be enhanced in food by nanoemulsion technology (42-44). The natural pigment that gives the spice turmeric its yellow colour, could be enhanced by encapsulation in nanoemulsions (43, 44). Nanoemulsions could improve stability and oral bioavailability of polyphenols like licopene and quercetin (45, 46). A stearin-rich milk fraction was used as emulsifier of α-tocopherol, for the preparation of oil-in-water sodium caseinate-stabilized nanoemulsions (33, 44). Immobilization of α-tocopherol in fat droplets, composed by high melting milk fat triglycerides, provided protection against degradation (47).

SURFACE FUNCTIONALISED NANOMATERIALS

Surface functionalized nanomaterials impart newer functionality to the matrix, like antimicrobial activity or a preservative action through absorption of oxygen (47). Unlike inert nanomaterials, they are more likely to react with different food components, or become bound to food matrices, and hence may not be available for migration from packaging materials, or translocation to other organs outside the GI tract (48, 49).

Amorphous carbon nanocoating inside PET bottle have been reported to be very efficient in controlling oxygen and retaining carbon dioxide levels and can act as oxygen scavengers (50, 51).

Nanoparticle coated with PLGA, polylactic glycolic acid, an FDA-approved compound, is a copolymer of lactic and glycolic acids used as antimicrobial substance for longer shelf life of meat and various other food and yet to get tested clinically (48, 50).

ANALYTICAL USE OF NANONOPARTICLE IN FOOD INDUSTRY

The recent progress of analytical approaches involves detection, isolation and imaging techniques. The electronic nose is a device that uses an array of chemical sensors tied to a data-processing system sense food odours or volatile aroma changes during osmotic dehydration of apple, strawberry, etc., by the nanoparticle sensors and then signal is processed through analyzer equipped with LC/GC/MS-MS (34, 45, 47). Its fine and accurate performance gives reliability in detecting purity of the products. The 'electronic nose' can be used for quality control of milk during industrial processing or monitor product quality (32), quality assurance (33, 34). Similarly nanoparticle has been reported to sense the presence of natural colour gives the safety detection of the chemical adulterants of colouring materials in food (20), Nanosensors can also detect allergen proteins to prevent adverse reactions to foods, such as peanuts, soya protein, milk proteins, egg proteins, and gluten (21).

FOOD PACKAGING

A number of recent reports and reviews have identified many revolutionary use of nanotechnology in the area of food packaging (51). Carbon nanotubes can be used in food packaging to improve its mechanical properties (52). It was recently discovered that carbon nanotubes exhibit powerful antimicrobial effects and *Escherichia coli* bacteria died on immediate direct contact with aggregates of carbon nanotubes (53). In fact, the long, thin nanotubes puncture*E. coli* cells, causing cellular damage (54). Another example is incorporation of preservative benzoic acid to magnesium-aluminium hydrotalcite blended with polycaprolactone to control the release of the antimicrobial molecule films from polypropylene packaging materials (55).

SMART FOOD PACKAGING

Smart packaging responds to environmental conditions, repairs it or alert a consumer to pathogenic contamination (56). Nanoclay developed by Chemical giant Bayer Leverkusen, Germany are used dispersed in the plastic material and are able to block oxygen, carbon dioxide and moisture from reaching fresh meats or other foods (57). Nanocor and Southern Clay Products Austin, USA are now working on a plastic beer bottle that may increase shelf-life to years using nanotechnology (58). Researchers in the Netherlands further developed intelligent packaging that will release preservatives on command, if the packed food begins to spoil (58). Such packaging is already in use in brewing and dairy production and also consists of nanofilters that can filter out micro-organisms and even viruses. Using nanocoated packaging material Lactose can now be filtered from milk, and replaced with another sugar (55, 59), making milk suitable for the lactose-intolerant. Nanoceramic particles help in clustering of dirt molecules, from cooked oil to keep it fresh and the omega fatty acid intact (59, 60). Nano packaging with self-cleaning abilities or nanoscale filters allows the removal of all bacteria from milk or water without boiling (61).

Another important application of nanoparticles in food packaging is the degradation of ripening gas, such as ethylene (62, 63). The other improvements in nanotechnology for food packaging include carbon nanotubes that can be used in packaging material to improve its mechanical properties (64, 65). It has been recently discovered that they might exhibit powerful antimicrobial effects (63). A methodology used to produce polymer nanocomposites with low-cost fibrous materials similar to expensive carbon nanotubes exhibiting optimized dispersion, interfacial bonding, and attractive physical and other properties has been reported for food packaging (66-68). Silver containing Chitosan-based nanocomposite films showed antiallergenic activity in food usage (69-71). PEG coated nanoparticles loaded with garlic essential oil could be used to enhance storage life (67, 68). Phytoglycogen octenyl succinate nanoparticles with [-polylysine significantly also found to increase the shelf life of the product. Here, the nanoparticle created a stronger defense against oxygen, free radical and metal ions that cause lipid oxidation (12, 13). This could reduce the possibly of food spoiling or drying out (23, 24).

EMULSIFICATION – A TECHNIQUE OF PRODUCTION OF FOOD NANOPARTICLES

Nanosized Self-assembled Liquid Structures related to the nanosized vehicles are used as vehicles to fortify with targeted nutraceuticals (36, 40). Other potential applications include assisted delivery of food components like lycopene, beta-carotene, CoQ, omega-fatty acids, phytosterols, and isoflavones (41).

Scientists have reported different ways to fabricate nanoparticles in the unique range that is suitable for the food and drug delivery system (47). Synthetic protein nanostructure acts as surrogate mimics, such as viruses and plasmid for food and drug delivery system (58, 59). The benefits of protein nanoparticles include nontoxicity stability for long duration, nonantigenicity and biodegradability (30, 60).

EMULSIFIED NANOPARTICLE IN FOOD

Emulsified nanoparticles containing glycerine acts as scavengers of pesticides, dirts, from fruits and vegetables (70, 71). Nanoemulsions are gaining popularity in food industry due to their high clarity (71). Beside delivering Nano emulsified bioactives and flavors to a beverage without a change in product appearance (72) they can be used as carrier of antibacterial agents against a variety of food pathogens, for removal of Gram-negative bacteria from food surface, decontamination of food processing plant equipments and for reduction of surface contamination of chicken skin (73). Nano or micro encapsulated physicochemical components of fish oil, sugar beet pectin, soya protein has been considered as an alternative to milk proteins (62). Gum Arabic is another popular choice for the encapsulation of functional food ingredients as well as beverage application (38). Solid lipid nanoparticles are formed by controlled crystallization of food nanoemulsions and have been reported to deliver lycopene and carotenoids (67).

ENCAPSULATION

Nano Encapsulation

Nanocapsules consist of a shell and an internal space in which the desired active compounds are enclosed. The shell is usually built from polymers or lipids (58). The advantage of nanocapsules is that they can deliver the desired active compound in a targeted way, so less amount of active compound may be required for a desired result (59).

Novel encapsulation techniques based on cold-set gelation for delivering heat-sensitive bioactives including probiotics, nutraceuticals have been introduced (62). Use of Maillard conjugates of milk proteins and polysaccharides have been reported for encapsulating bioactives like whey proteins and lactoglobulin, beet pectin, egg albumin, lactoferrin polysaccharide gums for drug targeting (69).

Lipid-based nanoencapsulation systems enhance the performance of antioxidants and different bioactive molecules including nutraceuticals such as vitamins, antioxidants, proteins, and curcumin by improving their solubility and bioavailability, *in vitro* and*in vivo* stability, and preventing their unwanted interactions with other food components (30-32, 43). Scientists formulated beta-carotene within a nanostructured lipid carrier that allows the normally hydrophobic beta-carotene to be easily dispersed and stabilized in beverages (33).

A nanomaterial, called NovaSOL, containing two nutrients to burn fat has been developed by German based company Aquanova Darmstadt, Germany (72). Nanocochleates consists of a purified soy based phospholipid that contains at least about % by weight of lipid that can be phosphatidyl serine, dioleoylphosphatidylserine, phosphatidic acid, phosphatidylinositol, phosphatidyl glycerol and/or a mixture of one or more of these lipids with other lipids (58). Additionally or alternatively, the lipid can include phosphatidylcholine, phosphatidylethanolamine, diphosphotidylglycerol, dioleoyl phosphatidic acid, distearoyl phosphatidylserine, dimyristoyl phosphatidylserine, and dipalmitoyl phosphatidylgycerol (63). Nanocochleates are nanocoiled particles that wrap around micronutrients and have the ability to stabilize and protect an extended range of micronutrients and the potential to increase the nutritional value of processed foods (66).

Low bioavailability and poor solubility correlated with the phytochemicals and nutraceuticals leads to their inadequate absorption resulting in their reduced biological activity (73). By efficient encapsulation of nutraceuticals, smart delivery and sustained release from the nanoformulation the challenge has been tried to overcome (67).

Toxicology of Edible Nanoparticles

It is important to put insight into the toxicological aspects of nanoparticles in the food chain which can impart some possible adverse health effects (73). A nano particle has small size and their large total surface area. It differs from the constituent molecules. Till date only a few data is available on the exposure and harmful effects of nanoparticles, and their distribution pattern in the human system. Its ability to cross barriers in the body to develop toxicokinetic and toxicodynamic properties of nanomaterials compared to conventional chemicals (74). The use of nanoparticles in food needs to be well documented including the associated exposure risks to the consumers. Furthermore, we also have to clearly identify the effects of manufactured and naturally occurring nanoparticles; As previously mentioned the chemical composition and the size, distribution, surface properties and the morphology of nanomaterials can play a very important role (75, 76). For many nanoparticles the mechanism of action in the biosystem is not yet clearly known or how does it affects the system to develop oxidative stress, inflammatory reactions and the interactions with biomolecules such as DNA and proteins (76, 77). It is well known that the nanoparticles equipped with new chemical and physical properties have the potential to interact with the living systems and cause unexpected toxicity (78-80). So far, warnings about nanofoods have not reached a high priority in terms of public attention (79). Different untested nanoproducts are being used in more than food products, food packaging and contact materials without FDA approva (80). A listing of nanorelated food and beverage is provided by the Nanotech Project in its Nanotechnology Consumer Products Inventory (81).

Regulation of Nanoparticle in Food Industry

Food nanotechnology is developing rapidly while only a little is known about its fate, and toxicity to the consumers (82). Nanoengineered food ingredients, additives and contact materials like packaging and surface active components have been reported to have potential implications for consumer safety and regulatory controls (75-77). Public concerned about the fate of modified nano food also gives a newer area for its safety research (72, 73). Few reports also suggested that the existing regulations of nanotechnology in several countries, and a certification system of nanoproducts needs to be modified and improved keeping increasing uses in mind (74, 75).

UK Soil Association Bristol (UK) reported that their revised organic standard would prohibit products and processes derived from nanotechnologies (48, 82-84). The current risk assessment approach used by FAO/WHO and Codex is available and appears suitable for ENMs in food (48, 85, 86).

Thus, mandatory testing of nanomodified foods is desirable before they are allowed on the market (87, 88). New approaches and standardized test procedures to study the impact of nanoparticles on living cells are urgently needed for the evaluation of potential hazards relating to human exposure to nanoparticles (89, 90). It is widely expected that nanotechnology-derived food products will be available increasingly to consumers worldwide in the coming years (88).

CONCLUSION

Nanotechnology has the potential to improve foods, making them tastier, healthier, and more nutritious, to generate new food products, new food packaging, and storage (90). However, many of the applications are currently at an elementary stage, and most are aimed at high-value products, at least in the short term (92). Successful applications of nanotechnology to foods are limited. Nanotechnology can be used to enhance food flavor and texture, to reduce fat content, or to encapsulate nutrients, such as vitamins, to ensure they do not degrade during a product's shelf life (87). In addition to this, nanomaterials can be used to make packaging that keeps the product inside fresher for longer (93). Intelligent food packaging, incorporating nanosensors, could even provide consumers with information on the state of the food inside (85). Also the utilization of nanoparticles in food packaging materials as sensor will continue to increase (94, 95). Finally, the potential applications of nanocapsules will continue to expand in all facets of the food industry from ingredients to packaging to food analysis methods are already looking into nanotech applications.

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