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USE OF NANOTECHNOLOGY IN FOOD PROCESSING, PACKAGING AND SAFETY – REVIEW

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ABSTRACT

This review focuses on the use of nanotechnologies in food processing and packaging with special attention to their reflection on food quality and safety. The topic of this review includes application of nanotechnology in food processing, application of nanotechnology in food packaging and food contact materials, nanotechnology and food safety as well as regulation of nanotechnologies to ensure food safety. Nanotechnology has potential applications in all aspects of food sectors including food processing, food packaging, food monitoring, production of functional foods, development of foods capable of modifying their colour, flavour or nutritional properties according to a person's dietary needs as well as production of stronger flavourings, colourings and nutritional food additives. Moreover, lowering the costs of food additive ingredients and increasing the shelf life of food products could be achieved using this technology. The food market demands technologies, which are essential to keep market leadership in the food processing industry to produce fresh authentic, convenient and flavourful food products. Prolonging the product shelf life and freshness as well as improving the quality of food are the target. Nanotechnology is a technology that has the potential to revolutionize the food industry. Developing smart packaging to optimize product shelf life using nanotechnologies has been the goal of many companies. Such packaging systems would be able to repair small holes/tears, respond to environmental conditions such as temperature and moisture changes and alert the customer if the food is contaminated. Nanotechnology can provide solutions for these, for example modifying the permeation behaviour of foils, increasing barrier properties (mechanical, thermal, chemical and microbial), improving mechanical and heat-resistance properties, developing active antimicrobial and antifungal surfaces, and sensing as well as signaling microbiological and biochemical changes and creates the nano-biodegradable packaging. Development of food analytical methods for the detection of tiny amounts of a chemical contaminant, virus or bacteria in food system is another potential use of nanotechnology. This will result in more safety for the food processing system. There is an urgent need for regulatory systems capable of managing any risks associated with nanofoods and the use of nanotechnologies in the food industry.

Key words: Nanotechnology, Nanofoods, Packaging, Safety, Biodegradable

INTRODUCTION

One nm is one thousandth of a micrometre (µm), one millionth of millimetre (mm) and one billionth a metre (m). The expression nanoscale is used to refer to objects with dimensions on the order 1-100 nm. To distinguish the nanoscale, it must be noticed that a strand of DNA is 2.5nm wide; a protein molecule is 5 nm wide [1]. Nanotechnology relates to materials, systems and processes, which operate at a scale between 1- 100 nanometers (nm). Nanotechnology has been also known as having one or more dimensions measuring 100 nm or less, or having at least one dimension at this scale, which affects the materials behavior and properties. For that reason, nanotechnology does not describe a single technology, but a range of technologies.

Nanotechnology is a platform technology. The properties of the recent nonomaterials offer many new opportunities for food industries, which include more potent food colouring, flavouring, nutritional additives and antimicrobial ingredients for food packaging. Nanotechnology is now widely used in many applications in food processing, packaging as well as in agricultural sectors to allow controlled release of herbicides and fertilizers. Moreover, nanotechnologies are used in different sectors, like pesticides, medicines, veterinary medicines, animal feed, biocides, food hygiene and biotechnology, which are now known as nano -biotechnology [2].

The tiny particles (smaller than 100 nm) are classified as nanoparticles, particle less than a micrometre (smaller than 1000 nm) is known as a submicroparticle and a particle larger than 1000 nm is known as microparticle. Nanoparticles have a large surface area, which typically results in greater chemical activity, biological activity and catalytic behaviour compared to large particles of the same chemical composition [3,4].

There are many nanomaterials which are used for different food applications on industrial scale. Titanium dioxide having a particle size of less than 100 nm is widely used as food additive and antimicrobial agent for food packaging and storage containers [5]. Silver nanoparticles are used as antimicrobial agents in food packaging, storage containers, chopping boards and refrigerators and also as health supplement [6]. Zinc and zinc oxide are used as nutritional additives and also as antimicrobial agents in food packaging [7]. Silicon dioxide and carbon have particles of a few hundred nm in size and are used as food additives and for food packaging [8]. Platinum and gold nano-wires are used as biosensors to improve the food analysis [6].

The food market demands technologies, which are essential to keep market leadership in the food processing industry to produce fresh authentic, convenient and flavourful food products. Prolonging the product shelf life and freshness as well as improving the quality of food are the target. Nanotechnology is a technology that has the potential to revolutionize the food industry. Detection of very small amounts of chemical contaminants, virus or bacteria in food systems is another potential use of nanotechnology [9].

Shefer [10] developed a multicomponent system. This system delivers multiple active ingredients that do not normally mix well, such as water-soluble and fat-soluble ingredients, and releases them consecutively. The system consists of solid hydrophobic nanospheres composed of a blend of food-approved hydrophobic materials encapsulated in moisture-sensitive or pH-sensitive bioadhesive microspheres. This encapsulation system has numerous benefits in food processing industry including ease of handling, enhanced stability, protection against oxidation, retention of volatile ingredients, taste masking, moisture controlled release, pH-controlled release, heat–triggered release, consecutive delivery of multiple active ingredients, change in flavour character, long-lasting organoleptic perception and enhanced bioavailability and efficiency [9,10,11].

Really, nanotechnologies are rapidly growing worldwide. Developing countries are also taking part in the development of this technological revolution. Latin America, Brazil, Mexico and Argentina are the leading nations in this area. However, there are other countries taking important steps to develop nanotechnologies and nanosciences [12]. Consequently, it could be noticed that nanotechnology is a scientific area of rapid growth worldwide; many consider it as the basis for the next industrial revolution. It is possible that in the near future no country would be able to escape from the necessity of researching and developing this technology.

Food safety means that all food products must be protected from chemical, biological, physical and radiation contamination through processing, handling and distribution. The present review focuses on the application of nanotechnology in the food processing and food packaging with special attention to their reflection on food quality and safety.

Application of nanotechnology in food processing

Nanofood describes the food, which has been cultivated, produced, processed or packaged using nanotechnology techniques or tools or to which nanomaterials have been added [13]. Nanotechnology is moving out of the laboratory and into every sector of food production. Nanotechnologies are commercially used in the food industry, packaging and storage applications. Estimates of commercially available nanofoods vary widely between 150-600 nanofoods and 400-500 nanofood packaging applications [14,15].

Nanotechnology has potential applications in all aspects food processing, food packaging and food monitoring. Production of functional foods such as soft drinks, ice cream, chocolate and chips are marketed as healthy foods by reducing fat, carbohydrate or calorie content or by increasing protein, fibre or vitamin contents. Development of foods capable of modifying their colour, flavour or nutritional properties according to a person’s dietary needs, allergies, or taste preferences, production of stronger flavourings, colourings and nutritional additives and lowering costs of ingredients. Increasing the shelf life of the products by using packaging materials, which can release antimicrobials or control air and moisture exchange with the environment can be done also by nanotechnology techniques [16]. At the present time, numerous nanofood products are in development. By 2010, it is estimated that sales of nanofoods will be worth almost 6 billion US dollars [14]. Nanofoods which contain nanoscale ingredients and additives are already available on the supermarket shelves. Nestle and Unilever are reported to be developing nanosize emulsion-based ice cream with a lower fat content but that retains a fatty texture and flavour [17].

Nano-encapsulated active ingredients including vitamins and fatty acids are now sold commercially for use in processing and preservations of beverages, meat, cheese and other foods. For example, industrial sausage and cured meat production requires the addition of many additives to speed up the production process, stabilize colour and improve taste. Aquanova, a German Company, has developed a nanotechnology based on carrier system using 30 nm micelles to encapsulate active ingredients such as vitamins C &E and fatty acids, which can be used as preservatives. Aquanova markets these micelles as "NovaSol". The German industry magazine “Fleischwirtschaft" claims that NovaSol offers considerable advantages of faster meat processing, cheaper ingredients, higher colour stability(See Fig. 1) and ready to use liquid form [18]. These nanoadditives have been available to German manufacturers since 2006.

Figure 1: Nanotechnology improves fast food industry

Nanoparticles are added to many foods to improve flow properties, colour and stability during processing, or to increase shelf life. For example, aluminosillcate materials are commonly used as anticaking agents in granular or powdered processed foods, while anatase titanium dioxide is a common food whitener and brightener additive, used in confectionery, some cheeses and sauces [19,20].

Nutritional additives are another growing source for the use of nanoparticles in foods. The Institute of Medicine, U.S National Academy of Sciences defines Functional Foods as foods that provide a health benefit beyond the traditional nutrients which they contain. Nano-encapsulation involves an active ingredient in a nano-size capsule. Dairy products, cereals, breads and beverages are now fortified with vitamins, minerals, probiotics, bioactive peptides, antioxidants and plant sterols. Some of these active ingredients are now being added to foods as nanoparticles or at particles of a few hundred nm in size [21].

Active ingredients including vitamins, preservatives and enzymes have recently been added to foods in microscale capsules. For instance, many of the commonly used Omega-3 food additives are micrometres in size, such as the 140-180 micron micro-encapsulated tuna fish oils, which are used by Nu- Mega Driphorm to fortify Australian bread [22].

Aquanova, Novasol range of nano-encapsulated bioactive ingredients in addition includes vitamins, co-enzymes, isoflavones, flavonoids, carotenoids, preserving agents, food colouring substances and other bioactive substances. These products are found in a wide range of food additives and in beverages additives, such as Solu tm E200 marketed by BASF, which is a vitamin E nano-solution, especially formulated for clear beverages like sports beverages, flavoured and enhanced waters [23].

The effectiveness of these ingredients depends on preserving and enhancing their bioavailability. Nano-sizing or nano-encapsulating active ingredients delivers greater bioavailability, improved solubility and increased potency compared to these substances in larger or micro-encapsulated form. The greater potency of nanoparticle additives may well reduce the quantities of the required additives, and also their greater chemical reactivity [24].

Nanotechnology also promises to provide a means of altering and manipulating food products to more effectively deliver nutrients like protein and antioxidants for precisely targeted nutritional and health benefits. Shefer developed the encapsulated system, which resulted in nanospheres or microspheres[9]. The major potential product applications for the nano-sphere/microsphere system are baked goods, refrigerated/frozen batters, tortillas and flat breads, processed meat products, seasonal confectionery, specialty products, chewing gums, dessert mixes, and nutritional foods [9,10,11].

There are many companies in the food industry that are using nanotechnology. Nutralease Ltd Company has developed novel carriers for nutraceuticals to be incorporated in food systems or cosmetics formulations, increasing the bioavailability of the product. Some of the nutraceuticals incorporated in the carriers include lycopene, beta-carotenes and phytosterols. These products are used in healthy foods, especially to prevent the accumulation of cholesterol [24].

Oilfresh Company introduced anti-oxidation device for the restaurant industry. This company has announced the introduction of Oilfresh1000 in the U.S. market, a catalytic antioxidant device for use in restaurant deep-frying machines, powered by nanotechnology. This product not only keeps frying oil fresh significantly longer, but also allows restaurants the flexibility of switching to more healthful vegetable oils. This results in better taste, crisper deep-fried foods, better consistency of product, lower costs and greater profits, and substantial benefits to health and environment [24].

George Weston Foods of Australia sells a version of its popular Tip Top bread, known as Tip Top–up, which contains microcapsules of tuna fish oil high in omega-3 fatty acids. Because the tuna oil is contained in a microcapsule, the consumer does not taste the fish oil, which is released during digestion once it has reached the stomach. The same technology is also employed in yoghurt and baby foods [24].

Many of the largest companies such as Heinz, Kraft foods and Nestle are investing in nanotechnology and they are on their way to commercializing the products. For example, they are employing the nanotechnology to change the structure of food, creating "interactive" drinks containing nano-capsules that can change colour and flavour (Kraft) and spreads, and also ice cream with nanoparticle emulsions (Unilever, Nestle) to improve texture. Others are inventing small nano-capsules that will smuggle nutrients and flavours into the body [22].

Processing techniques, which produce nanoparticles, particles up to a few hundred nanometres in size, and nanoscale emulsions are used in the manufacture of salad dressings, chocolate syrups, sweeteners, flavoured oils and many other processed foods [24].

The formation of nanoparticles and nanoscale emulsions can result from food processing techniques such as high pressure valve homogenization, dry ball milling, dry jet milling and ultrasound emulsification. Although many food manufacturers may remain completely unaware that their foods contain nanoparticles, it is likely that, these processing techniques are used precisely because the textural changes and flow properties they produce are attractive to the manufacturers [25].

Application of nanotechnology in food packaging and food contact materials

Food packaging is considered to be one of the earliest commercial applications of nanotechnology in the food sector [26]. About 400-500 nano-packaging products are estimated to be in commercial use at the moment, while nanotechnology is predicted to be used in the manufacture of 25% of all food packaging within the next decade [15].

The significant purpose of nano-packaging is to set longer shelf life by improving the barrier function of food packaging to reduce gas and moisture exchange and UV light exposure [27]. For example, Du Pont has announced the release of a nano-titanium dioxide plastic additive namely "DuPont light stabilizer210", which could reduce UV damage of foods in transparent packaging [28].

By 2003, over 90% of nano-packaging was based on nanocomposites, in which nanomaterials were used to improve the barrier function of plastic wrapping for foods, and plastic bottles for beer, soft drinks and juices. Nano-packaging can also be designed to release antimicrobials, antioxidants, enzymes, flavours and nutraceuticals to extend shelf life [29,30].

A UK research institute believes that it has identified safe and effective antimicrobial nanoparticles for food packaging, a discovery that could revolutionize food packaging in the future. The research team reported that nanoparticles of zinc oxide and magnesium oxide have been shown to be effective in killing micro-organisms. Ding and Prove developed new nanocomposites which are assemblies of functionalized nanoparticles, hundreds of micrometers in size, capable of disintegrating in liquid into nanoparticles that can get attached to and kill the microorganisms .These discoveries show what packaging will be like in the future [31].

El Amin reported that exciting new nanotechnology products for food packaging are in the pipeline or, as in the case of anti-microbial films, have already entered the market [32]. He added that in the food packaging sector, nanomaterials are being developed with enhanced mechanical and thermal properties to ensure better protection of foods from external mechanical, thermal, chemical or microbiological effects. This would endow packaged foods with an additional level of safety and functionality. This technology would potentially increase the shelf life of foods.

El Amin has stated that rising consumer demand for improved quality, extended shelf life and environmentally-friendly products, along with enhanced regulations in the EU is pushing for more innovation in the food packaging sector[33]. He added that the food packaging manufacturers are responding to the consumer and regulatory trends by not only focusing on developing economic and effective packages for protecting the food products, but also on the aesthetic value of the packages. Customers today demand a lot more from packaging in terms of protecting the quality, freshness and safety of foods. He believes that the nanotechnology, which uses microscopic particles, is effective and affordable and will bring out suitable food packaging in the near future [33].

A scientific and industrial research at the Norwegian Institute of Technology is using nanotechnology to create tiny particles in the film, to improve the transportation of some gases through the plastic film to pump out dirty air such as carbon dioxide. It is hoped that the concept could be used to block out harmful gases that shorten the shelf life of the foods. The scientists are looking at whether the film could also provide barrier protection and prevent gases such as oxygen and ethylene from deteriorating foods [34].

Waxy coating is used widely for some foods such as apples and cheeses. Recently, nanotechnology has enabled the development of nanoscale edible coatings as thin as 5 nm wide, which are invisible to the human eye. These edible nano-coatings could be used on meats, cheese, fruits, vegetables, confectionery, bakery goods and fast foods. They could provide a barrier to moisture and gas exchange, act as a vehicle to deliver colours, flavours, antioxidants, enzymes and anti-browning agents and could also increase the shelf life of manufactured foods, even after the packaging is opened [17,35]. The U.S. Company Sono-Tec Corporation announced in early 2007 that it has developed an edible antibacterial nano-coating, which can be applied directly to bakery goods. It is currently testing the process with its clients [36].

Another trend in this respect is the chemical release nano-packaging. This technique enables food packaging to interact with the food. The exchange can be processed in both directions. Packaging can release nanoscale antimicrobials, antioxidants, flavours, fragrances or nutraceuticals into the food or beverages to extend its shelf life or to improve its taste or smell [30, 37].

In many instances chemical release packaging also incorporates surveillance elements, where the release of nano-chemicals will occur in response to a particular trigger event. Conversely, nano-packaging using carbon nanotubes are being developed with the ability to pump out carbon dioxide that would otherwise result in food or beverages deterioration. Nano-packaging that absorbs undesirable flavours is also in development stage [38].

The chemical release packaging is also designed to release biocides in response to the growth of a microbial population, humidity or other changing conditions. Other packaging and food contact materials incorporate antimicrobial nanomaterials, that are designed not to be released, so that the packaging itself acts as an antimicrobial agent. These products commonly use nanoparticles of silver, although some use nanosize zinc oxide or chlorine dioxide and other materials as shown in Table 1 [39, 40].

Packaging equipped with nano-sensors is also designed to track either the internal or external conditions of food products, pellets and containers, throughout the supply chain. For example, such packaging can monitor temperature or humidity over time and then provide relevant information of these conditions, for example by changing colour. Some of these nano-sensors are under development as example in the Georgia Tech in the United State used modified carbon nanotube as biosensor to detect microorganisms, toxic substances and spoilage of foods or beverages [37]. Another example, Opel, which makes Opalfilm incorporating 50nm carbon black nanoparticles was used as biosensor that can change colour in response to food spoilage [41]. Titanium dioxide nanoparticles based, oxygen-sensing inks were used as Tamper proofing [42].

Industrial nanotech (OTC: INTK), a company that specializes in nanotechnology innovation and product development, has announced recently the successful application of the company, s8217, sNansulate_protective coating to provide thermal insulation and corrosion protection of dairy processing equipment. The company reported that it has received a repeat order for Nansulate PT from a dairy plant located in Crowell, Texas. The Nansulate PT was used to coat dairy processing tanks and pipes in order to protect them against corrosion and insulateyes against heat loss, increasing efficiency of the manufacturing process by reducing both energy and corrosion-related expenses. The US dairy industry is increasing annual production at a rate of approximately 2.8% per year, with current forecasts for 2007 milk production at 183 billion pounds. Given these massive production volumes and annual increases, energy conservation and equipment protection are becoming critical issues for the industry [37, 43].

Nanotechnology is also enabling sensor packaging to incorporate cheap Radio Frequency Identification (RFID) tags. The nano-enabled RFID tags are much smaller, flexible and can be printed on thin labels. This increases the tags versatility and thus enables much cheaper production. Other nano-based track and trace packaging technologies are also being improved. For instance, a United States company Oxonica Inc, has developed nano-barcodes to be used for individual items or pellets, which must be read with a modified microscope. These have been developed primarily for anti- counterfeiting purposes [44]. An ingestible nano-based track and trace technology is promised by pSiNutria, a spin out of nanotechnology company pSivida. Potential pSiNutria products include products to detect pathogens in food, for food tracing, and preservation and temperature measurements in food storage [45].

Another trend in the application of nano-packaging is the nano-biodegradable packaging. The use of nanomaterials to strengthen bioplastics (plant-based plastics) may enable bioplastics to be used instead of fossil-fuel based plastics for food packaging and carry bags (see Table 2) [46, 47].

Several German research institutes, industry partners and the Munich University of Technology have joined forces to develop non-stick nanofood packaging for mayonnaise and tomato sauce bottles. The researchers have applied thin films, which measure less than 20 nm to the inside surface of food packaging. They have already developed their first samples, and hope to release the new packaging commercially in the next 2-3 years. The researchers are promoting their product as an environmentally friendly solution to reduce leftover traces of condiments in bottles. However, there are concerns that manufactured nanomaterials may be released into the environment from waste streams or during recycling [48].

Nanotechnology and food safety

Detection of tiny amounts of a chemical contaminant, virus or bacteria in food system is another potential use of nanotechnology. The exciting possibility of combining biology and nanoscale technology into sensors is promising as it will take a significantly reduced response-time to sense a potential problem. This will result in more safety for the food processing system. Nano-sensors that are developed by researchers at both Purdue and Clemson universities use nanoparticles, which can either be tailor-made to flavours, colours or alternatively, be manufactured out of magnetic materials. These nanoparticles can then selectively attack any food pathogen. Also, these sensors employ either infrared light or magnetic materials, can note the presence of even a minuscule traces of harmful pathogens. The advantage of such a system is that, potentially thousands of nanoparticles can be placed on a single nano-sensor to rapidly and accurately detect the presence of any number of different bacteria and pathogens. Also, these nano-sensors can gain access into the tiny crevices where the pathogens often hide. The application of nanotechnologies on the detection of pathogenic organisms in food and the development of nanofood safety is also studied at the Bioanalytical Microsystems and biosensors laboratory at Cornell University. These studies focused on the development of rapid and portable biosensors for the detection of pathogenic organisms in the environment and foods. This system focuses on the very rapid detection of pathogens in routine drinking water testing, food analysis, environmental testing and in clinical diagnostics [9,10,11].

Launois reported that silver nanoparticles could improve the safety of the world's food supply, according to a research project at Iowa State University in the United States of America[49]. Silver nanoparticles cannot currently be added directly to foods as little is known about their adverse effects on human health and their impact on ecological systems. However, the research programme is examining how silver nanoparticles could work as antimicrobial agents in foods, with the goal of developing food-related applications such as microbe-resistant fabrics or non-biofouling surfaces. This may lead to new approaches for killing food-borne pathogens and enhancing the food safety. He also added that nanoparticles could provide us with multi-ingredient antimicrobial mixtures that would be physically compatible with other compounds for killing microorganisms and improving food safety [49].

Nanotechnology could also be applied in the food analysis in order to detect fairly low amounts of toxins produced by microorganisms. For example, *Staphylococcus aureus* is capable of synthesizing thermostable enterotoxins A, B, C, D and E. About 100-200 ng of these enterotoxins are sufficient to cause toxic infection. Therefore, the presence of this bacterium in food could become a health hazard if it is stored at temperature that allows its growth. The nanotechnology has developed a test for detection of *S. aureus* based on the use of magnetic beads, which can detect most of *S. aureus* strains at a very low viable count. This will result in improving foodsafety. Similar results were also obtained for *Listeria monocytogenes*. Aflatoxins are carcinogenic, mutagenic, teratogenic and immunosuppressive substances, which are produced as secondary metabolites by the fungi *Aspergillus flavus* and A. parasiticus growing on a variety of food products. A maximum tolerance level is 2 ng AFB1/g of mice. A competitive ELISA test using a 96-well screen- printed microplate for immunosensor has been developed for AFB1 detection. This system combines the high selectivity of immunoanalysis with the ease of electrochemical probes and the speed of multisample analysis [50]. These applications of nanotechnology systems in food analysis would improve food safety and quality and control the hazards, which could affect human health.

Regulation of nanotechnologies to ensure food safety

The health implications of food processing techniques that produce nanoparticles and nanoscale emulsions also warrant the attention of food regulations. The potential for such foods to pose new health risks must be investigated in order to determine whether or not related new food safety standards are required [51]. There is an urgent need for regulatory systems capable of managing any risks associated with nanofood and the use of nanotechnologies in food industry. Governments must also respond to nanotechnology's broader social, economic, civil liberties and ethical challenges. To ensure democratic control of these new technologies in the important area of food and agriculture, public involvement in nanotechnology decision making is essential [52].

The U.K.RS/RAE2004 has recommended that chemicals in the form of nanoparticles or nanotubes must be treated as new substances. The ingredients in these nanoparticles must undergo a full safety assessment by the relevant scientific advisory association before these are permitted to be used in the food products. Also, the ingredients lists of food products should disclose the fact that nanoparticle materials have been added. Furthermore, the release of nanoparticles and nanotubes into the environment must be avoided as far as possible [52].

The European Union regulations for food and food packaging have recommended that for the introduction of new nanotechnology, specific safety standards and testing procedures are required [53]. In the United States, nanofood and most of the food packaging is regulated by the United States Food and Drug Administration (US FDA), while organic chemicals are regulated by the Environmental Protection Agency (EPA). However, neither EPA nor FDA has recognized nanomaterials as the new chemicals or have required any new oversight of them [54].

The US. FDA stated that if the chemicals have already been approved for commercial use in large particle form, nanoparticles of these chemicals do not legally require any additional authorization or trigger new safety testing [55]. Also, food ingredients that are classified as "generally recognized as safe" (GRAS) do not require any premarket authorization from the FDA. The GRAS system also fails to differentiate between substances in larger particle or nanoparticle form.

In Australia, nanofood additives and ingredients are regulated by Food Standards Australia and New Zealand (FSANZ), under the Food Standards Code [56]. Also Australian regulations appear to be struggling to stay abreast of the rapid expansion of nanotechnology into agriculture and food systems.

CONCLUSION

In conclusion, we could recommend that there is an urgent need for regulation of nanomaterials before their incorporation into food processing, packaging, and food contact. Nanomaterials must not cause any health risks for consumers or to the environment.. More research studies are required to investigate the hazards of nanomaterials, taking the size as a main factor even though some of chemical materials in the form of large particles are safer than when they are in the nano state.

Table 1: Antimicrobial food packaging based on nano-materials and their application in food sectors

Company	Applications in food sectors
Song Sing Nano Technology Co.,Ltd	Cling warp for food treated with zincoxide
Blue Moon Goods ,A-DOGlobal, Quan Zhou Hu Zheng Nano Technology co., ltd and Sharper Image	Food storage containers treated with silver
Sharper Image	Plastic bags for food storage treated with silver
A-DO global	Chopping boards treated with silver
Nano Care Technology ltd	Kitchenware treated with silver
Baby Dream Co., Ltd	Cup for baby treated with silver
Daewoo, Samsung and LG	Refrigerators treated with silver
Song Sing Nanotechnology Co	Tea pot treated with silver

Table 2: Nano- composite biodegradable plastics development and their purposes in food technology

Institute or company	Nano- materials	Purposes
Technical University of Denmark and others	Nanocomposite biopolymers using nano clay and other minerals	Nanoclay and other minerals to strengthen bioplastics
Rohm and Haas, USA	Nanocomposite biopolymers using Paraloid BPM-500	To strengthen PLA, a biodegradable plastic resin made from corn ,while maintaining the plastic's transparency
Plantic Technologies, Australia	Nano composite biopolymers ,filler unspecified	Supplied to 80% of Australian chocolate tray market , including Cadbury Australia
Australia's Commonwealth Scientific and Industrial Research Organization	Nanocomposite biopolymer filler unspecified	combustible compostable ,renewable and carbon-dioxide neutral
"Sustainpack": 35 research Institutes, Universities and corporate partners from 13 European countries	Nanocomposite biopolymers using nano clay	To strengthen fiber based, biodegradable packaging , and to make the packaging water repellent

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