

Nanotechnology and Food Industry

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1. Introduction

Human population will reach 9,100 million by 2,050, which supposes an increase of 34% respect present situation. This growth will occur in emerging countries mainly. As a consequence of that, there will be an increase in global demand for foods, feed and energy. Initial estimation on the increment of this world demands are in the order of 70%. Accordingly, the pressure on resources (in special water and crops) will be higher. World surface devoted to crop production will be increased, in order to meet demands on food energy and other industrial uses and so, the environmental impact in some areas could be high.

In order to obtain commodities and other feedstock in a sustainable way it is necessary to improve the current working methods and control the environmental impact, acting on:

- Water management and use,
- Agriculture,
- Animal exploitation and, in general,
- Food processing.

In a broad context, some factors affecting living standards are the water availability and food. In fact, life expectancy and health are determined by both. Considering the expected demand on food (and water) as well as the global situation, several technological challenges should be overcome to make a rational use of resources possible. In this sense, nanotechnology could suppose a great tool in solving that situation.

Where is the interest of nanotechnology? Which are the possibilities of nanotechnology in relation to foods and food production? Is it possible to improve crops using nanotechnology? Which are the advantages concerning water and use management? How is it envisaged to achieve those potential benefits at a global scale?

A general view on the nanotechnology concerning foods and water is presented in this chapter and some answers to the former questions are proposed.

According to Chaudhry et al., 2011, in food nanotechnology different categories can be specified:

- When food ingredients are processed to form nanostructures.
- When additives are used in nanocapsules (or reduced somehow to nanometric size).
- When nanomaterials are used in surfaces, contact surface development, packaging materials intelligent packaging and nanosensors.

- When nanomaterials are used in the development of new pesticides, veterinarian drugs or other agrochemical aimed at production improvement.
- When nanomaterials are used in the removal of unwanted substances from foods and water.

The state of the nanotechnology in relation with food production and water use is presented in this chapter through some examples. Why the nanotechnology shows a great application potential will be explained presenting some of the most recent findings. Therefore, a general view on how nanotechnology could be a solution for the improvement of methods used in the food production and water uses is provided.

1.1 Basic notions on nanotechnology

Nanotechnology can be briefly defined as 'the engineering of very small systems and structures'. Actually, nanotechnology consists in a set of technologies than can be developed and used in several activities and agro-food sector it is not an exception.

The main feature of nanotechnology is defined by the size of the systems of work: the 'nanoscale'. At this scale the matter presents properties which are different (and new) than the observed at macroscopic level. These properties emerge as a consequence of the size of the structures that produces the material and their interactions. Somehow, in nanotechnology, atomic and molecular forces turn on determinant factors over other effects of relevance at higher scales. Other properties and possibilities of nanotechnology, which have great interest in food technology, are high reactivity, enhanced bioavailability and bioactivity, adherence effects and surface effects of nanoparticles.

According to the former, which is the magnitude order defining nanoscale?. Although there is a consensus about considering this as a range between 10 and 100 nm, there is growing evidence on particles and systems of several hundred of nanometres with activity that can be related with a typical behaviour of nanomaterial (Ashwood et al., 2007).

The definition 'working under 100 nm' could be considered a common approach when defining nanotechnology, but this approach could be too restrictive in the agro-food sector, as well as when the effects on health and environment are considered.

At present several definitions about the term 'nano' are presented by organisations at international level. For instance, Commonwealth Scientific and Industrial Research Organisation (CSIRO) or the Food and Drug Administration (FDA) define nanomaterial as that material under 1,000 nm.

According to the ISO/TS 8004-1:2010 norm, nanotechnology is: 'The application of scientific knowledge to control and utilize matter in the nanoscale, where properties and phenomena related to size or structure can emerge'. And 'nanoscale' is defined as: 'Size range from approximately 10 nm to 100 nm'.

Regardless of the former, in this chapter nanoscale will be considered when the working range is less than 1,000 nm. This decision comes from the fact that a clear distinction can be made when considering the production of foods and water use:

- Application could be devoted to be a part of the food that will be not absorbed. (i.e. packaging)
- Application is designed to be an ingredient or additive that will be consumed.

So, since the final aim is the search for a kind of functionality (mainly physiological type) through the control of the size of the matter and, considering the fact that particles of several

hundred of nanometres showing activity can be found, it seem reasonable to extent the definition up to 1,000 nm.

Despite that the potential of nanotechnology has been already recognised and applied in other industrial sectors (electronic, medical, pharmaceutical energetic sector and material sciences), the application on the agro-food sector has been limited up to now. The most promising applications of nanotechnology in foods includes: Enhancement of activity and bioavailability of nutrients and activity principles of foods, improvement of organoleptic features (colour, flavour), better consistence of food matrix, new packaging development, food traceability, safety and food monitoring during transport and storage.

In the case of the water use, the high nanoparticle activity allows the use of new purification techniques and removal of unwanted substances. In agriculture, the increase of bioavailability and the particles behaviour could boost the reduction of the side-effects in environment.

2. Potential applications of nanotechnology in the agro-food industries

2.1 Can nanotechnology enhance the access to the crops?

The pressure on crops for agricultural production will increase in the future (both the area available for cultivation and the consumption of water required for this purpose). This is related to the fact that soil is used not only for food production but also for other products of industrial interest such as biofuels. To give some figures, the annual cereal production will have to increase from 2.1 billion to 3 billion while the annual meat production will have to double.

The scientific community trust in nanotechnology as a tool which could help to solve the challenge faced by the farmer: get highly productive crops while minimizing the use of synthetic chemicals. Despite the promising use of this technology in agriculture, most applications are still under research: nanotechnology and the genetic improvement of crops and production of more selective, effective and easier to dose plant protection products (FAO / WHO, 2009; Nair et al., 2010). Nanotechnology will likely have something to say about the search of alternative energy sources and cleaning and decontamination of water or soil resources. Researches also work in the application of nanotechnology in surveillance and control systems to determine when is the best moment to harvest or to monitor crop safety (Joseph & Morrison, 2006).

But the crops will not only be benefited from the potential advantages of this technology, but also could be used as organic producers of nanoparticles.

2.1.1 Nanotechnology and crops genetic improvement

This technology, combined with others such as biotechnology, can make genetic manipulation of plants easier. It allows that nanoparticles, nanofibers or nanocapsules are used as vectors of new genetic material instead of conventional viral vectors. These new vehicles could carry a larger number of genes as well as substances able to trigger gene expression (Miller & Senjen, 2008; Nair et al., 2010) or to control the release of genetic material throughout time.

Chitosan is one of the most studied non-viral gene vectors since its positive charge density allows the condensation of DNA by electrostatic interaction, protecting the entrapped genes

from nuclease action. However, chitosan nanocarriers have still not replaced conventional vectors. These vehicles are often associated with low transfection efficiencies. Authors like Zhao et al., 2011 are recently working on the enhancement of this property through modification of chitosan nanocomplexes with an octapeptide. They have condensed DNA into spherical nanoparticles of around 100-200 nm size with higher transfection efficiencies and lower cytotoxicity than those of DNA complexed with unmodified chitosan. Their transfection capacity varies depending on cell type. Authors like Mao et al., 2001 when they used as a genetic vehicle chitosan nanoparticles, found higher levels of gene expression in human kidney cells and bronchial cells than in cancerous cells. Wang et al., 2011 worked with *Jatropha curcas* callus cells and demonstrated the integration of DNA carried by this type of nanoparticles in their genome.

Chitosan nanoparticles are quite versatile, as well as their transfection efficiency can be modified, they can be PEGylated in order to control the release of genetic material as time goes by (Mao et al., 2001). This effect of time controlled genetic material release can be achieved by encapsulating pDNA into poly (DL-lactide-co-glycolide) particles. Specifically speaking, Cohen et al., 2000 achieved sustained release of pDNA over a month. Nonetheless the major advantage of nanobiotechnology is the simultaneous delivery of both DNA and effector molecules to specific sites. This effect has been achieved in intact tobacco and maize tissues when using gold-capped mesoporous silica nanoparticles (MSNs) as plasmid DNA transfers (Nair et al., 2010).

2.1.2 Production of nano-agrochemicals

Nanotechnology can help significantly to improve crop management techniques and it seems to be particularly useful in the use and handling of agrochemicals. Usually, only a very small amount of a given active compound is needed for treatment. Nowadays larger amount of chemicals, which are applied several times, are used in the field and nanotechnology could help to increase efficacy and to prevent losses. These losses can be explained for several reasons: UV degradation, hydrolysis, microbiota interaction or leaching. This way of handling chemicals brings negative effects to the environment (soil degradation, water pollution and side effects in other species). It is postulated that active substances in their nano form will allow to formulate more effective products, with time controlled action, active only under certain environmental conditions and against specific organisms, or able to reach and act on specific sites inducing changes in plant metabolism.

Research in this field is carried out by groups such as Wang et al., 2007 who formulated beta-cypermethrin nanoemulsions. They were more effective than commercial micro-emulsions of the same compound. The surface-functionalized silica nanoparticle (SNP) developed by Debnath et al., 2011 (about 15-30 nm) caused 90% mortality in *Sitophilus oryzae* when comparing its effectiveness with conventional silica (> 1 μm). Qian et al., 2011 achieved 2 weeks of validamycin sustained release when nano-sized calcium carbonate (nano-CC) was used. Guan et al., 2010 encapsulated imidacloprid with a coating of chitosan and sodium alginate through layer-by-layer self-assembly, increasing its speed rate in soil applications.

In the synthesis of products active only under specific environmental conditions work among others, Song et al., 2009 group, who showed that triazophos can be effectively protected from hydrolysis in acidic and neutral media by including it in a nano-emulsion, while its release was very easily achieved in alkaline media. Other examples of selective

chemicals are the nanoparticles functionalized with the aim of being absorbed through insects' cuticle. The protective wax layer of insects is damaged and leads them to death by desiccation. This approach is safe for plants and entails less environmental damage. Nair et al., 2010 reported that certain nanoparticles are able to reach sap, and Corredor et al., 2009 found that they can move towards several sites in pumpkins. In other words, nanoparticles have the ability to act in sites different from their application point.

Substances in their nano form can affect cellular metabolism in a specific manner; for instance Ursache-Oprisan et al., 2011 reported an inhibition in chlorophyll biosynthesis caused by magnetic nanoparticles. But nanomaterials not only influence plants, but also animals like *Eisenia fetida* earthworms which avoid silver nanoparticles enriched soils as was evidenced by Shoults-Wilson et al., 2011.

2.1.3 Alternative energy sources and nanotechnology

One of the biggest challenges in this century is the search for new and feasible energy sources different from fuel, nuclear or hydroelectric power. Alternative energy should maintain socio-economic development without jeopardizing the environment. According to U.S. Energy Information Administration, more than 90% of the total energy produced during the first eight months of 2010 in the USA was obtained from coal, gas, nuclear, oil and wood. This energetic mix finds explanation in the fact that renewable energies (solar, wind, geothermal and tidal) are still non cost-effective.

Although, it is not the aim of this chapter to talk about the connection between energy and agriculture, it is worth to mention that agricultural sector requires important energy inputs (direct but also indirect). We think any step forward in the production; storage or use of new energy sources could be easier and faster with the help of nanotechnology. Then society will be moving towards a more sustainable, affordable and less dependent on fuel agriculture.

2.1.4 Water and soil resources remediation

Furthermore being vehicle for active substances (pesticides, plant growth regulators or fertilizers), nanoparticles can also be synthesized with a catalytic oxidation-reduction objective. The latter application would reduce the amount of these active substances present in the environment and also the time during which it is exposed to their action (Knauer & Bucheli, 2009). This section focuses on the application of reduction-oxidation catalytic nanoparticles as soil decontaminants, while the role of nanotechnology in water remediation is developed in section 2.3. Nanotechnology and water supplies.

The research focus is twofold in this issue: first, try to accelerate the degradation of residual pesticides in the soil, and secondly, improving these pollutants' detection and quantification methods.

Between those who try to accelerate the decomposition of these contaminants in soil, are Shen et al., 2007 who synthesized magnetic Fe₃O₄-C18 composite nanoparticles (5-10 nm) more effective than conventional C18 materials as cleaner substances of organophosphorous pesticides. Zeng et al., 2010 proved that TiO₂ nanoparticles can enhance organophosphorous and carbamates' degradation rate (30% faster) in crop fields.

Currently, several authors are working in pesticide analysis methods' optimization. Magnetic composite nanoparticle-modified screen printed carbon electrodes (Gan et al.,

2010), electrodes coated with multiwalled carbon nanotubes (Sundari & Manisankar, 2011) or nano TiO₂ (Kumaravel & Chandrasekaran, 2011) are some examples of nanomaterials which have been successfully used. They all act as sensors of pesticides. As opposed to more conventional ones, these methods are more sensitive and selective.

2.1.5 Crop monitoring systems

Nanotechnology is contributing very much in the development of sensors with applications in fields such as: agriculture, farming or food packaging. In agriculture, nano-sensors could make real-time detection of: humidity, nutrient status, temperature, pH or pesticides, pollutants and pathogens presence in air, water, soil or plants. All these collected data could help to save agro-chemicals and to reduce waste production (Baruah & Dutta, 2009; Joseph & Morrison, 2006).

2.1.6 Particle farming

One of the cornerstones of nanotechnology is the synthesis of nanoparticles and their self-assembly (Gardea et al., 2002) since the methods used until now are very expensive and some of them involve the use of hazardous chemical reagents.

Alternative nanoparticles production processes are continually sought in order to make them more easily scalable and affordable. One of these routes of synthesis under study is known as "particle farming" and involves the usage of living plants or their extracts as factories of nanoparticles. This process opens up new opportunities in the recycling of wastes and could be useful in areas such as cosmetics, food or medicine.

The latest research in this field focus on the synthesis of gold and silver nanoparticles with various plants: *Medicago sativa* (Bali & Harris, 2010; Gardea et al., 2002), *Vigna radiata*, *Arachis hypogaea*, *Cyamopsis tetragonolobus*, *Zea mays*, *Pennisetum glaucum*, *Sorghum vulgare* (Rajani et al., 2010), *Brassica juncea* (Bali & Harris, 2010; Beattie & Haverkamp, 2011) or extracts from *B. juncea* and *M. sativa* (Bali & Harris, 2010), *Memecylon edule* (Elavazhagan & Arunachalam, 2011) or *Allium sativum* L. (Ahamed et al., 2011).

Depending on the nanoparticle's nature, specie of plant or tissue in which they are stored, metal nanoparticles of different shapes and sizes can be obtained. However, all these processes share the advantages of being simple, cost-effective and environmentally friendly.

Apart from the potential benefits of nanotechnology in agricultural sector (described throughout this section), it also involves some risks. Farmers' chronic exposure to nanomaterials, unknown life cycles, interactions with the biotic or abiotic environment and their possible amplified bioaccumulation effects, should be seriously considered before these applications move from laboratories to the field.

2.2 Nanotechnology and animal production

Livestock contribute 40 percent of the global value of agricultural output and support the livelihoods and food security of almost a billion people (FAO, 2009). Rapidly rising incomes and urbanization, combined with underlying population growth, are driving demand for meat and other animal products in many developing countries, being the annual growth rate 0,9% in developed countries and 2,7% annual worldwide rate. In the last decade, per capita consumption in developing countries is nearly twice and this tendency keeps on

growing surpassing 100 million tonnes of produced meat in Asia in 2007 for instance (FAO, 2009).

Therefore, some of the challenges the animal production sector will have to deal with are:

- Look for an environmentally friendly sustainable production system that contributes to maintain environment preventing further degradation (livestock is responsible for 18 percent of global greenhouse gas emissions, (FAO, 2009) and livestock grazing occupies 26 percent of the earth's ice-free land surface), this joint to the increasing supply of meat products to a growing population (food demand is foreseen to be twice by 2050 due to the socio-economic and population growths, FAO, 2009). However, this growing population has not always higher economic resources (FAO estimates that between 2003–05, 75 million more people were added to the total number of undernourished and high food prices share part of the blame and this number increased in 2007 up to 923 million (FAO,2008).
- Diseases control in animal-food production sector, since these diseases are extended quickly now than in the past due to the market globalisation, so this point is a key to preserve human health and food safety (according to a study carried out in USA, UK and Ireland during the last decade approximately 20% of the retired food for food safety came from the meat sector, 12% from food processed products and 11% from vegetable and fruits sectors (Agromeat, 2011). Animal diseases reduce production and productivity, disrupt local and national economies, threaten human health and exacerbate poverty being essential its minimisation.
- An accurate traceability of products derived from the meat sector in an international growing market, which would warrant the product identity and avoid possible food fraud in this sector.

In this way, nanotechnology will be able to solve these problems in the animal production sector. In order to explain this issue, we will speak of the different areas within the animal production where nanotechnology can give support and provide some important solutions. These fields can be classified within 5 categories (Kuzma, 2010) being currently all of them under research and development.

- Pathogen detection and removal
- Veterinary medicine
- Feed improvement and waste remediation
- Animal breeding and genetics
- Identity preservation and supply-chain tracking

2.2.1 Pathogen detection and removal

This first category includes the use of nanodetectors not only to detect pathogens but to bind and remove them. An example will be the case of *S. typhi* detection in chickens skins, which uses magnetic particles functionalised with antibodies that after binding the pathogen, removes them by means of the introduction of magnetic forces. Other case is the study against foot-and mouth disease (FMD) virus in chickens, with the development of surfaces based on nanostructured gold films with topography matched to that of the size of FMDV. These surfaces are functionalized with a single chain antibody specific for FMDV in such a way that liquid crystals will uniformly anchor on these surfaces. FMDV will bind to these surfaces in such a way that it will give rise to easily visualized changes in the appearance of liquid crystals anchored on these surfaces and so virus presence is detected (Platypus Technologies LLC, 2002).

The benefit of this application would allow improving human health reducing the risk of diseases derived from food consumption and allow great benefits for animal health, likewise an economic advantage when producing. However, this technology is not still very developed and it is necessary studies to guarantee the lack of toxicity of these nanoparticles. Also, nanotechnology is used in the diagnosis of animal diseases control based on microfluidic, microarray, electronic and photo-electronic, integrated on-chip and nanotechnology together with analytical systems, which enable the development of point-of-care analysers (Bollo, 2007).

2.2.2 Veterinary medicine

In the veterinary medicine field, nanoparticles to deliver animal drugs like growth hormones (somatotropine) in pigs through PGLA nanocapsules and the improvement in animal vaccination are two of the application examples. Among vaccination products, some polystyrene nanoparticles bound to antigens are experimentally being proved in sheep (Scheerlinck et al., 2005) and vaccines against *Salmonella enteritidis* based on an immunogenic subcellular extract obtained from whole bacteria encapsulated in nanoparticles made with the polymer Gantrez (Ochoa et al., 2007).

Animal production and food safety will be increased and this will lead to cheaper and greater availability of meat products. However, some of these measures could not be successfully applied in some countries, as it would be the case of hormones supply to animals, which is not accepted as good practice by consumers or even banned in some countries.

2.2.3 Feed Improvement and waste remediation

In the category of feed improvement and waste remediation are being studied the use of nanoparticles in feed for pathogen detection. These particles would bind pathogens in the gut of poultry preventing its colonization and growth and avoiding its presence in waste.

Other example would be the use of nanoparticles to detect chemical and microbiological contamination in feed production. Advantages of both applications are clear: Farms would be more environmentally friendly and alternatives for using of antibiotics to face pathogens will be proposed. The former option could be very interesting due to the growth of antibiotic resistance found in animals and humans. However, life cycle of these particles must be verified in order to warrant that these particles are not harmful for the animal and that they don't end up on animal-derived food products or food chain.

Toxicology must be studied and environmental exposure, likewise the effect that animal wastes containing these particles would have. In feed production case, workers safety must be studied and the effect of leftovers remaining in farms and fields.

Within this part, we can also mention the use of polymeric nanocapsules to carry bioactive compounds (such as proteins, peptides, vitamins, etc.) in such a way that they will be able to pass through the gastrointestinal mucus layer and/or epithelial tissue providing or increasing the absorption of these bioactive compounds (Luppi et al., 2008; Plapied et al., 2011), improving the availability of these nutrients and therefore, the quality of animal production.

2.2.4 Animal breeding and genetics

Genetic animal therapy is one of the possible applications in a near future. Currently, studies of genes delivery in animal cells for selection and temporal expression are being carried out in order to determine specific features of livestock (Mc Knight et al., 2003).

Animal health and breeding would be improved as well as animal production. For instance, some kind of genetic diseases could be avoided and genetic configuration could be determined in a way that animals will be more fertile. However, before more studies about toxicity, safety and legislation must be made. Moreover, public perception and current legal framework related to genetic modification would have to change a lot, since society opposition is still rather difficult to save.

2.2.5 Identity preservation and supply-chain tracking

Concerning traceability and identity preservation chips of DNA are being studied in order to detect genes in feed and food, likewise nanobarcodes to get feed (Jayarao et al., 2011) and animal traceability from farm to fork. This will aid to maintain animals healthy but also to improve public health, since feed traceability would help to prevent and avoid possible food related illnesses, being able to find quickly the source of such diseases and even to prevent them.

In conclusion, the potential benefit of these technologies would allow a diminution cost and an improvement in the animal production sector as much in quality as in quantity, the waste reduction, increasing efficiency in the use of resources and rising safety in animal derived food products.

Possible risks related to human and animal health and also the environmental impact have to be overcome before applying of these technologies. Other matters such as exploitation rights, intellectual property and legal issues derived from the use of these inventions and patents must be considered too.

2.3 Nanotechnology and water supplies

In this decade, the demand of water supplies is rapidly growing and the competition for water resources is being every day a bigger concern. Currently, 70% of the obtained fresh water in the entire world is used in agriculture, while 20% is used in the industry and 10% are devoted to municipal uses (FAO, Agotamiento de los Recursos de Agua dulce).

The access to inexpensive and clean water sources is an overriding global challenge mainly due to:

- The global climate change that will contribute to fresh water scarcity.
- The constant growth in world population. Water sources demand has exceeded by a factor of two or more the world population growth, (FAO, Agotamiento de los Recursos de Agua dulce valoración ambiental: Indicadores de Presión Estado Respuesta), this means that the expected population growth will be pressing water resources. In order to have a rough idea, the daily drinking-water requirements per person are 2-4 litres. However, it takes 2000 - 5000 litres of water to produce a person's daily food, if this is added to the increasing population growth... (FAO. FAOWATER. Water at a Glance: The relationship between water, agriculture, food security and poverty.)
- The raising industrial and municipal water waste. Every day, 2 million tons of human waste is disposed of in water courses. Worldwide total water waste volume was estimated in more than 1.500 km³ in 1995, knowing that every litre of waste water contaminates 8 litres of freshwater, 12.000 km³ of water resources from the planet are estimated not being available for its use. If this figure maintains its growth at the same

rate than the population is increasing (by 2050, population will reach 9.000 million people), the planet will lose every year around 18.000000 km³ of water resources (UNESCO, 2007).

- The large quantities of water used to produce increasing amounts of energy from traditional sources.
- The intensive water use in agricultural (i.e., it takes 1-3 tonnes of water to grown 1kg of cereal; FAO. FAOWATER. Water at a Glance: The relationship between water, agriculture, food security and poverty) and livestock activities. Added to this, it is the fact that the foreseen urban population growth will increase pressure on local water resources, while food production demand is rising in remote areas to support the industrial animal production systems connected to cities.

These are some of the reasons why alternatives should be thought for obtaining and recycling water and in this point is where nanotechnology could provide innovative solutions.

Currently, there are several nanotechnology research lines concerning water treatment. Some of these examples are mentioned next:

- Magnetic nanoadsorbents, which can transform high polluted water in water for human consumption, sanitary uses and irrigation. Magnetic nanoadsorbents can be used to bind pollutants such as arsenic or petroleum and then could be easily eliminated by a magnet (Mayo et al., 2007; Wolfe, 2006).
- Water desalination by means of carbon nanoelectrodes. Water for human consumption could be obtained in areas, which are rich in high salinity water, using less economic and energy resources. An example would be the use of capacitive deionization (CDI), which is based on high-surface-area electrodes and that when are electrically charged can adsorb ionic components from water (Oren, 2008).
- Biofilms, which create surfaces that avoid bacterial adhesion and which would be self-cleaning, preventing fouling and hindering biocorrosion and pathogens in water distribution, connexion and storage systems. (Brame et al., 2011).
- Nanomaterials with catalytic and phototacalytic activities able to eliminate bacteria, pesticides, antibiotics and hormonal disruptors, likewise chlorine of organic solvents like trichloroethylene (hypercatalysis) from the environment. Remediation of groundwater contaminated with organochlorine compounds and other compounds can be done, having impact not only on water purification systems for drinkable water but on human health. Among some of the applications would be nanocomposites of dioxide of titanium, which in presence of UV-visible and solar light have bactericide and antiviral properties. Other application would be the hypercatalysis with palladium covered by gold nanoparticles that would eliminate organic solvents like trichloroethylene (Clean Water Project: WATER DETOXIFICATION USING INNOVATIVE vi-NANOCATALYSTS, FP7 Collaborative Project, ENV NMP227017, 2009-2012; Nutt et al., 2005; Senthilnathan & Ligy, 2010).
- Membranes systems based on metal nanoparticles, which prevent fouling to purify water in places where water quality is not good for human consumption and in water waste, reducing the number of treatment steps; nevertheless several drawbacks must be solved before applying it. Among these problems to be solved would be the use of metal-based nanoparticles, which implies a potential selection for antibiotic resistance. These multi-functional membranes would be self-cleaning, antifouling

performance and could inactivate virus and eliminate organic matter. An example would be reverse osmosis membranes and its spacers with nanosilver coating, which would improve bacteria removal and antifouling performance (Yang et al., 2009; Zodrow et al., 2009).

- Nanosponge for rainwater harvesting, a combination of polymers and glass nanoparticles that can be printed onto surfaces like fabrics to soak up water. This application can be very beneficial for tropical climate countries where humidity is high and there could be a more efficient water mist catching (Grimshaw, 2009).
- Nanomesh waterstick, a straw-like filtration device made of carbon nanotubes placed on a flexible and porous material. This stick cleans water as someone drinks and eliminates virus and bacteria. It has been already used in Africa (Seldom laboratories) and is currently available in the market. Speaking about active carbon, this one has been used together with nanofibres, in point-of-use water purifying systems. They are some kind of biodegradable tea-bags-like to filtrate water. Once, they have been used the nanofibres will disintegrate in liquids after a few days (developed by E. Cloete; Universidad de Pretoria).
- Nanoparticles with DNA able to track hydrological flows, which will allow to know water sources and if the water is polluted or not (Walter et al., 2005).

The key point is that these technologies would allow to treat processing and residual water from food industry and recycle and reuse them, contributing to the economy, environmental improvement and water security of local communities and industries.

This is essential in areas where water scarcity is a problem, drinkable water is difficult to obtain and water is considered as a precious resource.

Although the operation cost of some of these installations and facilities would be higher than the operation costs of the traditional facilities, the initial investment would be cheaper (construction costs), moreover life cycle of some of these materials is unknown and these are only some of issues that must be studied before trying to implement anything, so there is still a long way to cover before some of these applications can be real facts.

2.4 Nanotechnology in food processing

Up to now in this chapter, the nanotechnology applications have been referred to water use and commodity production but, nanotechnology can be a way to get better manufacturing food process (or even a completely new and different one). Actually, food sector could be facing a paradigm shift. As commented by Pray & Yaktine, 2009, nowadays foods are structured using a recipe (or formulation) whereas two simultaneous processes occur:

- Formation the structure (i.e: by means of phase creation, reactions, biopolymer transformation ...)
- Stabilization of the system (i.e. vitrification, crystallization, network formation...)

On the other side, nanotechnology affords the possibility of structure foods from the base elements (in an approach derived from its constituents self-assembly). Rather than the use of a recipe, nanotechnology raises the opportunity of using molecules as starting material, so that new interaction are achieved which in turn generates the required properties. The paradigm shift resides in the fact the food formulation will be based on the use of "food matrix precursors or structural elements". To achieve this possibility it will be necessary the development of new knowledge and techniques.

Some examples on the potentiality of the former approach is the development of new textures and flavours, the possibility of the design of low dense, low calorie foods but nutritionally enhanced. Those foods can be aimed at a nutrition adapted to different lifestyle and consumer conditions (i.e. obesity cases).

Two points are commented here to give a general view of the multiple possibilities of nanotechnology use in food processing:

- Food processing issues: mixing, component stability, safety, etc.
- Intrinsic food features: texture, flavour, taste masking, availability and delivery, etc.

Among the processing issues the most of the applications are related with the use of nanoparticles and nanocapsules. These particles enhance the products functionality, and they are responsible of that enhancement because they perform a protection function on:

- The contained active principle. Nanoparticles avoid the degradation produced by the surrounding environment of the food or by the manufacturing process. Gökmen et al., 2011, have reported that omega 3 was successfully nanoencapsulated and used in bread making. In addition of the positive effect in taste masking, thermooxidation during baking was reduced. As a consequence of that, the production of other further degradation by-products (i.e. acrylamide) was strongly reduced.
- The food itself. This happens when the active principle is used with a technological purpose. For instance nanoparticles containing essential oil have been used to improve antimicrobial activity in juices (Donsi et al., 2011). In this case, the addition of small amounts of nanoparticles containing terpenes to an orange and pear juice delayed or avoided the microbial growth (depending on the concentration). Organoleptic properties were maintained.

One advanced aspect of the use of nanotechnology is the possibility of acting straight onto the food structure. Nanostructured foods aimed at producing better texturized, flavoured and other properties can be obtained. In particular it can be highlighted the possibility of producing cream-like foods such as: ice-creams, spreads and low fat dressings. Leser et al., 2006, comment how polar lipids (monoglycerides and phospholipids) can be used with this purpose. Some of those polar lipids are capable of create nanostructures that finally result in crystalline phases. These structures can be used as a base for the development of spreads taking advantage on the texture properties emerging from interaction between nanostructures clusters. The manufacturing process will depend on water relative quantity, stirring, and the system temperature evolution.

The contribution of particles to the stability of foams and emulsions is another aspect of interest in the use of nanotechnology in foods. Most of the foods are (or have been during processing) dispersions like emulsions or foams. Several examples could be derived from bakery, confectionery, meat products, dressings and spreads. Another example is the prepared foods. In general, foam and emulsion stability can be improved in the presence of nanoparticles and nanostructures.

The macroscopic properties of dispersion can be improved by controlling the formation of nanostructures in the interphase (Rodríguez et al., 2007). The application of new techniques to food development such as Brewster angle microscopy (BAM), atomic force microscopy (AFM) y imaging ellipsometry (IE), will allow the study and application of those possibilities to processing.

Dickinson, 2010 presents a review about the use of inorganic nanoparticles (silica), fat crystals and protein nanoparticles. Main conclusions to highlight are:

- "Natural biopolymer structural assemblies are obviously attractive as (nano)particle building blocks"
- Polysaccharides (i.e. starch or cellulose) represent can be considered as a cheap and a quickly source of nanomaterial for food uses. Anyhow, it is required some type of modification to increase hydrophobicity.
- Proteins represent the best potential derived from the amphiphilic behaviour as well as due to their carrying capacity (i.e. casein nanotubes)
- The interaction between protein and polysaccharides is of great interest also. For instance, the interaction obtained from the interaction of caseinate and Arabic gum or, the heat degraded beta-lactoglobulin aggregates and stabilised by pectin. One important implication of this type of interaction could be the complexing between casein and a charged polysaccharide which can be used in the maintenance of solubility and functionality under acidic pH conditions

Another relevant aspect in food processing is the time. In this case, when considering the interaction between food components in a structure, the time required to reach a position should be considered. "In order to interact, different components of a food structure must come into position at the right time." (Pray & Yaktine, 2009) For example, the foam formation is a kinetic process that is initiated at the nanoscale in milliseconds, after that foam is stabilised at macroscopic level in the order of minutes. The capability of nanoparticles and nanosystems to arrange in time is then another issue to consider. In this sense, Sánchez & Patino, 2005 have reported how the diffusion speed of caseinate to the liquid-air interphase affects to the foam formation and, how depending on the concentration (above 2%), interphase saturation occurs and appear a micelle formation for sort times.

Besides processing features, a possible breakthrough in food manufacturing is the enhancement of the bioavailability. Nanoemulsions and nanoparticles suppose a delivery vehicle capable of override two great problems:

- Conservation in the food previous to the consumption and the stomach degradation
- The absorption of the compounds by the organism

In the last case, it should be considered that the main absorption route of foods is the intestine and nanotechnology could improve that somehow. Direct absorption of nanoparticles is controlled by size and surface chemistry of the particle. Generally nanoparticles can be done by an active transport mechanism or by a passive transport (Acosta, 2009).

In the first case (active transport) absorption happens by means of specific channels that present the epithelial intestinal cells. In this case absorption is controlled by the hormonal system and by homeostatic effect derived from blood levels of compounds. According to the last control mechanism, once a level is surpassed for an ingredient, it will be not absorbed and the excess is accumulated or excreted. Selective absorption can be conditioned by specific receptors in the cell surface (enterocytes and M cells). Those nanoparticles with a specific surface composition can be absorbed by this way. Generally, the M cells present a better permeability. For example, there is a great interest in the development of lecithin nanoparticles since it could be an improvement in the absorption of isoflavones by this route (Acosta, 2009).

Passive transport happens by means of diffusion though epithelial tissue. The particle has to be fixed to intestinal mucosa, and from there, to contact the cell. The absorption speed is determined by a concentration gradient. In an interesting work, Cattania et al., 2010, studied

the use *in vivo* of lipidic core nanocapsules. Those nanocapsules are fixed to gastrointestinal lumen and act as active principle reservoirs. Nanocapsules delivered the active principle once they were fixed by diffusion. As relevant conclusion of this work it is pointed that there is important differences between evaluation models used (*in vivo* and *ex vivo*), and the live model system complexity cannot be predicted by a simpler model, at least at this time.

In fact, nanomaterial dosimetry it is not clear at all. Despite this, there is a general consensus about the relation of particle size and bioavailability in the sense that, as far the size decreases, the bioavailability is improved. A size reduction under 500 nm produces a higher absorption of the active principle and more particle uptake regardless of the system composition. However, above 500 nm, the bioavailability depends on the system (Acosta, 2009). So, it is possible to obtain more effect from a food additive with the use of nanotechnology (with lower content in an active principle) than with the use of the traditional approach (i.e. microencapsulation).

Food properties can be enhanced this way but there is a necessity for new test and assay methods to evaluate the state of the particle in the food (or structure) and the effect on the organism and health.

Ultimately, nanotechnology application on foods supposes a great challenge but requires solving several aspects in the near future. Once those barrier have been overcome, manufacturing of foods adapted to especial necessities will be obtained, as well as the improvement in efficiency, action in the organism and even getting a better experience in the consume.

2.5 Food packaging

Most of the nanotechnology applications in food industry are in the packaging sector. It is expected that by 2015 this sector will be 19% of nanotechnology food applications.

This is mainly due to the big development of nanotechnology in this field, to a higher acceptance by consumers of the use of this technology in packaging than in food as ingredients and to the normative requirements, which are less restrictive than for the enforced current food legislation. All this contributes to the fact that there are many more applications in this area than in others of food sector, together with the necessity of a more sustainable, lighter and stronger at the same time, efficient and intelligent packages. These packages would be able to provide safer products with more quality and at the same time maintaining the products in the best possible conditions and with a longer shelf-life.

During the last decade, the use of polymers as material for food packaging has incredibly increased due to its advantages over the use of traditional materials.

In polymers world market, which has been increased of about 5 million tons in 1950 to almost 100 million tons at the present time, 42% corresponds to packaging and containers (Silvestre et al., 2011).

In the following section, some nanotechnology derived applications of materials in contact with food are mentioned. These applications are currently available or at research level.

2.5.1 Nanomaterials to improve packaging properties

As it was previously mentioned, polymers provide packaging with strength, stiffness, oxygen barrier, humidity, protection against certain food compounds attacks and flexibility (Sánchez-García et al., 2010b).

The possibility of polymers improving these features in food packaging by means of nanoparticles addition has allowed the development of a huge variety of polymers with nanomaterials in its composition (Azeredo, 2009; Bradley et al., 2011; Lagaron & López-Rubio, 2011).

The use of nanocomposites for food packaging not only protects food but also increases shelf-life of food products and solves environmental problems reducing the necessity of using plastics. Most of packaging materials are not degradable and current biodegradable films have poor barrier and mechanical properties, so these properties need to be considerably improved before these films can replaced traditional plastics and aid to manage worldwide waste problem (Sorrentino et al., 2007).

With the introduction of inorganic particles as clay in the biopolymer matrix (Bordes et al., 2009; 48, Utracki et al., 2011), numerous advantages are reached.

Natural structure of clay in layers at nanoscale level makes that when clay is incorporated to polymers, gas permeation will be restricted and product will be anti UV radiation proof. In addition, mechanical properties and thermal stability of package are improved.

Polymers made up of nanoclay are being made from thermoplastics reinforced with clay nanoparticles. At present, there are a huge number of nanoclay polymers available on the market. Some well-known commercial applications are beer and soft drinks bottles and thermoformed containers.

Other examples that can be mentioned are nitrate of titanium, which is used to increase mechanical strength and as aid in processing and dioxide of titanium to protect against UV radiation, in transparent plastics. Among these applications the oxide of nanozinc and nanomagnesium are expected to be affordable and safer solutions for food packaging in a near future (Lepot et al., 2011; Li et al., 2010).

Also carbon nanotubes (Sánchez-García et al., 2010a) or nanoparticles of SiO₂ have been used for improving mechanical and barrier properties of several polymeric matrices (Vladimirov et al., 2006).

The use as reinforcement elements of biodegradable cellulosic nanowhiskers and nanostructures obtained by electrospinning (Goffin et al., 2011; López-Rubio et al., 2007; Siqueira et al., 2009; Torres-Giner et al., 2008) must be highlighted too. Finally, to mention the use of biological nanofillers to strength bioplastics has the added value of generating formulations of complete biological base. These nanofillers have a high surface-mass ratio, an excellent mechanical strength, flexibility, lightness and in some cases, even they are edible, since they can be made from food hydrocolloids.

2.5.2 Active packaging

Active packaging is thought to incorporate components that liberate or absorb substances in the package or in the air in contact to food. Up to now, active packaging has been mainly developed for antimicrobiological applications, nevertheless other promising applications include oxygen capture, ethylene elimination, CO₂ absorption /emission, steam resistances and bad odours protection, liberation of antioxidants, preservatives addition, additives or flavours.

Nanoparticles more used in active packaging development are nanomaterials of metals and oxide of metals in antimicrobial packaging. Nanosilver use in packaging helps to maintain healthy conditions in the surface of food avoiding or reducing microbial growth. However,

its action is not as a preservative even though, it is a biocide (Morones et al, 2005; Travan et al., 2009). Based on these properties, a big number of food contact materials, which inhibit microorganisms' growth have been created (i.e. plastic containers and bags to store food).

2.5.3 Intelligent packaging

Nanotechnology can be also applied in coatings or labels of packaging providing information about the traceability and tracking of outside as well as inside product conditions through the whole food chain. Some examples of these applications are: leak detections for foodstuffs packed under vacuum or inert atmosphere (when inert atmosphere has been ruptured some compounds change of colour warning consumers that air has come inside in where should be an inert atmosphere) (Mills & Hazafy, 2009); temperature changes (freeze-thaw-refreezing, monitoring of cold chain by means of silicon with nanopores structure), humidity variations through the product shelf-life or foodstuffs being gone off (unusual microbial presence).

Currently, sensors based on nanoparticles incrustated in a polymeric matrix isolated to detect and identify pathogens transmitted by food are being studied. These sensors work producing a specific pattern of answer against each microorganism (Yang et al., 2007). Technology called "Electronic tongue" must be underlined, too. It is made up of sensor arrays to signal condition of the foodstuffs. The device consists of an array of nanosensors extremely sensitive to gases released by spoiling microorganisms, producing a colour change which indicates whether the food is deteriorated.

DNA-based biochips are also under development, which will be able to detect the presence of harmful bacteria in meat, fish, or fungi affecting fruit (Heidenreich et al., 2010).

3. Nanotechnology challenges

As described throughout part 2, the implementation of nanotechnology in the food industry offers a wide range of opportunities to improve farm management, livestock waste, processing and food packaging. According to Helmut Kaiser Consultancy, this market was valued at USD 2.6 bn in 2003, doubled in 2005 and is expected to soar to USD 20.4 bn in 2015 (Groves & Titoria, 2009).

Despite these figures, nanotechnology has a lot of work to do in the food industry compared to its implementation in other fields such as health and fitness, home and garden or automotive. These were the three categories with the largest number of nanoproducts in March 2011 (Project on Emerging Nanotechnologies, 2011).

According to the same source, in 2010 there were sold a total of 1317 different products based on nanotechnology. This figure is small compared with the R & D investment and shows that nanotechnology commercialization is still in its infancy not only in the food sector.

The main common themes addressed by all company surveys related to commercialising nanotechnology, are: high processing costs, problems in the scalability of R & D for prototype and industrial production and concerns about public perception of environment, health and safety issues (Palmberg et al., 2009).

At the same time, as research on new and different applications of nanotechnology is carried out, others should be done with the aim of developing reliable and reproducible

instrumental techniques for detecting, quantification and characterization of new materials in environmental, food and human samples. It will be necessary to study: different absorption pathways, exposure levels, metabolism, acute and chronic toxicity and its short or long term bioaccumulation. The knowledge gained in all these areas is essential to sketch a realistic and effective nanotechnology regulatory framework.

3.1 Scientific and technological challenges

There is currently a research boom in nanotechnology; both companies and universities are increasing their efforts to study the human health and environmental effects of exposure to nanomaterials. During last years, it has been shown that these materials can affect biological behaviours at the cellular, sub-cellular and protein levels due to its high potential to cross cell membranes. Some of these effects are not at all desirable, turning to be even toxic. Despite the efforts, conventional toxicity studies need to be updated to nanoscale. These new methods must define scenarios and routes of human exposure (so far there are only few studies involving oral routes), consider the behaviour of nanomaterials in watery environment and conditions that may influence its aggregation state and association with toxicants. Also, they must select a model organism to test toxicity.

In order to carry out such toxicity studies, it is necessary to implement new analytical methods able to detect the presence of very small quantities of nanomaterials in both environmental and food samples. This issue arouses so much interest that scientific journals such as *Trends in Analytical Chemistry* have published two special issues about characterization, analysis and risks of nanomaterials in environmental and food samples. Its papers emphasize that these are complex samples and therefore their analysis often involves four stages: (1) Sample preparation, (2) Imaging by means of different microscope techniques, (3) Separation and (4) Characterization by measuring size, size distribution, type, composition or charge density by, between others, light scattering techniques. Anyway it is very important to take into account that nanoparticles can change its structure and composition as a function of the medium and treatment. That is why resulting sample after its preparation may differ from the original one determining the reliability and conclusions of the whole analysis (Peters et al., 2011).

3.2 Socio-economic challenges

After years of public and private economic investments in R & D, nanotechnology in return is thought to develop new and more environmental friendly and efficient production methods in order to supply a growing population with commodities, and new and safer products with enhanced properties, and to generate qualified jobs as well as scientific advances.

In other words, one of the biggest challenges which nanotechnology faces up to is the ability to create an industrial and business scope. It is thought that nanotechnology will have an important impact on employment sooner than later, despite the fact that not all consultancies agree in their expectations. It depends, for instance, on nanomaterials' definition. The American NSF (National Science Foundation) estimated in 2001 that 2 million workers will be needed in nanotechnology based companies by 2015. According to LuxResearch in its 2004 report, 10 million jobs related to nanotechnology will have been created worldwide by 2014 (Palmberg et al., 2009). Although all long-term forecasts share

that they were made in a buoyant and optimistic economic scenario (before 2008 crisis), and they should be considered with caution.

Related to its geographical distribution and according to NSF, by 2015 45% of new jobs will be generated in USA and 30% in Japan. Other agencies think that job layout will change and countries like China, India or Russia will become more important (Seear et al., 2009).

Another aspect to consider when studying nanotechnology influence on employment is the workers' health. Professionals are not immune to the new materials' effects on health and could show symptoms related to chronic expositions (Seear et al., 2009). This fact would have repercussion on economic status of health systems.

In order to achieve private initiative investment in this sector, it is strictly necessary that a stable and effective regulatory framework exists, but also channels to inform and educate the public about what this technology is, its advantages, disadvantages but also the risks it may involve.

3.2.1 Development of an effective and specific legislation

The current implementation of nanotechnology in food industry does not count with a specific legislation. Although it does not mean that new food products, ingredients, surfaces or materials intended to come into contact with food are not obliged to pass safety controls before entering the market.

According to European Commission, the scope of the current legislation is wide enough to deal with new technologies (Commission of the European Communities, 2008). It should be applied what is established in one or other normative depending on the nanotechnology implementation and on the resultant product (ingredients, additives, packages...).

Against public agencies' opinion, other society sectors like Friends of the Earth defend that it is necessary to develop new nano-specific legislation which consider engineered nanomaterials as new substances with characteristic risks and properties and different from those associated with the same substance in its bulk form (Miller & Senjen, 2008).

These rules should be observed by any food producer, whether using nanotechnology or not. Although it is true that this technology implementation in the agro-food sector goes further than the observance of the regulations, codes or acts which appears in the table. It also concerns such different topics as: workplace health and security, water quality, wastes management, pesticides or animal health.

Implementation of this current legal framework is quite complex. It is necessary for a nanotechnology regulation to work properly in food industry that public agencies define precisely: (1) Nanomaterials, (2) An international regulatory body, (3) Detection, characterization and quantification methods and (4) Exposure and risk assessment of the new products.

The main problem is the lack of agreement between the most important agencies and international bodies in the legal definition of engineered nanomaterials. Council of the European Union defines it as follows: "any intentionally produced material that has one or more dimensions of the order of 100 nm or less or is composed of discrete functional parts, either internally or at the surface, structures, agglomerates or aggregates, which may have a size above the order of 100 nm to the nanoscale include: (i) those related to the large specific surface area of the materials considered; and or (ii) specific physico-chemical properties that are different from those of the nanoform of the same material" in the proposal for the novel foods amending Regulation (EC) No. 258/97 (Council of the European Union, 2009).

Use	European Union	United States of America	Australia & New Zealand.
General Food Safety	Regulation (EC) No.178/2002.	Federal Food, Drug and Cosmetic Act (the FDC Act).	Australian and New Zealand Food Standards Code (the Food Standards Code)
Novel Foods and Novel Food Ingredients	Regulation (EC) No.258/97.		Part 1.3. of the Food Standards Code
Food additives	Regulation (EC) No.1331/2008 Regulation (EC) No.1332/2008. Regulation (EC) No.1333/2008. Regulation (EC) No.1334/2008.		
Packaging and Food Contact Materials (FCMs)	Regulation (EC) No.1935/2004. Regulation (EC) No.450/2009.	Federal Food, Drug and Cosmetic Act (the FDC Act) in its Title 21, Chapter 9.	Standard 1.4.3 of the Food Standards Code

Table 1. Summary of the food related legislation in the UE, USA, Australia and New Zealand.

Institutions like International Union of Food Science & Technology (IUFoST) or House of Lords advice that engineered nanomaterials' legal definition shouldn't be based on size alone and recommend that it should refer in an explicit manner to its functionality. Other way, if the size threshold is fixed in 100 nm, producers could declare that their goods only contain particles with dimensions of 101 nm, avoiding the established safety controls (House of Lords, Science and Technology Committee, 2010a; Morris, 2010).

Overlapping between the different international regulatory entities or agencies is another difficulty related to nanotechnology implementation control. It is because this technology can be used in many and different fields and also because its resulting products should compete in a global market, this is why it is so important to define what body is going to organize the trade. Once this challenge has been overcome, trade barriers will be reduced and there will be a free movement of goods. Codex Alimentarius organized an expert meeting in June 2009 where they thought about the use of nanotechnology in the food and agriculture sectors and its potential food safety implications (FAO/WHO, 2009). On the other hand, entities such as Organisation for Economic Co-operation and Development (OECD) can also act as arbitrator in this issue on an international scale. Regarding this body,

Friends of the Earth Australia pointed out that many countries are not represented at the OECD, in particular developing nations (House of Lords, Science and Technology Committee, 2010a). There are also people who think that an international regulatory agency is unnecessary and agreements between countries are enough.

Apart from establishing nanomaterials' definition and deciding which organization is going to coordinate the international trade of nanotechnology food products, it is also necessary to standardize protocols and reliable detection, characterization and quantification methods of nanomaterials in food samples. Otherwise, any written regulation would be limited *per se* (Institute of Food Science & Technology, 2009).

Currently, food safety legislation in western countries is designed with the aim of offering the highest health guaranties. Each agency has established its own pre-market approval assessments for new products, additives, flavourings, enzymes and materials intended to come into contact with food. Any approved application will be included in a positive list which authorizes its use under certain concentrations and foods. If the application fails the assessment, (neither the company nor the authorities in charge are able to prove the substance's safety), its marketing will be denied.

Normally, every substance approved for human consumption is associated with a tolerable intake (expressed in concentration units). The nanomaterials inclusion in those lists will make necessary to change this units, because their effects are quite different from those in the macro-scale (Gergely et al., 2010). This is exactly the reason why it is strictly necessary the exposure and risk assessment of every new nanotechnology implementation in food industry.

3.2.2 Public perception generation from a critical approach

Public perception is a key point in the development of any new technology, since without public acceptance any opportunity for development, even if scientific-technological perspectives are gorgeous, would be vanished. The good news is that public perception can be created, changes and evolutions (an example of this would be genetically modified food products).

Nevertheless, for a true and lasting public perception, this one has to be created by and inside consumers of the mentioned technology, has not to be something only imposed from outside and for it some requirements must be accomplished (Magnuson, 2010; Yada, 2011).

Among the requirements would be the simple and transparent access to information, education related to nanotechnology to acquire the necessary knowledge for allowing society benefits and risks identification, as well as management of risk control by independent and reliable organisations, knowing cost impact and who will pay for its implementation, assessment of environmental impact and finally and more important, freedom of choice. This means allowing users of this technology to choose and decide consciously if they want to consume products in which nanotechnology has been used or not and for it again, here we are, the right to be informed.

Citizens' participation in committees and forums, where people give their opinion and can be informed in these matters and "nano" mandatory labelling would be some of the pending issues (Miller & Senjen, 2008), happily the path starts to be tracked in this direction.

Currently public perception of nanotechnology faced two problems: on one hand, the technical unknowledge of the subject and on the other hand the exaggerated expectatives arisen, which show it as the solution for all the problems together with the rejection to this excessive idealized vision.

The repulse to these exaggerated views, fear of nanotechnology being uncontrolled and becoming a threat, the fact that nanotechnology is a difficult concept to understand for consumers due to its complex nature and the small size of what is being treated (it's not something that can be seen just looking at it) contribute to the fact that there is still too many things to be done in this field.

According to a public perception document of nanotechnology published by the Food Standard Agency (Food Standards Agency, 2011), its success is conditioned by several factors. Next, some of the factors mentioned in this and other reports are shown:

- Use: On one side, consumers in general are more favourable to use nanotechnology in other sectors than Food sector (House of Lords, Science and Technology Committee, 2010b). This is due to food is not only perceived as from the functional point of view but related to health, environment, science, etc. not to mentioning personal and familiar habits in each home. On the other side, within Food sector it seems that public is more likely favourable to accept nanotechnologies in fat and salt reduction meals (issues that directly affect to its health) without taste and texture damage, than to accept it for new tastes and textures development (Joseph & Morrison, 2006).
- Physical proximity with food: As some authors have said consumers are more favourable to accept the use of nanotechnology in packaging than the use of the same as an additional food ingredient. Moreover, they better understand the advantages related to packaging use of nanotechnology (extended shelf-life of the product, intelligent packaging that shows when the product has gone off, etc.) (Harrington & Dawson, 2011). This was shown in a study carried out by Siegrist et al., 2007, 2008 that evaluated public perception of different kinds of food products. Results in 153 people interviewed were that packaging derived from nanotechnology was perceived as more beneficial than food modified with nanotechnology. The use of this technology is perceived as more acceptable if it is outside food. Furthermore, even if age didn't seem to be a determining factor, it was observed that people older than 66 years old was more favourable to consider the use of the nanotechnology in packaging, not being significant differences with respect to the other age groups.
- Concerns about unknowns in some issues: its effectiveness, human health risks, and regulation (40% people interviewed in a study carried out by the Woodrow Wilson Centre for Scholars, WWCS show their concerns with these issues), testing and research for safety (12% show their worries), environmental impact (10%), short and long term side-effects in food and food chain (7%), control and regulatory concerns, etc. As reported by the WWCS (Macoubrie, 2005) 40% of the study participants believes that regulatory agencies shouldn't be trust, from 177 participants 55% thought that voluntary standards applied by industry weren't enough to assess nanotechnology risks. However, after receiving a bit more of information, when they were asked to ban this technology until more studies of potential risks were carried out 76% of people considered that this measure would be exaggerated. When they were asked about how government and industry could increase their trust in nanotechnology, 34% answered

that increasing safety tests before the product will be on the market and 25% said that providing information to consumers supporting them to make an informed choice. Other suggestion was tracking risks of products on the market. These proposals of improvement of public information and consumers' education would allow them to make better choices and gain trust on industry and government, since lack of information is one the main mechanisms that breed suspicions and lack of trust. This coincides with the opinions shown in other reports, for example the one of FSA "Nanotechnology and food. TNS-BMRB Report" in which the consumers' acceptance is conditioned by transparent information transmission and the reliability in the involved authorities (Food Standards Agency, 2011).

- Information sources (Dudo et al., 2011; House of Lords, Science and Technology Committee, 2010a): Sources and means from which public obtain information conditions in part social perception, being more likely favourable to accept or defeat a new technology. Means from which consumers have obtained more information are mainly television and radio (22%) and from other people (20%) (Macoubrie, 2005). This probably will mean that those that had acquired their knowledge through television and radio have a general knowledge about nanotechnology and not a view as much scientific-technological as if they had acquired this knowledge through journals or specialised papers.
- Socio-demographic and cultural factors (Rollin et al., 2011): According to these authors women are less optimistic than men (33% vs. 49%), and slightly less supportive (53% vs. 59%); religious people were less likely to a favourable perception; the age is not a significant influencing factor in perception, although older people (more than 66 years old) are less likely favourable to the use of nanotechnology.
- Finally, different results were found when nanotechnology perception was studied in different countries. For instance, in 2005 in Europe, 44% of Europeans had heard about nanotechnology. In Europe, acceptance seems to be increasing. In 2002, only 29% agreed on the future positive impact of nanotechnology, and 53% answered "don't know", while in 2005, almost half (48%) considered that nanotechnology will have positive effects on their way of life in the next 20 years. In 2006, over half of Europeans interviewed (55%) support the development of nanotechnology as they perceived this technology as useful to society and morally acceptable. However, in USA in 2002 consumers were more optimistic about nanotechnology (50% optimistic) than Europeans (29% optimistic). Nevertheless, by 2005, European, US and Canadian citizens were equally optimistic about nanotechnology. Europeans were more concerned about the impact of nanotechnology on the environment and were less confident in regulation than North Americans.
- Public general interests in nanotechnology applications. Among these interest must be cited the following ones, 31% in medical applications, 27% better consumers products (i.e. less toxic paint coatings, rubbish bags that biodegrade, etc.), 12% general progress (i.e. qualitative and quantitative advance in human knowledge, improvement in communications, etc.), 8% environmental protection, 6% in food safety and 4% in energy, economy, and electronics, finally 3% shows interest in army and militar security (Macoubrie, 2005).
- Attitude towards risks-benefits balance. This point had a big influence in the consumers' acceptance or not of this technology. When expected risks were rather

lower than benefits public were more likely favourable to accept this technology, this could explain packaging issue too. Personal situation influences perception of the risks-benefits balance, for instance people with diseases like obesity, hypertension or diabetes usually prone to see higher benefits in the applications to mitigate these diseases than risks in their possible applications (Food Standards Agency, 2011).

None previous studies have been found about how nanotechnology's perception conditions behaviours regarding eating and food buying. These are very important facts, if a more useful and commercial approach of the real acceptance of this technology wants to be known, but to get it, first the access to this information must be simple and transparent.

4. Conclusions

Throughout this chapter a review on how the world is facing a situation where in the near future access to foods and water will be one of the main problems for a great part of the world has been described. The pressure on environment, efficiency on production systems and population growth will require new and imaginative solutions to answer those problems. A great part of these solutions could require a technological leap or a breakthrough to achieve the final result. In this sense, nanotechnology could result a great opportunity for that.

As previously mentioned, nanotechnology shows solutions for foods manufacturing and production as well as for the water management. These approaches raise technical possibilities that could help to solve the situation in real context. Despite this, it will be needed to invest more time, financial resources and technological means to achieve widespread nanotechnology application in the sectors described here. For this reason some years will be still required to see a general market application.

Challenges of the nanotechnology are technological and social. Technological challenges will require new analytical techniques so that we can understand how the things are actually working at the nanoscale. On the other hand, and according to the evidence, new evaluation methods for the determination of potential environmental and health effects of using nanotechnology are required. This way the responsible and safe use of the nanotechnology will be possible.

Concerning the social aspects, the achievement of a global consensus about the use of nanotechnology will be necessary so that some limits were respected, (at least from a health and safety point of view).

So, technological and scientific considerations are not enough for the development of nanotechnology. A great part of the possibilities and potential applications of nanotechnology in the near future will depend upon public acceptance. Society (as a whole) must evaluate critically and objectively nanotechnology.

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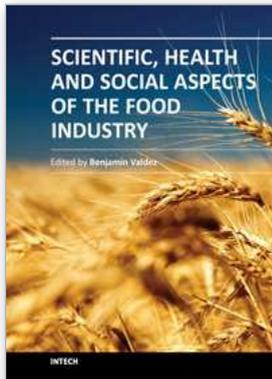
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This book presents the wisdom, knowledge and expertise of the food industry that ensures the supply of food to maintain the health, comfort, and wellbeing of humankind. The global food industry has the largest market: the world population of seven billion people. The book pioneers life-saving innovations and assists in the fight against world hunger and food shortages that threaten human essentials such as water and energy supply. Floods, droughts, fires, storms, climate change, global warming and greenhouse gas emissions can be devastating, altering the environment and, ultimately, the production of foods. Experts from industry and academia, as well as food producers, designers of food processing equipment, and corrosion practitioners have written special chapters for this rich compendium based on their encyclopedic knowledge and practical experience. This is a multi-authored book. The writers, who come from diverse areas of food science and technology, enrich this volume by presenting different approaches and orientations.

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