Nanotechnology and food

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This briefing paper discusses the state of the art of nanotechnology R&D and products in food and nutrition. After a short explanation of what nanotechnology is, present and expected future applications of nanotechnology in agriculture and food are discussed. The paper then follows the debate on food safety considerations which has emerged and discusses public awareness of nanotechnology in general and of applications of nanotechnology in food.

The aim of this briefing paper is to deliver concise, correct and balanced information to advance public debate among consumers, media, policy makers, producers and researchers as part of the European Commission-funded Nanobio-RAISE project.[1] It results from the combined contributions of natural and social scientists, industrialists, and governmental and public interest organisations across Europe. It is intended to provide information and does not represent the views or policy of the European Commission or any other body.

Introduction

Nanotechnology encompasses materials and devices with functional structures between 1 and about 100 nanometres. A nanometre is a thousandth of a thousandth of a thousandth of a metre (10^{-9}m) – about the length your fingernail has grown while reading this sentence or 60,000 times smaller than a human hair in diameter. Scientists have been developing nanotechnology in laboratories since about the 1980s. Now, according to claims by the manufacturers, several hundreds of products incorporating nanotechnology are already on the market worldwide including many in food and beverages. In the absence of international agreement on a standardised terminology for nanotechnology, it is not clear whether these products are truly made with it.[2] This briefing paper is intended to provide balanced information and advance public debate on the potential benefits, risks, ethical, legal and social implications of nanotechnology applied in agriculture and food.

What is nanotechnology?

Nanotechnology is a general technology, like biotechnology and information technology, integrated in a larger technological system or product. Nanotechnology is already used in some existing products such as anti-reflective coatings on car windows and tennis rackets strengthened with carbon nanotubes. Most of nanotechnology is still only a promise for enabling new products: five, ten, twenty or more years into the future. Nanoscience and nanotechnology are intrinsically interdisciplinary. Physicists, chemists, biologists, materials scientists, engineers and other scientists join forces in interdisciplinary teams studying how nature behaves at the scale of individual atoms and molecules and working to integrate particles of tens of nanometres diameter into potential products. Others are miniaturising micro-electronic chip design down to scales where quantum mechanics determines electronic behaviour allowing, for example, single electron switching. In 2005 worldwide total public and private investment was approximately €9.7 billion, including almost half from private sources.[3]

Materials and devices with nanostructures have different properties from the same materials and devices with larger scale. Some of these properties enable new products, for example nanostructured plastic conducts electrons rather than being insulating. This is expected to enable cheaper microchips. But free nanoparticles of otherwise non-toxic materials might inadvertently be toxic to humans or to the environment. As long as the particles are included in a bulk material no new risks are expected. Possible migration of the nanoparticles from such bulk materials into the food or the environment is the issue. Food safety experts are looking into whether the legislative controls on food packaging materials already in place for plastics etc are adequate to deal with the new properties of nanoparticles of the same food grade materials. Scientific toxicology research to assess the potential risks of engineered

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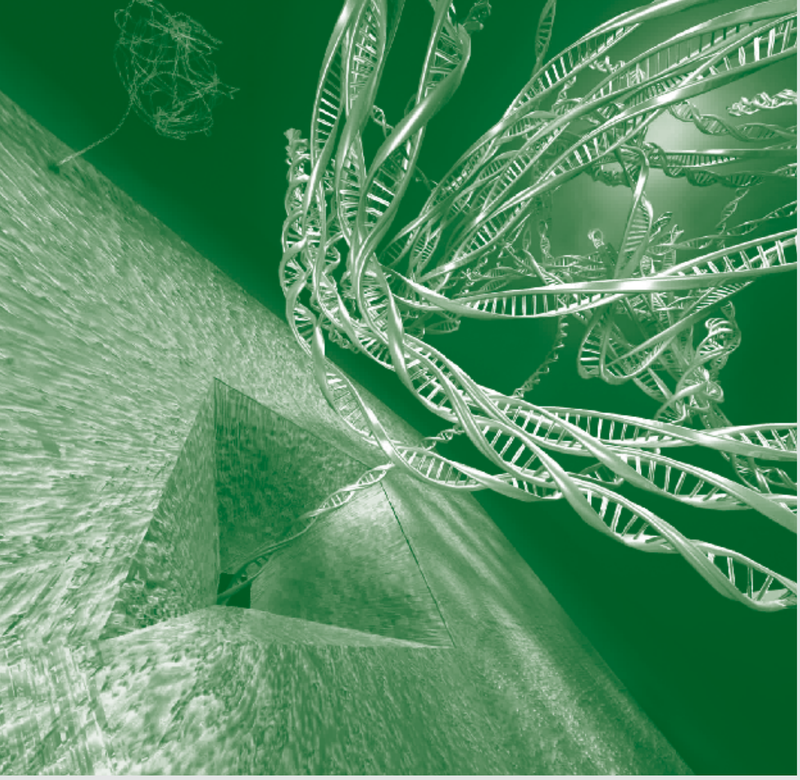


nanomaterials is only just starting and it will take some years before systematic data is available. Policy makers are assessing whether existing legislation regulating market access of products, which is not designed to deal with nanotechnology specifically, will require modification in the light of the emerging evidence on toxicological effects of synthetic nanomaterials. There is currently no consensus if any changes will be necessary, and whether the existing regulations themselves should be changed or merely the guidelines for their implementation specifying criteria for safety testing. The current legislation already requires strict testing, especially for products to which consumers will be exposed directly such as pharmaceutical or food products. One major need is commonly accepted definitions for nanotechnology and other relevant terms, such as nanoparticle and nanobiotechnology. National representatives, experts and industry and consumer and environmental organisation representatives are trying to reach a common understanding on useful terminology in the Organisation for Economic Cooperation and Development (OECD) and standardisation bodies including the worldwide International Standards Organisation (ISO) and European Committee for Standardization (CEN).

There are no common definitions about foods that may contain nanoparticles or ingredients in nano-particulate form. This is problematic because without common definitions, regulators, producers, consumers and other stakeholders can not identify and agree on what is really new about these foods and whether or not the current regulations and test methods are adequate to ensure food safety. It is not clear whether organic materials such as proteins and fat and sugar molecules which are in the nanometre length scale by nature should be considered nanomaterials and hence tested as a new food ingredient when adapted by food scientists to have new functionality. It is also not clear if the boundary of 100 nanometre is a sensible upper limit for applications of nanoscience and technology to food systems. Scientists still need to determine the size below which any particular material changes its properties. While some materials may have the same properties at any particle size, it is known, for example, that although gold is generally non-toxic, scientists have observed that gold nanoparticles show toxic effects[4] For other materials, tests still need to be done. In this briefing paper, the focus is on applications of nanotechnology in food.

Market trends in nanotechnology for food applications

Some food and beverage products are already produced with nanotechnology or include manufactured nanomaterials. Current market estimates for nanotechnology for food applications are between $410 million[5] and $2.6 billion in 2003[6]. Future expectations vary between a market share of food products based on nanotechnology of $5.8 billion by 2012[3] and of $20 billion by 2010.[4] However, it is unclear how valid such estimates are for the mid- to longterm future and without common definitions to distinguish nanotechnology for food applications from other food. Still, governments and food companies in many countries are investing substantially in nanotechnology development for food applications. In the USA, the Woodrow Wilson Institute has identified 160 projects in nanotechnology for agrifood applications, totalling and investment of about $15 million.[7] The Danish technology foundation has invested €2 million in research on nanotechnology for food applications in the Danish “Nanofood” consortium since 2006. In The Netherlands, the government is investing 50% of a €12 million research project on nanotechnology for food and health, and a larger research programme on nanotechnology for food applications has been proposed.[8] In 2005, Iran started a research programme on nanotechnology in agrifood including 35 laboratories.[9] Food applications of nanotechnology are also a priority in the UK and India.[10] Major food and nutrition companies including H.J. Heinz, Nestlé, Hershey, Unilever, Campina, Friesland Food, Grolsch, Kraft Foods, Cargill, Pepsi-Cola company, ConAgra Foods, General Mills, Danisco, Arla foods are engaged in research on nanotechnology for food applications. Materials manufacturers such as BASF and DSM are also interested in selling their nanomaterials to food producers.[6]

Nanotechnology applications in agriculture and food

Nanotechnology can be applied in all phases of the food cycle “from farm to fork” which are reviewed below. The following examples of potential future applications of nanotechnology in agriculture and food are mainly based on the Dutch MinacNed roadmap on Microsystems and Nanotechnology in Food [9 & 11] and Woodrow Wilson Project on Emerging Nanotechnologies[2] reports on nanotechnology on agriculture and food. Some of these applications will result in the presence of nanoparticles or nanostructured materials in the food. Other applications only use nanoelectronics or other nanotechnologies in food production where there is no direct interaction between the nanotechnology and the food system.

Agriculture/food production

Nanotechnology may be used in agriculture and food production in the form of nanosensors for monitoring crop growth and pest control by early identification of animal or plant diseases. These nanosensors can help enhance production and improve food safety. The sensors function as external monitoring devices and do not end up in the food itself.

Nanomaterials can also be introduced in or on the food itself. The effectiveness of pesticides may be improved if very small amounts are enclosed in hollow capsules with a diameter in the nanometre range which can be designed to open only when triggered by the presence of the pest to be controlled. Nanopesticide residues on the food and from animal feed and veterinary medicine, may end up inside the stomach but what happens then is not clear.[9]

Food processing

New types of membranes including micro and nano-sieves can be applied in food processing. The pores of the sieves are in the micrometer and nanometer range. They can be used for filtration of beer or of milk for cheese production[12]. In future, they may also be used for preparing water-filled fat colloids to produce low fat milk with the same taste as full fat milk which could then be used in creamy low fat ice cream. They can also be used for encapsulating valuable food ingredients such as minerals in a coating of another ingredient to boost take up by the body or to avoid these ingredients being lost during cooking.

Quality control and testing

Food safety is a major concern for food producers, consumers and food safety authorities. Nanosensors may help to improve food safety by enabling faster quality control and testing not only in the factory but also on the shelf and even in your refrigerator. These sensors can be integrated in the food processing equipment or in refrigerators and do not introduce nanoparticles into the food itself.

A nanosensor is a device consisting of an electronic data processing part and a sensing layer or part, which can translate a signal such as light, or the presence of an organic substance or gas into an electronic signal. The electrodes or the active layer can be structured at the nanometre scale. The whole device is usually at the scale of centimetres. A typical nanosensor would be the "electronic nose". Many sensors used for olfactory applications are based on MOSFET (Metal Oxide Semiconductor Field Effect Transistor) technology, which is commonly used in electronic circuits. Cantilever sensors are particularly interesting because they work in liquids. Such a cantilever sensor is equipped with tiny cantilevers with a biochemical layer which can detect the presence of a pest or disease. If the pest is present in a food product, molecules typical for that pest attach to the detection layer. The cantilever bends under the additional weight, leading to an electronic signal warning for the presence of the pest.

Nanosensors can be connected to an electronic or wireless network. They can, for example, be used for pest control of crops growing in the field or for quality control of milk during industrial processing. Other types of nanosensors can also be integrated in food packaging to show whether the product is still fit for human consumption. The nanosensors may for example change colour if the food is no longer fresh. Micro and nanosensors have been developed for food safety and quality control in the European project GOODFOOD (2004-2007).[13]

Food packaging and storage

Success of packaging materials for fresh products totally depends on the control of internal gas composition (O_2, CO5 pt) and water loss in packaging. Nanopackaging can create a modified atmosphere in packaging with controlled gaseous exchange, so that, for example, the shelf life of vegetables may be increased to weeks. The surface of an ordinary packaging material such as plastic or paper can be adapted to make it suitable for food by coating it with one or more sharply defined layers of tens of nanometres thickness. The plastic of drink bottles can contain clay nanoparticles to keep oxygen or water vapour in or out.

Antimicrobial agents are also being used to preserve food. Some of these are made with nanotechnology. The SAMSUNG refrigerator and food container Fresher Longer are coated with antimicrobial nanosilver particles. In the future active nano-coatings may also be applied on food packaging, for example, the Dutch Organisation for Applied Science (TNO) has developed a coating of starch colloids filled with an antimicrobial substance such that if micro-organisms grow on the packaged food they will penetrate the starch releasing the antimicrobial substance.[14] Nanoparticles which are included in food packaging or storage are not intentionally included in the food, but there is a chance these particles may migrate into the food.

Food additives

Currently, some food additives with nano-ingredients (according to claims by the producers) are being sold in the USA and Germany. These additives may imply that nanoparticles are present in the food. The additives are mainly aimed at the diet, sports and health food markets and contain minerals with a nano-formulation, such as silicon dioxide, magnesium, calcium, etc. The particle size of these minerals is claimed to be smaller than 100 nanometre so they can pass through the stomach wall and into body cells more quickly than ordinary minerals with larger particle size.

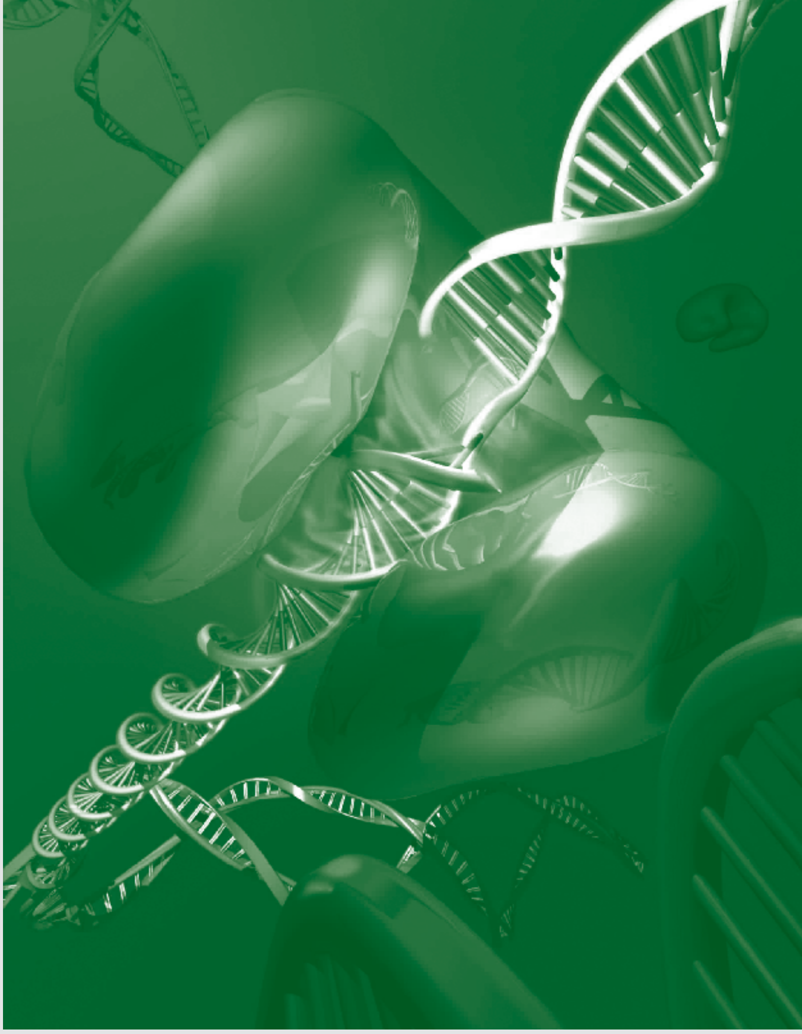
Nano-additives can also be incorporated in micelles or capsules of protein or another natural food ingredient. Micelles are tiny spheres of oil or fat coated with a thin layer of bipolar molecules of which one end is soluble in fat and the other in water. The micelles are suspended in water, or conversely, water is encapsulated in micelles and suspended in oil. Such nanocapsules can for example contain healthy Omega3 fish oil which has a strong and unpleasant taste and only release it in the stomach such as in "Tip Top Up"® bread sold in Australia.

Novel foods

Food and nutrition companies foresee a great deal of promise from nanotechnology in novel food products. In novel food, the ingredients which naturally occur in food are adapted for better taste, digestion or to address the specific nutrition needs of special groups such as babies, elderly or patients. Low fat milk, cheese and ice cream with the same taste as full fat products have already been mentioned. A Hungarian company has developed an ice gel for soft drinks or ice-cream. The jelly-like ice gel consists of very small ice crystals containing even tinier bubbles of carbon dioxide (CO_2). The CO_2 bubbles are 1-10 nanometres in diameter, much smaller than CO_2 bubbles in soft drinks. In the mouth, the ice gel causes a feeling similar to effervescent tablets.[15]

Since March 2007 a Dutch research centre in Atomic and Molecular Physics (AMOLF) and Unilever have been investigating human digestion processes at the atomic scale hoping to develop better novel foods such as healthy cholesterol replacements.[16] The trend is towards “personalised food”.

Not only the food itself may be adapted, external diagnostic devices incorporating nanosensors may also be used to achieve a diet which is better targeted to the needs of the body of an individual consumer. A future consumer may be able to use a fast handheld diagnostic device to test their body’s actual need for specific food ingredients such as minerals and adapt their diet accordingly and, similarly, a diabetic patient could use a glucose sensor to establish their need for insulin.[17]



Relevant nanomaterials

Several types of nanomaterials are considered relevant for applications in food. They can be subdivided into organic materials which are by nature of nanometre length scales and inorganic nanomaterials. Organic nanomaterials include proteins, fat and sugar molecules. Nutraceuticals consisting of food additives derived from plants are also organic nanomaterials used in food. Inorganic nanomaterials for applications in food, food additives, food packaging or storage include nano-clay platelets for food packaging; minerals such as silicon dioxide, calcium and magnesium; and silver nanoparticles for water purification or antimicrobial packaging or food storage.[16]

Food safety considerations

As already explained, scientists expect that food safety can be improved by applications of nanotechnology. Different types of nanosensors may in the future be used to monitor food quality throughout the food chain. Food processing technologies such as nano-sieves for separating microbes from the food are also expected to lead to improved food safety. Food and drinks quality may also be preserved for longer by incorporating nanoclay or antimicrobial nanoparticles in food packaging.[6, 9 & 10] But at present, it is not clear if nanoparticles in food are safe for consumers and the environment. Nanoparticles can be included intentionally in food as additives and in novel foods. Nanoparticles can also end up in food as residues of nano-pesticides, migrating from the packaging or from air, soil or water pollution. Food safety experts and regulators have started to discuss whether the present food safety legislation is adequate to ensure that novel nano-food products brought to the market are tested for safety.[18] There is some discussion whether nano-formulations of food additives or food grade packaging materials must be tested again if larger particles of the same materials are already allowed on the market.[19] For new nano-scale ingredients to be used in foods, the current EU Novel Food Regulation arguably imposes the need to test them for safety before they are allowed on the market. In any case, the producer has a legal responsibility only to introduce safe products onto the market. Risk assessment specialists in the agrofood sector are concerned about the lack of standard test procedures and handheld test equipment for controlling the safety of nanofood products. This means that even if a producer has tested the food for safety with conventional methods, there may still be unforeseen health and environmental risks. On the other hand, nature is full of organic nanoparticles. Proteins, sugar molecules, fat molecules all have nanometre sizes, and are safe for consumption.

Trends in regulation

The debate on regulating nanotechnology for food applications started in 2006 in the USA and Europe. The UK Institute of Food Science and Technology[20] has analysed existing European food safety legislation and concluded that the present food legislation is in principle sufficient to cover potential risks of nanofood although there were some doubts as to whether nano-additives of the same chemical composition of already approved food grade additives such as titanium dioxide for icing on cakes (a permitted white colouring), would have to be retested. Other concerns are mainly about implementation of the guidelines and of test protocols and instruments, as discussed above. The European Agency for the Evaluation of Medicinal products (EMEA) published a position paper on nanopharmaceuticals that reaches a similar conclusion.[21] The European Commission carried out a review of nanotechnology regulations adopted in June 2008 which concluded that *"Current legislation covers in principle the potential health, safety and environmental risks in relation to nanomaterials. The protection of health, safety and the environment needs mostly to be enhanced by improving implementation of current legislation."*[22] It is emphasised that there is a clear difference between a statement that uncertainties in knowledge mean it may be difficult to implement existing regulation and a statement that more regulation is needed.[23]

In the USA, the Food and Drug Administration (FDA) organised a public hearing in October 2006 about environment, health and safety of nanomaterials, including food applications, and is in the process of developing its policy plans. In Europe, policy makers responsible for food safety or nanotechnology in several EU Member States including UK, Germany, The Netherlands and Switzerland put the issues of nanotechnology and food safety on the agenda.[7] The European Food Safety Authority (EFSA) published its management plan for 2007 on 23 January 2007, including the establishment of a working group of the Advisory Forum of Member States representatives on risk assessment of nanoparticles. It intends to develop a harmonised approach on risk assessment and to collect the necessary data.[24]

Public Awareness

Currently, there is a huge lack of knowledge among the general public (as well as experts as discussed above) about nanotechnology as such and food applications in particular. Therefore there is a need for genuine public dialogue to hopefully avoid another GM-type situation developing. The seriousness was demonstrated by two "publifocus" conferences involving consumers where several applications of nanotechnology were discussed including food applications held in Switzerland and in Germany at the end of 2006.[25] The sixteen German consumers involved were positive about the opportunities for improved food safety by nano-based quality control but consider food applications of nano-ingredients a very sensitive area. The Swiss consumers were generally positive about nanotechnology but were most concerned about food applications. Both groups asked for labeling of nano-containing products although there

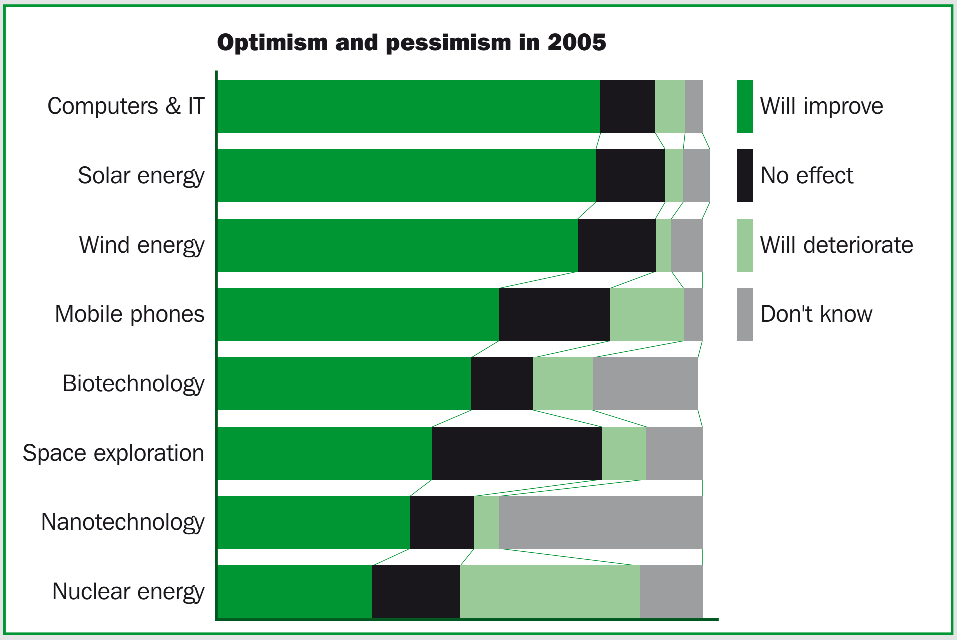


Figure 1: Eurobarometer 64.3: Europeans and Biotechnology in 2005

is a need to distinguish between "naturally occurring" molecules already present in food and artificially introduced manufactured nanoparticles that are not. There is a clear mistrust of (food) producers who may incorporate nanotechnology in products without indicating it on the label. German (Die Welt, ARD, Der Spiegel) and British (Observer, BBC Focus magazine) media have started reporting about food applications of nanotechnology, in some cases very critically.

In Europe, public awareness of nanotechnology is gradually emerging. According to the latest Eurobarometer study on biotechnology in 2005, 42% of respondents did not know if nanotechnology would have positive or negative impacts on their lives. 40% were positive, 13% expected no change, and 5% believed nanotechnology will deteriorate their life. Only 44% said they had heard of nanotechnology. Nanotechnology is considered morally acceptable, useful and not risky, and most respondents believe it should be encouraged. 55% of respondents support nanotechnology.[26]

In the USA, 80% of 1800 participants in a recent survey on nanotechnology had heard very little or nothing at all about nanotechnology. People's emotions play an important role in people's perception on nanotechnology, and values determine people's reactions to information on nanotechnology.[27] American consumers expect many advantages of nanotechnology for safer and better food. Out of a survey of 177 consumers, 6% mentioned this while on the other hand, 7% were concerned about potential risks of nanomaterials in the food chain.[28] There is a similar low level of knowledge about nanotechnology generally in the USA where more than 70% responded "neutral" to a survey question that asked participants to circle the word that represented their overall opinion of nanotechnology and its potential impact on their life and society.[29] However the 2006 National Science Foundation-funded survey in the USA of public perceptions of nanotechnology products found that US consumers are willing to use specific nano-containing products even if there are health and safety risks when the potential benefits are high which is similar to US attitudes regarding GMOs.[30]

In 2007 trade unions and environmental organisations are pressing for a precautionary approach to nanotechnologies and at the initiative of the International Union of Food, Farm and Hotel Workers expressed particular concern about the presence of nanoparticles in the food chain.[31] Consumer associations including the European Consumers' Organisation (BEUC) call for nanolabelling, especially for food products.[32]

Futuristic speculations

Not all ideas about future applications of nanotechnology in food closely resemble currently available food technologies. Even though such futuristic speculations are probably not the aim of present-day research, the fact that they are suggested in public media influences the public awareness about food based on nanotechnology. Some of these are that our grandchildren will eat vegetarian “meat” tasting the same as animal meat to guarantee a sustainable food supply for the whole world population or that we need food produced with nanotechnology as a form of preventive medicine. Consumers and journalists tend to use other images, for example in Willy Wonka’s Chocolate Factory[33] incorporating many kinds of artificial ingredients in novel chocolate bars with some unforeseen effects for the unsuspecting consumer. Originally, Kraft Food had proposed the idea of a transparent liquid filled with various encapsulated nano-ingredients which can become a glass of whisky, or orange juice, depending on the frequency of the microwave radiation used but following questions about safety by the Action Group on Erosion, Technology and Concentration (ETC–group) and others, Kraft seems to have abandoned it.[34] But this imaginative yet not totally impossible idea keeps popping up in the futuristic speculation about food produced with nanotechnology.

Conclusions

There is an urgent need for informed public debate on nanotechnology and food.
There are currently several dozen food and beverage products with nanotechnology on the market according to their producer or experts. Governments and food companies in several countries are investing in hundreds of projects developing nanotechnology in food and agriculture. Market analysts predict billion dollar markets for food produced with nanotechnology within five years. However, without commonly accepted definitions for nanotechnology, food produced with nanotechnology and other relevant terms, it is difficult to determine how many products actually include new nanomaterials.
Nanotechnology can be applied in all aspects of the food chain, both for improving food safety and quality control, and as novel food ingredients or additives, which may lead to unforeseen health risks. The current strict food legislation in Europe seems to be sufficient to cover food produced with nanotechnology. There are some concerns about implementation guidelines and risk assessment methods. The general public lacks awareness of nanotechnology in general, and applications of nanotechnology in food in particular. This must be addressed in public dialogue initiatives in the short term.

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