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NANOTECHNOLOGY AND FOOD

Introduction

Nanoscience and nanotechnology are concerned with the understanding and rational manipulation of materials at the atomic and molecular level, generally with structures of less than 100 nm in size. Scientifically *nanoscience* is defined as the study of phenomena and the manipulation of materials at the atomic, molecular and macromolecular scales, where the properties differ from those at a larger scale. *Nanotechnology* is defined as the design, production and application of structures, devices and systems through control of the size and shape of the material at the nanometre (10^{-9} of a metre) scale.

The electron microscope and, more recently, the development of tools such as probe microscopes, has provided unparalleled opportunities for understanding heterogeneous food structure at the sub-molecular level. This has provided new solutions to previously intractable problems in food science and offers new approaches to the rational selection of raw materials, or the processing of such materials to enhance the quality of food products. This ability to use nanoscience to improve the quality of materials through understanding and refining their nanoscale structures is an example of a form of nanotechnology that has been called *incremental nanotechnology* (Jones 2004b). When the reduction in size of structures leads to step changes in properties, that provide radical new solutions to problems and new commercial opportunities, these types of applications are considered to be examples of what has been termed *evolutionary nanotechnology* (Jones 2004b).

The prospect of the use of products of evolutionary nanotechnology in the food area is the area that has engendered most debate. The concern is that if changing the size of materials can lead to radical, albeit useful properties, can we be sure how size will affect other properties and, in particular, the potential toxicity of such materials?. Although the products of nanotechnology intended for food consumption are likely to be classified as novel products and require testing and clearance, there are concerns, particularly in the area of food contact materials, that there could be inadvertent release and ingestion of nanoparticles of undetermined toxicity. Such concerns need to be addressed because the ultimate success of products based on nanotechnology will depend on consumer acceptance.

The recent explosion in the general availability of nanoproducts makes it almost certain that nanotechnology will have both direct and indirect impacts on the food industry.

Potential indirect food applications of nanotechnology

Computing and communications: Silicon chips have been made by nanotechnology for over 20 years, and have led to advances in electronics, computing and communications. Continued incremental advances in these areas and the growing sophistication of communication devices will continue to influence the way consumers shop. New types of labelling, possibly based on polymer light emitting diodes, offer new ways to store, display and interrogate information on packaging. This will allow individuals to access more information about the source, history and storage of specific foods, their nutritional characteristics and their suitability to their genetic makeup and life-style.

Material science: Techniques such as micro-fluidics and, in the future, nano-fluidics will allow small factories or laboratories to be constructed on chips. Coupled with the ability to interrogate increasingly sophisticated databases, such advances should enhance authentication, and improve the safety of foods.

The natural tendency for food biopolymers to self-assemble into larger structures can be used to fabricate coatings, barriers and interfacial structures with controlled properties. Nanocomposites are already available as packaging or in coatings on plastic bottles to control gas diffusion and prolong the lifetime of various products. Nanotechnology is already being used worldwide to produce anti-microbial food contact materials commercially available as packaging, or as coatings on an ever increasing number of products such as food containers, chopping boards and refrigerators. There is currently research on 'smart' surfaces that could, for example, detect bacterial contamination and react to combat infection. Although many of these materials contain nanoparticles, they are generally regarded as safe, provided their use does not lead to the release and ingestion of these particles. Concern has been expressed over the long-term fate and disposal of these materials, which might then lead to release of nanoparticles into the environment. These types of concerns have led to debate on the labelling, approval, traceability and regulation of these materials.

Potential direct food applications of nanotechnology

Nanostructures in food: Food proteins are often globular structures 1-10 nm in size. Most polysaccharides (carbohydrates) and lipids (fats) are linear polymers with thicknesses less than nanometres in size, the functionality of many raw materials and the successful processing of foods arise from the presence, modification and generation of forms of self-assembled nanostructures. Examples include the planer assemblies of cellulose fibrils in plant cell walls, the crystalline structures in starch and processed starch-based foods that determine gelatinisation and influence the nutritional benefits during digestion, the fibrous structures that control the melting, setting and texture of gels, and the 2D nanostructure formed at oil-water and air-water interfaces that control the stability of food foams and emulsions.

Understanding the nature of nanostructures in foods allows for better selection of raw materials and enhanced food quality through processing. Techniques such as electron microscopy and the newer probe microscopies, such as atomic force microscopy (AFM), have begun to reveal the nature of these structures, allowing rational selection, modification and processing of raw materials.

For example, the creation of foams (e.g. the head on a glass of beer) or emulsions (e.g. sauces, creams, yoghurts, butter, margarine) involves generating gas bubbles, or droplets of fat or oil, in a liquid medium. This requires the production of an air-water or oil-water interface and the molecules present at this interface determine its stability. These structures are one molecule thick and are examples of 2D nanostructures. A source of instability in most foods is the presence of mixtures of proteins and other small molecules such as surfactants (soap-like molecules or lipids) at the interface. AFM has allowed these interactions to be visualised and understood and has led to generic strategies for improving the stability of the protein networks that can be applied widely in the baking, brewing and dairy industries. This form of incremental nanotechnology is likely to lead to continued improvement in food quality, but is unlikely to require modifications to food regulation or labelling. Novel raw materials with new molecular structures and properties, identified through nanoscience, would require clearance for use in foods.

Nanoparticles in foods

The area that has led to most debate on nanotechnology and food is the incidental or deliberate introduction of manufactured nanoparticles into food materials. This debate largely concerns the risk and benefits, given the lack of knowledge on the potential bio-accumulation and possible toxicity of nanoparticles.

The report on 'Nanofoods' from the Helmut Kaiser Consultancy (2004) estimates an increasing growth in the development of food-related nanoproducts and patent applications.

Food contact materials: Various additives or ingredients are approved for use in food contact materials. The types of materials approved and the regulations on their use will vary for different countries. If the materials do not partition into foods then there should be little concern over the safety of their use in food contact applications. Should some degree of partitioning occur then the limitations on their use are based on an acceptable daily uptake (ADI) for these additives or ingredients.

The inclusion of nanoparticles in food contact materials can be used to generate novel types of packaging materials and containers. Nanoparticles of pigments such as TiO_2 become transparent but retain their UV absorption characteristics. This suggests applications in transparent wraps, films or plastic containers where absorption of UV radiation needs to be avoided. Layered composites containing nanoparticles (such as nano-clays) are being used to generate long pathlengths through materials to reduce gas diffusion and prolong the shelf-life of products.

At present any regulation of the use of additives or ingredients does not appear to take into account the size of the material and how this could affect ADI values. Thus, technically, it may be possible for a supplier to sell nanoparticles of food-approved ingredients or additives as approved for use in food contact applications. Ultimately, however, there must be an obligation that the final products which use these food contact materials are safe.

Foods: Worldwide commercial foods and food supplements containing added nanoparticles are becoming available. A major growth area appears to be the development of 'nanoceuticals' and food supplements (Chen *et al.*2006). The general approach is to develop nano-size carriers or nano-sized materials, in order to improve the absorption and, hence, potentially the bioavailability of added materials such as vitamins, phytochemicals, nutrients or minerals. The materials can be incorporated into solid foods, delivered as liquids in drinks, or even sprayed directly onto mucosal surfaces. The important issues are whether the carriers and the encapsulated products are normally absorbed, digested and metabolised. If they are, then the interest is in whether the absorption and metabolism remains the same for the nano-form of the material, and whether there could be new issues related to enhanced levels of absorption: the aim of encapsulation will be to optimise rather than just increase bioavailability. There are added concerns for materials such as minerals which are normally largely excreted: will the nano-form lead to enhanced bioaccumulation, reduced excretion, and thus a need to establish new ADIs for these materials in the nano-form.

The number of food-related nano-products is increasing rapidly, and examples include:

- nanoparticles of carotenoids that can be dispersed in water, allowing them to be added to fruit drinks providing improved bioavailability;
- a synthetic lycopene has been affirmed GRAS ("generally recognised as safe") under US FDA procedures;
- nano-sized micellar systems containing canola oil that are claimed to provide delivery systems for a range of materials such as vitamins, minerals or phytochemicals;
- a wide range of nanoceutical products containing nanocages or nanoclusters that act as delivery vehicles, e.g. a chocolate drink claimed to be sufficiently sweet without added sugar or sweeteners;
- nano-based mineral supplements, e.g. a Chinese Nanotea claimed to improve selenium uptake by one order of magnitude;
- patented 'nanodrop' delivery systems, designed to administer encapsulated materials, such as vitamins, transmucosally, rather than through conventional delivery systems such as pills, liquids or capsules; and

- an increasingly large number of mineral supplements such as nano-silver or nano-gold.

Regulation, labelling and approval

There are several generic issues related to regulation, labelling and approval of nano-products:

- In the UK the Royal Society and the Royal Academy of Engineering produced a report on nanotechnology. They identified a lack of knowledge on the bioaccumulation and toxicity of nanoparticles. Based on this they suggested caution in the use of nanoparticles in consumer products until more information was available on their safety.

- Although regulatory authorities agree with the need to be cautious in the use of new technologies such as nanotechnology, they anticipate that most applications of nanotechnology in food to be considered for approval will be safe and beneficial to the consumer. It is generally suggested that there is a need to evaluate new products on a case-by-case basis and then consider any necessary amendment of regulations. They reason that they could not ban a nano-product unless there was some evidence that the product was actually harmful. Such an approach to regulation could be perceived by consumers as a loophole that could allow industry to introduce products onto the market without adequate testing or approval. Given the ambiguity of the status of the use of nanoparticles of food-approved ingredients or additives in food or food contact materials, the authorities responsible for regulation should make clear statements about their use and that they consider that new products based on the use of added manufactured nanoparticles in food or food contact materials should be regarded as novel products, requiring evaluation and approval.

- The attitude to regulation, labelling and approval of products of food nanotechnology varies from country to country. However, nanoproducts are becoming widely available through the internet. The lack of consistency in regulation, labelling and approval of such products make it difficult for consumers to exercise choice in a rational manner.

- Consumer attitudes are likely to be vital to the successful application of nanotechnology in the food industry. Given the lessons of the GM debate in the UK and Europe, it is important that the benefits and risks of nanotechnology are openly discussed, and that it is important to consider the issue of labelling. In particular, the use of the term ‘nano’ or related terms as part of the branding of a product is at present ill-defined. It would be useful if regulators provided guidelines as to when such branding was appropriate and justified. Where the term ‘nano’ is used there should be a requirement that producers define how nanotechnology has been used in the development of the product, and why this process enhances the quality of the product.

- Special attention should be given to novel uses of nanoparticles as anti-microbial agents on surfaces such as cutting boards, refrigerators or utensils. The key questions here are whether such materials are released on contact with food, whether they are ingested, and if they are, their impact on human health and the acceptable levels of intake of such materials on a daily basis. New applications such as the use of nanoparticles as anti-microbial agents in edible films and coatings are likely to arise in the future and will raise new issues on the ingestion, accumulation and safety of such products.

- There is a need for further research into the consequences of the ingestion of nanoparticles. There is a specific need for research on materials not normally adsorbed, digested and metabolized on ingestion. For these materials the research should consider the effect of size on the bioaccumulation and toxicity of such particles, as well as the benefits and risks of any anti-microbial effects on the microbial ecology of the mouth and the gut.

- Consideration should be given to the consequences of the use of nanotechnology to enhance the bioavailabilty of nutrients. This should consider the safety of the products, the consequences of enhanced or altered metabolism, and also the need for labelling, regulation and testing of health claims for such food supplements.

- Where the safety data or ADIs for manufactured nanoparticles of food-approved ingredients or additives differs from that of the bulk materials, then there may be a need for selective or distinctive labelling of these nanoproducts.

Conclusions

At present it seems likely that nanotechnology will impact on the food industry. Most aspects of incremental nanotechnology are likely to enhance product quality and choice and will be perceived as progressive changes in standard and accepted technology. There are a few issues, particularly regarding the accidental or deliberate use of nanoparticles in food, or food contact materials, which may provoke consumer concern. It is particularly important to ensure that consumers are able to exercise choice in the use of the products of nanotechnology and that they have the information to assess the benefits and risks of such products.

Further reading

Chau, C-F, Wu, S-H and Yen, G-C (2007) The development of regulations for food nanotechnology**.** *Trends Food Sci. Technol.* **18:**269-280.

Chen, H, Weiss, J and Shahidi, F (2006) Nanotechnology in nutraceuticals and functional foods. *Food Technol.***60 (3):** 30-36.

Jones, RAL (2004a) Soft Machines: Nanotechnology and Life. Oxford University Press.
A good book about nanotechnology for the general reader.

Jones, RAL (2004b) The future of nanotechnology.
Describes potential scenarios for the use of nanotechnology, and also introduces the ideas of incremental and evolutionary nanotechnology.
http://physicsweb.org/articles/world/17/8/7

Morris, VJ (2005) Is nanotechnology going to change the future of food technology? *Int. Rev. Food Sci. Technol.* **3:** 16-18.

IUFoST-recommended authoritative websites on nanotechnology and food

[Australia] Earth Policy Centre, University of Melbourne, Victoria, Australia.
Nanotechnology. Assessing the Environmental Risks for Australia
http://www.earthpolicy.org.au
http://www.earthpolicy.org.au/nanotech.pdf

BASF
www.corporate.basf.com/en/innovationen/felder/nanotechnologie
BASF policy on nanotechnology and information on products. This company has produced dispersible lycopene as nanoparticles in order to enhance its bioavailability.

European Commission
http://www.cordis.europa.eu/nanotechnology/
The European Commission nanotechnology website provides news and information about European nanotechnology research and an overview of nanotechnology-related activities at the European Commission. It highlights elements specifically relevant to nanotechnology in Europe such as the European Strategy and the Action Plan, projects and funding opportunities in the Framework Programmes and related publications and events

EC Questions and Answers Fact Sheet on Nanotechnology Risk Assessment
Issued 20 October 2005

http://www.europa/eu.int/rapid/pressReleasesAction.do?reference=MEMO/05/385&format=HTMLaged=0&language=EN&guiLanguage=en

EC Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR)
Opinion**:** The appropriateness of existing methodologies to assess the potential risks associated with engineered and adventitious products of nanotechnologies. 78 pp.
http://www.europa.eu.int/comm/health/ph_risk/committees/04_scenihr/docs/scenihr_cons_01_en.htm

ETC Group
Down on the Farm: The Impact of Nano-Scale Technologies on Food and Agriculture. 23 November 2004.
www.etcgroup.org
www.etcgroup.org/en/materials/publications.html?pub_id=80
Thought provoking views of potential applications on nanotechnology in agriculture and food.

European Nanotechnology Gateway
www.nanoforum.org
Hub for information on nanotechnology in Europe and worldwide.

European Union
www.efsa.europa.eu/en.html
The European Food Safety Authority (EFSA) is the keystone of European Union risk assessment regarding food and feed safety. In collaboration with national authorities and open consultation with stakeholders, EFSA provides independent scientific advice and clear communication on existing and emerging risks.

Helmut Kaiser Consultancy
Study: Nanotechnology in Food and Food Processing Industry Worldwide 2003-2006-2010-2015. Helmut Kaiser Consultancy (2004).
www.hkc22.com/nanofood.html
This is a study on nanofoods which can be purchased from the website.

Institute of Nanotechnology
http://www.nano.org.uk
The Institute of Nanotechnology works closely with governments, universities, researchers, and companies worldwide on developing and promoting all aspects of nanotechnology. It also serves as a key organizer of international scientific events, conferences and educational courses designed to encourage nanotechnology uptake by industry, as well as stimulating interest in less developed countries.

[Japan] Council for Science.
Joint report by the Royal Society (UK) and the Council for Science (Japan). Available from the UK Royal Society website
www.royalsociety.ac.uk
http://www.nanonet.go.jp/english/info/report/rep20060626.html
Report of workshop on potential health, environmental and societal impacts of nanotechnologies

[Switzerland] Federal Office for the Environment (FOEN) and the Federal Office of Public Health (FOPH).
http://www.innovationsgesellschaft.ch/actions.htm
Comprehensive Report on Risks of Engineered Nanoparticles - providing solid ground for subsequent political actions

[UK] Food Standards Agency
Nanotechnology.
www.food.gov.uk

[UK] Institute of Food Science and Technology
Nanotechnology. February 2006.
www.ifst.org
www.ifst.org/uploadedfiles/cms/store/ATTACHMENTS/Nanotechnology.pdf

[UK] Royal Society
Nanoscience and Nanotechnologies: Opportunities and Uncertainties. Available from the Royal Society website.
www.royalsociety.ac.uk/
www.royalsociety.ac.uk/landing.asp?id=1210

United States Department of Agriculture
Nanoscale Science and Engineering for Agriculture and Food.
http://www.nseafs.cornell.edu/web.roadmap.pdf
Report of a US workshop outlining a roadmap for possible nanotechnology applications in food and agriculture.

[US] Food and Drug Administration
US FDA forms internal Nanotechnology Taskforce.
http://www.fda.gov/nanotechnology/nano_tf.html
http://www.fda.gov/nanotechnology/taskforce/report2007.html

[US] Institute of Food Technologists
Functional Materials in Food Nanotechnology. IFT Scientific Status Summary.
Weiss, J, Takhistov, P and McClements, DJ (2006) *J. Food Sci.* **71 (9);** R107-R116.
http://www.ift.org

Woodrow Wilson Charitable Trust for Scholars / The Pew Charitable Trusts
Project on Emerging Technologies.
http://www.nanotechproject.org
Provides access to a nanotechnology consumer products inventory

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The International Union of Food Science and Technology (IUFoST) is the global scientific organisation representing over 200,000 food scientists and technologists from more than 60 countries. It is a voluntary, non-profit association of national food science organisations linking the world's food scientists and technologists.
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