# Food innovation and nanotechnology—do they go together?

**Kathy Groves,[*] Pretima Titoria and Wayne Morley**

*Leatherhead Food Research, Randalls Road, Leatherhead, Surrey, KT22 7RY, UK*

Innovation is the key to progression in any business and food is certainly no exception. In order to innovate successfully, the application of science and technology to practical matters is needed, and therefore it is important to keep in touch with new, emerging technologies and advances. Nanotechnology as a quintessential emerging technology can offer real benefits regarding innovation, both to the food industry and to the consumer. One might note that it is in fact not one technology but very many technologies with wide applications in all areas of life, not just foods. Nanotechnologies have controversial connotations with some consumers and the media are concerned about why the industry wants to use them and whether they are safe. This article presents a review of the potential applications of nanotechnologies in foods, discussing what is out there now as well as risks and benefits.

Innovation is the key to progression in any business and food is certainly no exception. The drivers for the food industry to innovate and produce new foods or new processes or packaging are many and varied. They include the following developments:

- Healthier foods (such as increasing nutrient availability or reducing fat, salt, sugar etc.)
- Nutritional foods that supply a "healthier body"
- Improved ingredient performance
- New textures and flavours
- Safer foods through reduced or inhibited pathogen growth
- Faster, cheaper analysis of food ingredients and contaminants
- Cleaner processing
- Accurate shelf-life prediction for waste reduction and improved food quality
- "Cleaner" labels (removal of chemical additives)
- Increased sustainability of the industry as a whole.

[*] Corresponding author. E-mail: KGroves@LeatherheadFood.com

*Nanotechnology Perceptions* **7** (2011) 141–147
*Received* 2 June 2011

In order to innovate successfully, the harnessing of science and technology is needed, and therefore it is important to keep in touch with new, emerging technologies and advances. These are often in the nonfood arena, hence a "lateral thinking" approach is needed to make the link and cross technology boundaries. The role of science in food production might come as a surprise to the consumer. Although many know that foods sold in the retail market are produced on a large scale, there is little known about the use of science and technology needed to bring this about. Foods are more complex than is thought; for example, those involving the production and stabilization of emulsions used in many sauces, soups and salad dressings; controlled crystallization of fat in bread, spreads and confectionery products; and the manufacture and use of the many ingredients supplied to help stabilize foods and give them a specific texture or other property. All this is aside from the development of the machinery needed to mix large volumes of ingredients, mill to a specific size, cool or heat to controlled temperatures and rates, move and deposit in precise sizes or volumes, and finally assemble and then package. These operations all have to be carried out safely not only in terms of operator use but also in terms of microbiological quality: foods have to be hygienically produced and packaged and labelled in accordance with safety and regulatory laws. Following this they have to be delivered quickly to retail shops or directly to customers and only stored and sold within the interval assessed as the shelf-life of the product. This shelf-life or "best before"/"use-by" date is very difficult to assess accurately since it is not only the microbiological safety that is of concern but also the quality and flavour of the food itself that can change on storage.

Nanotechnology, an emerging technology, can offer real benefits in many of these aspects, both to the food industry and to the consumer. It is in fact not one technology but very many technologies with wide applications in all areas of life, not just foods. Nanotechnologies are used to enable the manufacture of nanomaterials with special properties. Typical examples of nonfood applications include the use of carbon fibres in high quality goods such as professional equipment and automobiles, providing increased strength with lighter weight; nanosensors for rapid diagnostics such as blood sugar measurement for diabetics; dirt-repelling nanocoatings for clothing and buildings; nanosilver for antimicrobial wound dressings and nano-encapsulated particles for cosmetics and sunscreens applied to the skin.

### *Potential applications for the food industry*

In terms of the food supply chain, there are four main areas that could benefit from nanotechnology in some way. These are:

- Agriculture
- Food ingredients and processing
- Food packaging
- Health supplements and colours and flavours.

### *Agriculture*

Examples of the potential use of nanotechnologies (nano-enabled products) include nanosensors for the detection of pathogens in plants, animals or foods, as well as kits for ultrarapid analysis of chemical contaminants at the point of production, or monitoring soil conditions and plant growth. Widespread deployment of nanosensors should facilitate the delivery of animal feed more effectively to promote healthy, rapid growth and the more efficient delivery of pesticides.

### *Food ingredients and processing*

Potential applications of nanotechnology in food ingredients include encapsulated nutrients to deliver enhanced bioavailability, encapsulated taste maskers or flavour enhancers, and production of nanosized conventional ingredients that have increased or novel functionality. In processing, the antidirt coatings developed for buildings and clothing could be further developed and applied to machinery in the processing plant. This would enable more efficient energy use in appliances such as heat exchangers by reducing fouling of pipework, hence less down-time for cleaning. The surfaces would also be more antimicrobial, giving a safer production process overall. In a more sophisticated application, it should be possible to design nanostructured filters or adsorbents to specifically remove unwanted substances such as allergens from foods.

### *Food packaging*

Antimicrobial coatings incorporating nanoparticles made from substances such as silver could be and have been used in food packaging to prevent growth of pathogens. Nanoplatelets have been incorporated in polymers to increase shelf-life by preventing or delaying oxygen transport through packaging. Examples include plastic beer bottles impregnated with nanoclay to slow oxygen transport, and silver nanoparticles incorporated in plastic food containers.

In addition to these applications, there are developments in sensors that allow detection of changes to the contents of the packaged food, detecting microbial growth through gas production. Packages incorporating such sensors would display a warning sign such as a red bar indicating the food is past its shelf-life and should not be eaten, which should be more reliable than the present practice of simply printing a limiting date based on average experience. This could be extended to be incorporated in a dynamic bar code or similar, allowing the food to be rejected at the point of sale. Since it is reported that some 25% of food produced is wasted through spoilage, this application should provide a large improvement in food supply.

### *Health supplements and colours/flavours*

There is presently a large increase in interest in how diet affects general health. This is not just restricted to the developed Western world but also now touching emerging markets. It has been shown that reducing the size of nutrient particles allows them to be more efficacious and will probably enable them to be more easily incorporated into food products. Supplementing foods in this way could be considered as available only to higher income groups given the present generally high costs of nanoparticles, however there is an argument that those on a poor diet through whatever reason could benefit from this approach also, since the same dietary efficacity can be acheved using less material, of interest if the supplement is intrinsically costly.

As well as delivering nutrients, foods also need to taste good and look attractive. Colours are complex and with the drive towards more "natural" ingredients, processing of foods can cause problems by distorting or degrading natural colours or flavours. The use of nanotechnology to protect them from degradation during the manufacturing process is one example of potential improvements.

### *What is already out there?*

This is a frequently asked question; the answer is that in the global arena, food applications of nanotechnology are very few. In the last few years there has been an increase in food products launched with a claim that nanotechnology has been used, however in each year the total has been well under 100 products. By category the majority of these have been in wellbeing supplements, with dairy and drinks applications following.

Packaging accounts for a number of food applications claiming nanotechnology use, particularly with antimicrobial coatings or increased shelf-life. Encapsulated nanosized nutrients have been the major use in health (wellbeing) supplements. There are, however, not many products on the market that involve true nanotechnology applications. There is certainly an increasing level of research, and in the first few months of 2011 a search in the science journals using the key words “nanotechnology” and “food” produced over 500 publications. These covered a very wide range of topics, including a kit for the rapid detection of melamine in milk, the synthesis of antimicrobial particles such as zinc oxide, the manufacture of nano-emulsions of nutrients, and other ingredients such as whey proteins for use as natural carriers. There is also a strong scientific effort into the nanostructuring of foods and fat in foods to control satiety or the feeling of fullness after a meal.

### *Consumer concerns and debate*

Already with the discovery and commercial development of carbon fibre the concerns as to the safety and health risks of the material became a strong discussion point, even though this was before the real nano era. The concerns revolved mainly around the similarities in appearance in the electron microscope between the carbon fibres and asbestos. In addition, the unusual properties that might arise with nanoparticles generally because of their small size became an issue for some, the argument being that such small particles could penetrate through the body’s natural defences. Concerns exist with respect to the ingestion of nanoparticles of substances such as silver, titanium and silica due to their enhanced reactivity at the nanoscale.

As a result of many studies on the potential for nanotechnology and detailed reports from learned and professional organizations[1] and more recently the House of Lords select Science & Technology Committee report on nanotechnologies for foods[2] and EFSA’s draft report on guidance on risk assessment of nanomaterials,[3] the debate on the safety issues in using nanomaterials has become positioned more publicly.

[1] *Nanoscience and Nanotechnologies: Opportunities and Uncertainties*. Royal Society of London/Royal Academy of Engineering (2004). http://www.nanotec.org.uk/report/Nano%20report%202004%20fin.pdf

[2] *Nanotechnologies and Food. Science & Technology Committee First Report* (2010). http://www.publications.parliament.uk/pa/ld200910/ldselect/ldsctech/22/2202.htm

[3] *Guidance on the Risk Assessment of the Application of Nanoscience and Nanotechnologies in the Food and Feed Chain*. EFSA (2011). http://www.efsa.europa.eu/en/efsajournal/pub/2140.htm

The debate is expected to have an important outcome in that any potential risks of nanomaterials need to be controlled and therefore appropriate regulations need to be agreed and set in place. In order to regulate, there needs to be an agreed definition for nanoparticles and nanotechnologies, and hopefully methods to measure the size of food particles in the nanoscale. This measurement of nanoparticles is in fact a very difficult problem to overcome since by definition the particles are extremely small and may be present in small amounts. There are laboratories that provide a nanoparticles measurement service but generally, not especially in foods; indeed there are no clear methods for foods.[4]

The general definition of nanomaterials has not been finally agreed but the Commission of the European Communities proposed at the end of 2010 that any material is a nanomaterial if it meets one of the following criteria:

- It consists of particles with one or more external dimensions in the size range 1–100 nm for more than 1% of their number size distribution;
- It has internal or surface structures in one or more dimensions in the size range 1–100 nm;
- It has a specific surface area per volume greater than 60 $m^2/cm^3$, excluding materials consisting of particles with a size less than 1 nm.[5]

The Technical Committee 229 of the International Standards Organization is also preparing an internationally agreed definition.

While the debate on the definition and measurement of nanoparticles in foods has focused on the term "engineered", there is also an issue as to what risks, if any, are associated with nanoparticles of "natural" food ingredients such as fats, proteins and starches. These natural components of foods exist in molecular form at the nanoscale, and manipulation of them within the food has been around for a long time. As an example, the protein fibres actin and myosin in muscle are structured within the range of the definition of the nanoscale. The extent of dispersion of these proteins during processes such as curing, marinading or cooking affects the texture of, for example, beefsteak or chicken. As an example of a processed food product, low fat spreads rely on the controlled crystallization of fat around water droplets, which are stabilized by hydrocolloids such as proteins. These structures and others, such as stabilizing membranes in emulsions or foams, exist and are produced or engineered at the nanoscale. In addition, ingredients such as icing sugar, flour and cocoa that are milled or ground are likely to have a non-negligible percentage of particles below 100 nm in diameter, almost certainly putting them into the nanomaterials category. Within the industry, solubility has been advocated as a good property to differentiate natural ingredients from engineered ones like silver or silica, but this would wrongly classify natural substances like cocoa or flour.

In a recently published study of consumer attitudes commissioned by the UK Food Standards Agency,[6] citizen forums were presented with information on nanotechnologies in foods and potential applications and asked for their views. In summary, the participants' initial

[4] An EU-funded project ("Nanolyse") is developing measurement techniques for engineered nanoparticles in foods.

[5] G. Liden, The European Commission tries to define nanomaterials. *Ann. Occup. Hyg.* **55** (2011) 1–5.

[6] FSA Citizens Forums: Nanotechnology and Food (2011). http://www.food.gov.uk/multimedia/pdfs/publication/fsacfnanotechnologyfood.pdf

reactions to the application or research into nanotechnology fell into three main areas:

- Why are we doing this?
- Who is it for?
- Is it worth it?

Different applications of nanotechnologies and food were received with different levels of approval by participants. For example, health-based applications such as lowering salt, sugar or fat in foods were viewed more positively than seemingly more trivial applications such as creating new textures and flavours.

In addition, participants viewed nanotechnology in food packaging as more acceptable than direct food applications, even though these applications are more associated with the "hard" (insoluble) nanoparticles such as silica or silver (as opposed to "soft" (soluble) nanoparticles such as globulin proteins), as they considered that materials in packaging would not be eaten. Consumers did nonetheless want reassurance that nano-objects present in packaging will not migrate into food, that packaging will be environmentally friendly and that costs will not be too high.

One of the interesting views that came out of the FSA study was that consumers did not see the relevance of applying science to the development or production of foods. This shows the wide gap between consumers and manufacturers in the understanding of how food products are made and needs to be addressed if acceptance of new technologies such as nanotechnology is to be achieved.

In the debate about global changes and the impact on food supply, population growth in many countries and the growing affluence of key markets such as big Asian countries, the impact of climate change on food production, and the tightening demand for key ingredients are all factors that will drive innovation. The European Union (EU) plan for sustainable food production states that emerging technologies are expected to play a major part in delivering this.[7] If the benefits of nanotechnology and other emerging technologies are to be realized and not follow the ill-fated European genetically modified (GM) foods industry, then a dialogue between all the stakeholders of information on food research and how it applies to food manufacture needs to be ongoing. This directly applies to food innovation, but raises the issue of whether it is realistic, or indeed necessary, for food companies to share their early research ideas. Certainly from a food innovation viewpoint, nanotechnology and innovation do go together.

Leatherhead Food Research takes a very positive stance on nanotechnology and believes that it has a crucial role to play in food innovation in the future. This is evidenced in two key ways, firstly through Leatherhead's role in monitoring developments in nanotechnology in the food industry through its NanoWatch® programme, and secondly through active involvement in research programmes designed to identify the benefits of nanotechnology in food.

NanoWatch has run for three years and provides a watching brief of relevant scientific developments on behalf of a consortium of Leatherhead member companies. These allow them to stay on top of developments and identify opportunities for the future. Running in parallel and in partnership with the UK organizations Nano KTN and NanoCentral is a series of workshops and conferences that explore identified developments, including those from outside the food

[7] http://ec.europa.eu/research/agriculture/scar/pdf/scar_feg_ultimate_version.pdf

industry. Again, the idea is to provide a platform for balanced debate of the issues around nanotechnology and the sharing of benefits both to manufacturers and consumers.

Leatherhead's interest and involvement in nanotechnology research programmes centres around the understanding that the technology can offer real functional benefits to a range of critical food ingredients. The food industry is blessed with a significant and committed supplier base of ingredients manufacturers and suppliers that invest significant sums in the development of new and improved materials. Leatherhead has an important responsibility in the independent assessment of these materials but has a wider role in extending the functionality still further. One of the ways of achieving this is through the novel processing of ingredients such as the production of safe comestible nanoparticles.

All manufacturers and suppliers of prepared foods are looking to reduce the levels of expensive, highly functional ingredients in their products. Nanotechnology offers an important way of achieving this simply by increasing the surface area of the ingredient, as has already been demonstrated with salt and sugar crystals. The cryocrystallization of fats is a research area that emerged from Leatherhead's interest in nanotechnology as it seemed to produce very small particles of fat with interesting properties. When evaluated in shortcrust pastry applications it was possible to reduce both the total and saturated fat levels with no loss in sensory characteristics. Further studies have since taken place on a confidential basis in other food product sectors. The benefits of nanotechnology to the consumer are clear from these examples and the manufacturers too will be able to exploit the benefits that the technology brings. Furthermore, Leatherhead believes that extension of the technology to the cocryocrystallization of fats and other ingredients, both fat- and water-based, will deliver further functional benefits.

In conclusion, nanotechnology has an important role to play in food innovation in the future and those manufacturers and suppliers that embrace it and clearly demonstrate the benefits to their consumers are likely to achieve success.