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Nanoforum Report:

Nanotechnology in Agriculture and Food

May 2006

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A Nanoforum report, available for download from www.nanoforum.org

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May 2006

1. Introduction

The current global population is nearly 6 billion with 50% living in Asia. A large proportion of those living in developing countries face daily food shortages as a result of environmental impacts or political instability, while in the developed world there is a food surplus. For developing countries the drive is to develop drought and pest resistant crops, which also maximize yield. In developed countries, the food industry is driven by consumer demand which is currently for fresher and healthier foodstuffs. This is big business, for example the food industry in the UK is booming with an annual growth rate of 5.2%[1] and the demand for fresh food has increased by 10% in the last few years.

The potential of nanotechnology to revolutionise the health care, textile, materials. information and communication technology, and energy sectors has been well-publicised. In fact several products enabled by nanotechnology are already in the market, such as anti-bacterial dressings, transparent sunscreen lotions, stain-resistant fabrics, scratch free paints for cars, and self cleaning windows. The application of nanotechnology to the agricultural and food industries was first addressed by a United States Department of Agriculture roadmap published in September 2003.[2] The prediction is that nanotechnology will transform the entire food industry, changing the way food is produced, processed, packaged, transported, and consumed. This short report will review the key aspects of these transformations, highlighting current research in the agrifood industry and what future impacts these may have.

1.1 What is Nanotechnology?

Nanotechnology is the manipulation or self-assembly of individual atoms, molecules, or molecular clusters into structures to create materials and devices with new or vastly different properties. Nanotechnology can work from the top down (which means reducing the size of the smallest structures to the nanoscale e.g. photonics applications in nanoelectronics and nanoengineering) or the bottom up (which involves manipulating individual atoms and molecules into nanostructures and more closely resembles chemistry or biology).

The definition of nanotechnology is based on the prefix "nano" which is from the Greek word meaning "dwarf". In more technical terms, the word "nano" means 10^{-9}, or one billionth of something. For comparison, a virus is roughly 100 nanometres (nm) in size. The word nanotechnology is generally used when referring to materials with the size of 0.1 to 100 nanometres, however it is also inherent that these materials should display different properties from bulk (or micrometric and larger) materials as a result of their size. These differences include physical strength, chemical reactivity, electrical conductance, magnetism, and optical effects.

1.2 Nanotechnology in the Food Market

Nanotechnology has been described as the new industrial revolution and both developed and developing countries are investing in this technology to secure a market share. At present the USA leads with a 4 year, 3.7 billion USD investment through its National Nanotechnology Initiative (NNI). The USA is followed by Japan and the European Union, which have both committed substantial funds (750 million and 1.2 billion, including individual country contributions, respectively per year).[3] The level of funding in developing countries may be comparatively lower, however this has not lessened the impact of some countries on the global stage. For example, China's share of academic publications in nanoscale science and engineering topics rose from 7.5% in 1995 to 18.3% in 2004, taking the country from fifth to second in the world.[4] Others such as India, South Korea, Iran, and Thailand are also

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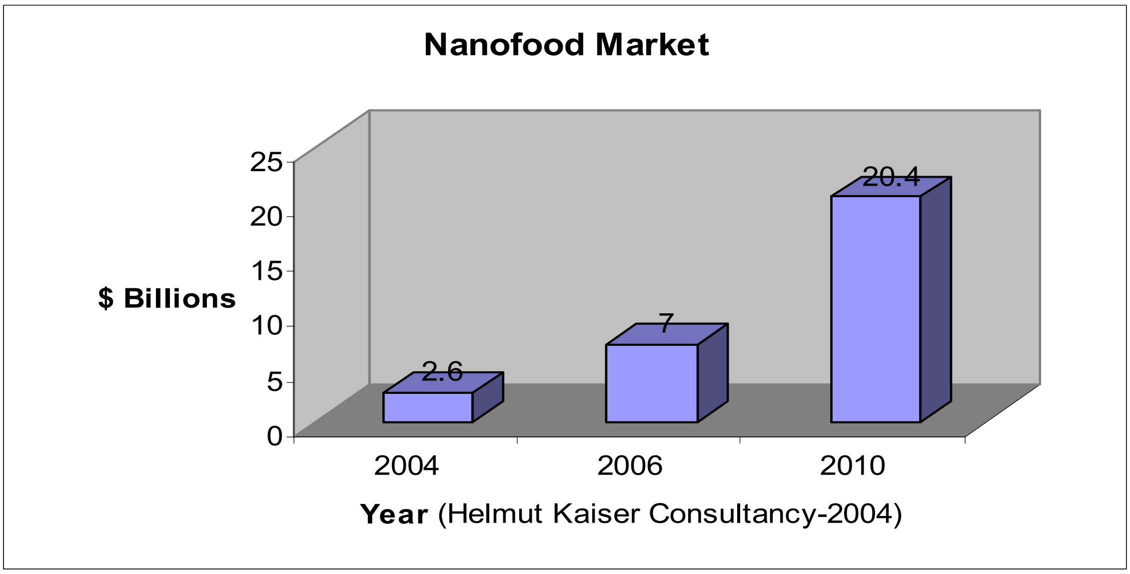
[1] Taylor Nelson Sofrès, 52 weeks ended 5 January 2003, Geest estimates

[2] Nanoscale science and engineering for agriculture and food systems, Dept. of Agriculture, United States, 2003.

[3] Some Figures about Nanotechnology R&D in Europe and Beyond, European Commission, December 2005

[4] Ranking the Nations: Nanotech's Shifting Global Leaders, Lux Research Inc.

catching up with a focus on applications specific to the economic growth and needs of their countries. Iran for example has a focused programme in nanotechnology for the agricultural and food industry. A recent study from the Helmuth Kaiser Consultancy predicts that the nanofood market will surge from 2.6 billion USD to 20.4 billion USD by 2010 (see Figure below).[5] The report suggests that with more than 50% of the world population, the largest market for Nanofood in 2010 will be Asia lead by China.



World Nanofood market

More than 400 companies around the world today are active in nanotechnology research and development (R&D) and this number is expected to increase to more than 1000 within the next 10 years. In terms of numbers, the USA leads, followed by Japan, China, and the EU. An estimate by the Business Communications Company, a technical market research and industry analysis company shows that, the market for the nanotechnology was 7.6 billion USD in 2003 and is expected to be 1 trillion USD in 2011.[6] However, the full potential of nanotechnology in the agricultural and food industry has still not been realised.

[5] Helmuth Kaiser Consultancy, Nanotechnology in Food and Food Processing Industry Worldwide, 2004

[6] Business Communications Company, Inc., Global Nanotechnology market to reach $29billion by 2008

2. Nanotechnology in Agriculture

The EU's vision is of a "knowledge-based economy" and as part of this, it plans to maximise the potential of biotechnology for the benefit of EU economy, society and the environment. There are new challenges in this sector including a growing demand for healthy, safe food; an increasing risk of disease; and threats to agricultural and fishery production from changing weather patterns. However, creating a bio economy is a challenging and complex process involving the convergence of different branches of science.

Nanotechnology has the potential to revolutionize the agricultural and food industry with new tools for the molecular treatment of diseases, rapid disease detection, enhancing the ability of plants to absorb nutrients etc. Smart sensors and smart delivery systems will help the agricultural industry combat viruses and other crop pathogens. In the near future nanostructured catalysts will be available which will increase the efficiency of pesticides and herbicides, allowing lower doses to be used. Nanotechnology will also protect the environment indirectly through the use of alternative (renewable) energy supplies, and filters or catalysts to reduce pollution and clean-up existing pollutants.

An agricultural methodology widely used in the USA, Europe and Japan, which efficiently utilises modern technology for crop management, is called Controlled Environment Agriculture (CEA). CEA is an advanced and intensive form of hydroponically-based agriculture. Plants are grown within a controlled environment so that horticultural practices can be optimized. The computerized system monitors and regulates localised environments such as fields of crops. CEA technology, as it exists today, provides an excellent platform for the introduction of nanotechnology to agriculture. With many of the monitoring and control systems already in place, nanotechnological devices for CEA that provide "scouting" capabilities could tremendously improve the grower's ability to determine the best time of harvest for the crop, the vitality of the crop, and food security issues, such as microbial or chemical contamination.[7]

2.1 Precision Farming

Precision farming has been a long-desired goal to maximise output (i.e. crop yields) while minimising input (i.e. fertilisers, pesticides, herbicides, etc) through monitoring environmental variables and applying targeted action. Precision farming makes use of computers, global satellite positioning systems, and remote sensing devices to measure highly localised environmental conditions thus determining whether crops are growing at maximum efficiency or precisely identifying the nature and location of problems. By using centralised data to determine soil conditions and plant development, seeding, fertilizer, chemical and water use can be fine-tuned to lower production costs and potentially increase production- all benefiting the farmer.[8] Precision farming can also help to reduce agricultural waste and thus keep environmental pollution to a minimum. Although not fully implemented yet, tiny sensors and monitoring systems enabled by nanotechnology will have a large impact on future precision farming methodologies.

One of the major roles for nanotechnology-enabled devices will be the increased use of autonomous sensors linked into a GPS system for real-time monitoring. These nanosensors could be distributed throughout the field where they can monitor soil conditions and crop growth. Wireless sensors are already being used in certain parts of the USA and Australia. For example, one of the Californian vineyards, Pickberry, in Sonoma County has installed wi-fi systems with the help of the IT company, Accenture.[9] The initial cost of setting up such a system is justified by the fact that it enables the best grapes to be grown which in turn produce finer wines, which command a premium price. The use of such wireless networks is of course not restricted to vineyards, for example Forbes Magazine has reported that small

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[7] The US Department of Agriculture, Nanoscale science and engineering for Agriculture and food systems

[8] Precision Agriculture: Changing the Face of Farming, Doug Rickman, J.C. Luvall, Joey Shaw, Paul Mask, David Kissel and Dana Sullivan

[9] Virtual Vineyard, Gregory J. Millman, Accenture, http://www.accenture.com/xdoc/en/ideas/outlook/3_2004/pdf/case_sensor.pdf

nanosensors are being used by Honeywell (a technology R&D company with global branches) to monitor grocery stores in Minnesota.[10] This technology enables shop keepers to identify food items which have passed their expiry date and also reminds them to issue a new purchase order. The global market for wireless sensors is predicted to be 7 billion USD by 2010.[11]

The union of biotechnology and nanotechnology in sensors will create equipment of increased sensitivity, allowing an earlier response to environmental changes. For example:

- Nanosensors utilising carbon nanotubes[12] or nano-cantilevers[13] are small enough to trap and measure individual proteins or even small molecules.
- Nanoparticles or nanosurfaces can be engineered to trigger an electrical or chemical signal in the presence of a contaminant such as bacteria.
- Other nanosensors work by triggering an enzymatic reaction or by using nano-engineered branching molecules called dendrimers as probes to bind to target chemicals and proteins.[14]

Ultimately, precision farming, with the help of smart sensors, will allow enhanced productivity in agriculture by providing accurate information, thus helping farmers to make better decisions.

2.2 Smart Delivery Systems

The use of pesticides increased in the second half of the 20th century with DDT becoming one of the most effective and widespread throughout the world. However, many of these pesticides, including DDT were later found to be highly toxic, affecting human and animal health and as a result whole ecosystems. As a consequence they were banned. To maintain crop yields, Integrated Pest Management systems, which mix traditional methods of crop rotation with biological pest control methods, are becoming popular and implemented in many countries, such as Tunisia and India.

In the future, nanoscale devices with novel properties could be used to make agricultural systems "smart". For example, devices could be used to identify plant health issues before these become visible to the farmer. Such devices may be capable of responding to different situations by taking appropriate remedial action. If not, they will alert the farmer to the problem. In this way, smart devices will act as both a preventive and an early warning system. Such devices could be used to deliver chemicals in a controlled and targeted manner in the same way as nanomedicine has implications for drug delivery in humans. Nanomedicine developments are now beginning to allow us to treat different diseases such as cancer in animals with high precision, and targeted delivery (to specific tissues and organs) has become highly successful.

Technologies such as encapsulation and controlled release methods, have revolutionised the use of pesticides and herbicides. Many companies make formulations which contain nanoparticles within the 100-250 nm size range that are able to dissolve in water more effectively than existing ones (thus increasing their activity). Other companies employ suspensions of nanoscale particles (nanoemulsions), which can be either water or oil-based and contain uniform suspensions of pesticidal or herbicidal nanoparticles in the range of 200-400 nm. These can be easily incorporated in various media such as gels, creams, liquids etc, and have multiple applications for preventative measures, treatment or preservation of the harvested product.

One of the world's largest agrochemical corporations, Syngenta, is using nanoemulsions in its pesticide products. One of its successful growth regulating products is the Primo MAXX® plant growth regulator, which if applied prior to the onset of stress such as heat, drought,

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[10] Quentin Hardy, Sensing opportunity, Forbes Magazine, 2003

[11] ONWorld Press Release, Wireless sensor networks: A mass market opportunity

[12] Carbon nanotubes are rolled sheets of graphite that are hollow and a few nm in diameter, but can be several micrometres (or more) long.

[13] Cantilevers are micro-scaled structures that can be modified to bind specific chemicals. Binding causes the cantilever to bend (much like a diving board), and this movement is detected optically or electronically.

[14] Down on the farm, ETC group, 2004: http://www.etcgroup.org/documents/ETC_DOTFarm2004.pdf

disease or traffic can strengthen the physical structure of turfgrass, and allow it to withstand ongoing stresses throughout the growing season.[15] Another encapsulated product from Syngenta delivers a broad control spectrum on primary and secondary insect pests of cotton, rice, peanuts and soybeans. Marketed under the name Karate® ZEON this is a quick release microencapsulated product containing the active compound lambda-cyhalothrin (a synthetic insecticide based on the structure of natural pyrethrins) which breaks open on contact with leaves.[16] In contrast, the encapsulated product "gutbuster" only breaks open to release its contents when it comes into contact with alkaline environments, such as the stomach of certain insects.[17]

In other areas, scientists are working on various technologies to make fertiliser and pesticide delivery systems which can respond to environmental changes. The ultimate aim is to tailor these products in such a way that they will release their cargo in a controlled manner (slowly or quickly) in response to different signals e.g. magnetic fields, heat, ultrasound, moisture, etc.

New research also aims to make plants use water, pesticides and fertilizers more efficiently, to reduce pollution and to make agriculture more environmentally friendly. Smaller companies are forming alliances with major players such as LG, BASF, Honeywell, Bayer, Mitsubishi, and DuPont to make complete plant health monitoring systems in the next 10 years using nanotechnologies.

2.3 Other Developments in the Agricultural Sector due to Nanotechnology

Agriculture is the backbone of most developing countries, with more than 60% of the population reliant on it for their livelihood. As well as developing improved systems for monitoring environmental conditions and delivering nutrients or pesticides as appropriate, nanotechnology can improve our understanding of the biology of different crops and thus potentially enhance yields or nutritional values. In addition, it can offer routes to added value crops or environmental remediation.

Particle farming is one such example, which yields nanoparticles for industrial use by growing plants in defined soils. For example, research has shown that alfalfa plants grown in gold rich soil, absorb gold nanoparticles through their roots and accumulate these in their tissues. The gold nanoparticles can be mechanically separated from the plant tissue following harvest.[18]

Nanotechnology can also be used to clean ground water. The US company Argonide is using 2 nm diameter aluminium oxide nanofibres (NanoCeram) as a water purifier. Filters made from these fibres can remove viruses, bacteria and protozoan cysts from water.[19] Similar projects are taking place elsewhere, particularly in developing countries such as India and South Africa. The German chemical group BASF's future business fund has devoted a significant proportion of its 105 million USD nanotechnology research fund to water purification techniques. The French utility company Generale des Eaux has also developed its own Nanofiltration technology in collaboration with the Dow Chemical subsidiary Filmtec. Ondeo, the water unit of French conglomerate Suez, has meanwhile installed what it calls an ultrafiltration system, with holes of 0.1 microns in size, in one of its plants outside Paris.[20]

While some companies are working on water filtration, others such as Altairnano are following a purification approach. Altairnano's Nanocheck contains lanthanum nanoparticles that absorb phosphates from aqueous environments. Applying these in ponds and swimming pools effectively removes available phosphates and as a result prevents the

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[15] http://www.syngentaprofessionalproducts.com/to/prod/primo/

[16] http://www.syngentacropprotection-us.com/prod/insecticide/Karate/

[17] Syngenta's US Patent No. 6,544,540: Base-Triggered Release Microcapsules

[18] Liz Kalaugher, Alfalfa plants harvest gold Nanoparticles, Nanotechweb

[19] http://nanotechweb.org/articles/news/3/4/7

[20] Small times, http://www.smalltimes.com/document_display.cfm?document_id=6959

growth of algae. The company expects this product to benefit commercial fish ponds which spend huge amounts of money to remove algae.[21]

Research at Lehigh University in the US shows that an ultrafine, nanoscale powder made from iron can be used as an effective tool for cleaning up contaminated soil and groundwater- a trillion-dollar problem that encompasses more than 1000 still-untreated Superfund sites (uncontrolled or abandoned places where hazardous waste is located) in the United States, some 150,000 underground storage tank releases, and a huge number of landfills, abandoned mines, and industrial sites.[22] The iron nanoparticles catalyse the oxidation and breakdown of organic contaminants such as trichloroethene, carbon tetrachloride, dioxins, and PCBs to simpler carbon compounds which are much less toxic. This could pave the way for a nano-aquaculture, which would be beneficial for a large number of farmers across the world. Other research at the Centre for Biological and Environmental Nanotechnology (CBEN) has shown that nanoscale iron oxide particles are extremely effective at binding and removing arsenic from groundwater (something which affects the water supply of millions of people in the developing world, and for which there is no effective existing solution).[23]

3. Nanotechnology in the Food Industry

The impact of nanotechnology in the food industry has become more apparent over the last few years with the organization of various conferences dedicated to the topic, initiation of consortia for better and safe food, along with increased coverage in the media. Several companies which were hesitant about revealing their research programmes in nanofood, have now gone public announcing plans to improve existing products and develop new ones to maintain market dominance. The types of application include: smart packaging, on demand preservatives, and interactive foods. Building on the concept of "on-demand" food, the idea of interactive food is to allow consumers to modify food depending on their own nutritional needs or tastes. The concept is that thousands of nanocapsules containing flavour or colour enhancers, or added nutritional elements (such as vitamins), would remain dormant in the food and only be released when triggered by the consumer.[24] Most of the food giants including Nestle, Kraft, Heinz, and Unilever support specific research programmes to capture a share of the nanofood market in the next decade.

The definition of nanofood is that nanotechnology techniques or tools are used during cultivation, production, processing, or packaging of the food. It does not mean atomically modified food or food produced by nanomachines. Although there are ambitious thoughts of creating molecular food using nanomachines, this is unrealistic in the foreseeable future. Instead nanotechnologists are more optimistic about the potential to change the existing system of food processing and to ensure the safety of food products, creating a healthy food culture. They are also hopeful of enhancing the nutritional quality of food through selected additives and improvements to the way the body digests and absorbs food. Although some of these goals are further away, the food packaging industry already incorporates nanotechnology in products.

3.1 Packaging and Food Safety

Developing smart packaging to optimise product shelf-life has been the goal of many companies. Such packaging systems would be able to repair small holes/tears, respond to environmental conditions (e.g. temperature and moisture changes), and alert the customer if the food is contaminated. Nanotechnology can provide solutions for these, for example modifying the permeation behaviour of foils, increasing barrier properties (mechanical, thermal, chemical, and microbial), improving mechanical and heat-resistance properties,

[21] Altairnano, http://www.altairnano.com/applications.html

[22] NanoApex, http://news.nanoapex.com/modules.php?name=News&file=article&sid=3790

[23] http://cohesion.rice.edu/centersandinst/cben/research.cfm?doc_id=5100

[24] John Dunn, "A Mini Revolution," *Food Manufacture*, September 1, 2004. http://www.foodmanufacture.co.uk/news/fullstory.php/aid/472/A_mini_revolution.html

developing active antimicrobic and antifungal surfaces, and sensing as well as signalling microbiological and biochemical changes.[25]

The financial outlook for nanotechnology enabled packaging looks buoyant. The current packaging market stands at 1.1 billion USD and is predicted to increase to 3.7 billion USD by 2010. Within this, the Smart Packaging industry is growing faster than predicted and is already showing signs of maturity. Research by the financial firm Frost and Sullivan, found that today's consumers demand much more from packaging in terms of protecting the quality, freshness and safety of foods, as well as convenience. They conclude that this is one of the main reasons behind the increased interest in innovative methods of packaging.[26]

There are several organizations developing Smart Packaging systems. For example, Kraft foods, along with researchers at Rutgers University in the US, is developing an "electronic tongue" for inclusion in packaging. This consists of an array of nanosensors which are extremely sensitive to gases released by food as it spoils, causing the sensor strip to change colour as a result, giving a clear visible signal of whether the food is fresh or not.

Bayer Polymers has developed the Durethan KU2-2601 packaging film, which is lighter, stronger and more heat resistant than those currently on the market. The primary purpose of food packaging films is to prevent contents from drying out and to protect them from moisture and oxygen. The new film is known as a "hybrid system" that is enriched with an enormous number of silicate nanoparticles. These massively reduce the entrance of oxygen and other gases, and the exit of moisture, thus preventing food from spoiling.[27]

Breweries would ideally use plastic bottles to ship beer, as these are lighter than glass and cheaper than metal cans. However, alcohol in beer reacts with the plastic used for the bottles, severely shortening shelf-life. Voridan, in association with Nanocor, has developed a nanocomposite containing clay nanoparticles, called Imperm. The resultant bottle is both lighter and stronger than glass and is less likely to shatter. The nanocomposite structure minimises loss of carbon dioxide from the beer and the ingress of oxygen to the bottle, keeping the beer fresher and giving it up to a six-month shelf life.[28] The technology has been adopted by several companies including the Miller Brewing Co.. Honeywell Specialty Polymers, has also successfully engineered plastic beer bottles that incorporate nanocomposites giving an extended shelf life (up to 26 weeks). The "Aegis" nylon 6 is the barrier layer in this 3-layered construction and has been used since late 2003 in the 1.6-litre Hite Pitcher beer bottle from Hite Brewery Co. in South Korea.[29] In a different strategy, Kodak is developing antimicrobial films that have the ability to absorb oxygen from the contents of the package, thus impeding food deterioration.

Other organizations are looking at ways in which nanotechnology can offer improvements in sensitivity or ease by which contamination of food is detected. For example, AgroMicron has developed the NanoBioluminescence Detection Spray which contains a luminescent protein that has been engineered to bind to the surface of microbes such as Salmonella and E. coli. When bound, it emits a visible glow, thus allowing easy detection of contaminated food or beverages. The more intense the glow is, the higher the bacterial contamination. The company aims to market the product under the name BioMark and is currently designing new spray techniques to apply in ocean freight containerized shipping as well as to fight bioterrorism.[30]

In a similar strategy to ensure food safety, EU researchers in the Good Food Project have developed a portable nanosensor to detect chemicals, pathogens and toxins in food.[31] This circumvents the need to send samples to laboratories (which is both costly and lengthy), allowing food to be analysed for safety and quality at the farm, abattoir, during transport, processing or at the packaging plant. The project is also developing a device using DNA

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[25] Nanotechnology targets new food packaging products, www.foodproductiondaily.com

[26] http://www.foodproductiondaily.com/news/ng.asp?id=63704

[27] Nanoparticles make Durethan® films airtight and glossy, Bayer Polymers

[28] Safer And Guilt-Free Nano Foods, Josh Wolfe, Forbes/Wolfe Nanotech Report, www.forbes.com

[29] http://www.ptonline.com/articles/kuw/12437.html

[30] http://www.agromicron.com/BTP.htm

[31] http://www.goodfood-project.org/

biochips to detect pathogens- a technique that could also be applied to determine the presence of different kinds of harmful bacteria in meat or fish, or fungi affecting fruit. The project also has plans to develop microarray sensors that can be used to identify pesticides on fruit and vegetables as well as those which will monitor environmental conditions at the farm. These have been coined "Good Food sensors".

The EU-funded BioFinger project, which has the aim of developing "versatile, inexpensive, and easy-to-use diagnostic tools for health, environmental and other applications", has found a different application in food analysis. The device uses cantilever technology, in which the tip of the cantilever is coated with chemicals allowing it to bend and resonate when it binds specific molecules (such as those on the surface of bacteria). The BioFinger device incorporates the cantilevers on a disposable microchip making it small and portable.[32]

The US military is developing super sensors to be used in times of terrorist attacks on food supplies. Current systems can take several days to confirm the presence of pathogens in food, however new nanotechnology enabled super sensors will be able to detect pathogens immediately. Such technology would have widespread applications in the food industry.

Researchers at the University of Bonn are developing dirt repellent coatings for packages using the lotus effect (water beads and runs off the surface of lotus leaves as a result of nanoscale wax pyramids which coat the leaves). Abattoirs and meat processing plants in particular could benefit from such technology. A research group at the University of Leeds in UK has determined that nanoparticles of magnesium oxide and zinc oxide are highly effective at destroying microorganisms. As these would be much cheaper to manufacture than silver nanoparticles, this could have tremendous applications in food packaging.[33]

Nanotechnology has also found applications in monitoring and tagging of food items. Radio Frequency Identification (RFID) technology was developed by the military more than 50 years ago, but has now found its way to numerous applications from food monitoring in shops to improving supply chain efficiency. The technology, which consists of microprocessors and an antenna that can transmit data to a wireless receiver, can be used to monitor an item from the warehouse to the consumer's hands.[34] Unlike bar codes, which need to be scanned manually and read individually, RFID tags do not require line-of-sight for reading and it is possible to automatically read hundreds of tags a second. Retailing chains like Wal-Mart, Home Depot, Metro group, and Tesco, have already tested this technology. The main drawback is the increased production costs due to silicon manufacturing. With the fusion of nanotechnology and electronics (nanotronics), these tags should become cheaper, easier to implement and more efficient.

A group of scientists from Northern European food industries have created a Nanofood consortium with the aim of fostering the applications of nanotechnology in the food industry in a responsible manner, to strengthen the effort to develop healthy and safe foods. The founding companies include Arla Foods, Danisco A/S, Aarhus United A/S, Danish Crown amba, Systematic Software Engineering A/S, and the Interdisciplinary Nanoscience Centre (iNANO). With a mission to provide safe food to consumers, the consortium's priorities are: to develop sensors which can almost instantly reveal whether a food sample contains toxic compounds or bacteria; to develop anti-bacterial surfaces for machines involved in food production; to develop thinner, stronger and cheaper wrappings for food; and the creation of food with a healthier nutritional composition.[35]

A study by Denmark's Centre for Advanced Food Studies (LMC), an alliance of Danish institutions working in food sciences, has structured their priorities for the 7th Framework programme.[36] The six priority areas are:

- basic understanding of food and animal feed for intelligent innovation
- systems biology in food research

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[32] http://www.biofinger.org/

[33] http://www.foodproductiondaily.com/news/ng.asp?n=59980-nanotech-discovery-promises

[34] Radio ID Tags: Beyond Bar Codes, http://www.wired.com/news/technology/0,1282,52343,00.html

[35] New consortium to secure safe and healthy food, Press release,14-06-2005, http://www.scanbalt.org/sw4126.asp

[36] Danish food researchers list priorities for FP7 and underline relevance of nanoscience, Press release, 01-09-2005, www.lmc.dk

- biological renewal in the food sector/biological production
- technology development
- nutrigenomics
- consumer needs-driven innovation and food communication

They believe that a focus on these areas will create a holistic and an interdisciplinary approach in food research and development in Europe. They are aiming to produce nanomaterials with functional properties, along with nanosensors and nanofluidic technology to be applied in food sciences. Other interests include the development of intelligent packaging materials, making it possible to monitor the condition of products during transportation or in display counters, and bio based packaging techniques.

3.2 Food Processing

In addition to packaging, nanotechnology is already making an impact on the development of functional or interactive foods, which respond to the body's requirements and can deliver nutrients more efficiently. Various research groups are also working to develop new "on demand" foods, which will remain dormant in the body and deliver nutrients to cells when needed. A key element in this sector is the development of nanocapsules that can be incorporated into food to deliver nutrients. Other developments in food processing include the addition of nanoparticles to existing foods to enable increased absorption of nutrients.

One of the leading bakeries in Western Australia has been successful in incorporating nanocapsules containing tuna fish oil (a source of omega 3 fatty acids) in their top selling product "Tip-Top" Up bread. The microcapsules are designed to break open only when they have reached the stomach, thus avoiding the unpleasant taste of the fish oil.[37]

The Israeli Company Nutralease, utilises Nano-sized Self-assembled Liquid Structures (NSSL) technology to deliver nutrients in nanosized particles to cells. The particles are expanded micelles (hollow spheres made from fats, with an aqueous interior) with a diameter of approximately 30 nm.[38] The nutrients or "nutraceuticals" are contained within the aqueous interior. Nutraceuticals that have been incorporated in the carriers include lycopene, beta-carotene, lutein, phytosterols, CoQ10 and DHA/EPA. The Nutralease particles allow these compounds to enter the bloodstream from the gut more easily, thus increasing their bioavailability. The technology has already been adopted and marketed by Shemen Industries to deliver Canola Activa oil, which it claims reduces cholesterol intake into the body by 14%, by competing for bile solubilisation. This technology also has potential applications in the pharmaceutical industry.

A number of chemical companies are researching additives which are easily absorbed by the body and can increase product shelf life. Biodelivery Sciences International have developed nanocochleates, which are 50 nm coiled nanoparticles and can be used to deliver nutrients such as vitamins, lycopene, and omega fatty acids more efficiently to cells, without affecting the colour or taste of food.[39] Kraft foods have established a consortium of research groups from 15 universities to look into the applications of nanotechnology to produce interactive foods. These will allow the consumer to choose between different flavours and colours. The consortium also has plans to develop smart foods which will release nutrients in response to deficiencies detected by nanosensors, and nanocapsules which will be ingested with food, but remain dormant until activated. All these new developments will make the concept of super foodstuffs a reality, and these are expected to offer many different potential benefits including increased energy, improved cognitive functions, better immune function, and anti-aging benefits.

Nanotechnology has already been used in the cosmetics industry to produce transparent creams. Royal BodyCare, a company utilizing nanotechnology in nutritional sciences, has marketed a new product called NanoCeuticals which is a colloid (or emulsion) of particles of less than 5 nm in diameter. The company claims the product will scavenge free radicals,

[37] http://www.foodscience.afisc.csiro.au/foodfacts/foodfacts11-fishoil.htm

[38] http://www.nutralease.com/technology.asp

[39] http://www.biodeliverysciences.com/bioralnutrients.html

increase hydration and balance the body's pH.[40] The company has also developed NanoClusters™, a nanosize powder combined with nutritional supplements. When consumed, it enhances the absorption of nutrients.

Food and Cosmetic Companies are working together to develop new mechanisms to deliver vitamins directly to the skin. For example, Nestlé, which has a 49% stake in L'Oréal, is developing transparent suncreams to deliver vitamin E directly to skin. The aim is to manufacture a cream which is absorbed by the skin and releases Vitamin E slowly, in addition to providing UV protection. Transparent UV-blocking creams are already on the market and L'Oréal expects the cream with added functionality to be marketed soon. Other competitors such as Estée Lauder are manufacturing anti-ageing formulations that make use of nanoparticles.

The US based Oilfresh Corporation has marketed a new nanoceramic product which reduces oil use in restaurants and fast food shops by half. As a result of its large surface area, the product prevents the oxidation and agglomeration of fats in deep fat fryers, thus extending the useful life span of the oil. An additional benefit is that oil heats up more quickly, reducing the energy required for cooking.[41]

Wageningen University in Netherlands has recently established a research centre which will focus its research on the application of nanotechnology in the food industry. The Wageningen BioNT (Bionanotechnology) Centre will concentrate on various topics including: sensing and diagnostics of food quality and safety; encapsulation and delivery of nutrients; micro- and nanodevices for physical and (bio)chemical processing; chemical biology; nanotoxicology; and consumer science and technology assessment.[42]

The German company Aquanova has developed a new technology which combines two active substances for fat reduction and satiety into a single nano-carrier (micelles of average 30 nm diameter), an innovation said to be a new approach to intelligent weight management. Called NovaSOL Sustain, it uses CoQ1O to address fat reduction and alpha-lipoic acid for satiety. The NovaSol technology has also been used to create a vitamin E preparation that does not cloud liquids, called SoluE, and a vitamin C preparation called SoluC. The NovaSOL product can be used to introduce other dietary supplements as it protects contents from stomach acids.[43]

In a different strategy, Unilever is developing low fat ice creams by decreasing the size of emulsion particles that give ice-cream its texture. By doing so it hopes to use up to 90% less of the emulsion and decrease fat content from 16% to about 1%.[44]

The Woodrow Wilson International Center for Scholars in the US has produced a consumer database of marketed nanotechnology and has so far identified more than 15 items which have a direct relation to the food industry. The list includes nanoceuticals developed by RBC Life Sciences and Canola Activa oil developed by Shemen Industries; the use of silver nanoparticles in refrigerators manufactured by LG Electricals, Samsung and Daewoo to inhibit bacterial growth and eliminate odours; All Spray For Life® which is manufactured by Health Plus International and uses a newly-designed pre-metered, non-aerosol Nanoceautical Delivery System (NDS) for transmucosal administration of dietary supplements, resulting in increased-bioavailability compared with gastrointestinal absorption. A detailed list of products is available on the website.[45]

[40] Royal Body Care, http://smartwoman.royalbodycare.com/Nanotechnology_Revolution.aspx

[41] Oilfresh Corporation, http://www.oilfresh.com/of1000.html

[42] http://www.biont.wur.nl/nl

[43] http://www.aquanova.de/product-micelle.htm

[44] How super-cows and nanotechnology will make ice cream healthy, Daily Telegraph (21.8.05)

[45] http://www.nanotechproject.org/index.php?id=44&id=44&action=view&dbq=food&p=0

4. Conclusions

Globally, many countries have identified the potential of nanotechnology in the agrifood sector and are investing a significant amount in it. The United States Department of Agriculture (USDA) has set out ambitious plans to be achieved in the short, medium and long term, and aims to discover novel phenomena, processes and tools to address challenges faced by the agricultural sector. Equal importance has been given to the societal issues associated with nanotechnology and to improve public awareness. The UK's Food Standards Agency (FSA) has commissioned studies to assess new and potential applications of nanotechnology in food, especially on packaging. At the same time more money has been given by other Government departments towards research and development which includes the development of functional food, nutrient delivery systems and methods for optimizing food appearance, such as colour, flavour and consistency.

This R&D is not just restricted to developed countries. Developing countries such as Iran have adopted their own nanotechnology programmes with a specific focus on agricultural applications. The Iranian Agricultural ministry is supporting a consortium of 35 laboratories working on a project to expand the use of nanotechnology in agro sector.[46] The ministry is also planning to hold training programs to develop specialized human resources in the field. They have already produced their first commercial nanotechnology product Nanocid, a powerful antibacterial product which has potential applications in the food industry. The product has also widespread applications in the production of various kinds of detergents, paints, ceramics, air conditioning systems, vacuum cleaners, home appliances, shoes and garments. India has allocated 22.6 million USD in its 2006 budget to the Punjab Agricultural University in Ludhiana, in acknowledgement of its pioneering contribution to the Green Revolution. Its research on high-yielding crop varieties helped boost food production in the 1960s and new projects include the development of new tools and techniques for the agriculture industry.

Whatever the impacts of nanotechnology on the food industry and products entering the market, the safety of food will remain the prime concern. This need will strengthen the adoption of nanotechnology in sensing applications, which will ensure food safety and security, as well as technology which alerts customers and shopkeepers when a food is nearing the end of its shelf-life. New antimicrobial coatings and dirt repellent plastic bags are a remarkable improvement in ensuring the safety and security of packaged food.

However, there is concern over the use of nanoparticles in food and its manipulation using nanotechnologies, which has the potential to elicit the same issues raised in the GM debate. In this context, a recent report from the Institute of Food Science and Technology in the UK, argues that more safety data is required before nanoparticles can be included in food. The report points out that current legislation does not force companies to label food items containing nanoparticles; and so consumers are unlikely to be aware of such applications in food items. It calls for an appropriate pre-market safety evaluation focusing on the effects of particle size as well as composition.[47] The ETC group has gone further and has called for a moratorium on nanotechnology for agrifood.[14] It has also accused major companies and high tech universities of seeking patents on new food items which may shut out innovative companies in less developed countries.[48]

Finally, it may be possible one day to manufacture food from component atoms and molecules, so-called "Molecular Food Manufacturing". Already some research groups are exploring this, but still from a top-down approach, using cells rather than molecules. Although the practical application of such technology is far into the future, it is expected that this could allow a more efficient and sustainable food production process to be developed where less raw materials are consumed and food of a higher nutritional quality is obtained.

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[46] Iran agro sector developing nanotech, www.iranmania.com/News

[47] http://www.ifst.org/uploadedfiles/cms/store/ATTACHMENTS/Nanotechnology.pdf

[48] Nanotechnology and Intellectual Property, ETC Group, http://www.etcgroup.org/article.asp?newsid=508

Further Reading

The interested reader is directed to the following sources which offer a more detailed analysis of nanotechnology applications in the agricultural and food industries than could be provided in this short report:

- "Down on the Farm" – published by the ETC Group (2004) www.etcgroup.org/documents/ETC_DOTFarm2004.pdf
- "Nanoscale Science and Engineering for Agriculture and Food Systems" – a report from the USDA workshop (2003) www.nseafs.cornell.edu/web.roadmap.pdf
- The Woodrow Wilson International Center for Scholars "Project on Emerging Nanotechnologies" www.nanotechproject.org/
- "A review of potential implications of nanotechnologies for regulations and risk assessment in relation to food" – published by the Food Standards Agency (2006) www.food.gov.uk/multimedia/pdfs/nanotech.pdf
- The Institute of Food Science & Technology statement on Nanotechnology www.ifst.org/uploadedfiles/cms/store/ATTACHMENTS/Nanotechnology.pdf
- The European Technology Platform "Food for Life" http://etp.ciaa.be/asp/about_etp/welcome.asp
- "NANOFOREST - A nanotechnology roadmap for the forest products industry" – published by STFI-Packforsk (2005) www.stfi-packforsk.se/upload/3352/Finalroadhem.pdf
- "Science for Agricultural Development - Changing contexts, new opportunities" – published by the Science Council of the Consultative Group on International Agricultural Research www.cgiar.org/enews/december2005/scienceforagrdev.pdf
- "Nanotechnology and the Developing World" - Fabio Salamanca-Buentello, Deepa L. Persad, Erin B. Court, Douglas K. Martin, Abdallah S. Daar, Peter A. Singer (2005). PLoS Med 2(4): e97. www.utoronto.ca/jcb/home/documents/PLoS_nanotech.pdf
- "Nanotechnology and the Poor: Opportunities and Risks" – published by the Meridian Institute (2005) www.meridian-nano.org/gdnp/NanoandPoor.pdf

About Nanoforum

Nanoforum is a pan-European nanotechnology information network funded by the EC under FP5, to provide information and support to the European nanotechnology community. On the Nanoforum website (www.nanoforum.org), all users (whether they are members of the public, industry, R&D, government or business communities) can freely access and search a comprehensive database of European nanoscience and nanotechnology (N&N) organizations, and find out the latest on news, events and other relevant information. In addition, Nanoforum publishes its own specially commissioned reports on nanotechnology and key market sectors, the economical and societal impacts of nanotechnology, as well as organizing events throughout the EU to inform, network and support European expertise.

The Nanoforum consortium consists of:

The Institute of Nanotechnology (UK)	http://www.nano.org.uk
VDI Technologiezentrum (Germany)	http://www.vditz.de/
CEA-Leti (France)	http://www-leti.cea.fr/uk/index-uk.htm
Malsch TechnoValuation (Netherlands)	http://www.malsch.demon.nl/
METU (Turkey)	http://www.physics.metu.edu.tr/
Monte Carlo Group (Bulgaria)	http://cluster.phys.uni-sofia.bg:8080/
Unipress (Poland)	http://www.unipress.waw.pl/
FFG (Austria)	http://www.ffg.at/
NanoNed (Netherlands)	http://www.stw.nl/nanoned/

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