Science Progress (2014), 97(2), 173–182
Doi:10.3184/003685014X13995384317938

Current Commentary

Eating small: applications and implications for nano-technology in agriculture and the food industry

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1. Introduction.

That synthesis might be undertaken by the direct manipulation of atoms was suggested by Richard Feynman in 1959, although term "nano-technology"[1] was not coined until 1974, by Norio Taniguchi. In 1986, K. Eric Drexler published his book *Engines of creation: the coming era of nanotechnology*, which contained the notion of a nanoscale "assembler" with the capacity to build copies of itself and other items, by atomic level manipulation. The ground-breaking invention, in 1981, of the scanning tunnelling microscope (STM) demonstrated that individual atoms could be visualised, and the technology was further developed to physically move adsorbed atoms and molecules around on a surface[2]. Notable examples[2] demonstrated for publicity purposes are the sign-writing of "IBM" using 35 xenon atoms on a Ni(110) surface, and of "2000" using 47 CO molecules on a Cu(211) surface, by researchers in the eponymous organisation, to auger in the new millennium. Considerably larger molecules can also be moved using an STM tip, for example 1,4-diiodobenzene and biphenyl, which have been towed around on copper surfaces. The tunnelling electrons may also be used to initiate chemical reactions, the products of which can be subsequently manipulated over the surface, so providing proof of chemical change having occurred, *e.g.* the conversion of iodobenzene to biphenyl. As a definition, *nanotechnology* (*nanotech*) can be described as the manipulation of matter over an atomic, molecular, and supramolecular dimension. *Molecular nanotechnology* is the intention of manipulating atoms and molecules, so to create macroscale products. The prefix "nano" is derived from the Greek word meaning "dwarf". The US National Nanotechnology Initiative[3] defines nanotechnology as, "the manipulation of matter with at least one dimension in the range 1 – 100 nm", where quantum mechanical effects become increasingly important as the smaller end of the range is accessed. It is critical that the particular materials, and devices made from them, should possess properties that are different from the bulk (micrometric or larger) materials, as a consequence of their small size, which may include enhanced mechanical strength, chemical reactivity, electrical conductivity, magnetism and optical effects (*e.g.* Figure 1).

One nm is one billionth, or 10^{-9}, of a metre, which in relative size to a metre is about the same as that of a marble to the Earth[4]. Placed in a different context, an average man's beard grows about 1 nm in the time it takes him to lift the razor to his face[4]. The lower limit is set by the size of atoms, which are the fundamental building blocks of nanotechnology devices, while the upper limit is of a more arbitrary quality but is of the dimension at which the particular phenomena of the quantum realm begin to appear, which are essential to the nano-device. A device that is merely a miniaturised form of an equivalent macroscopic version does

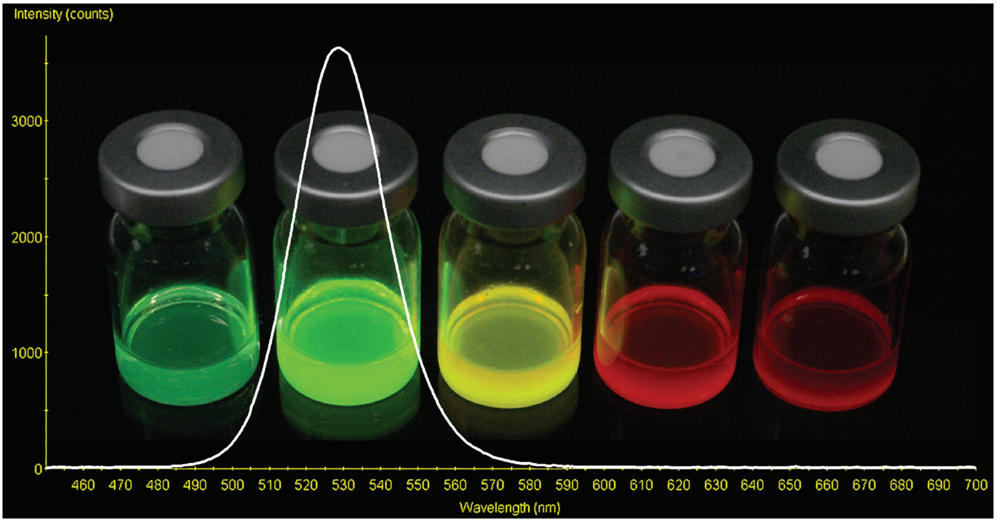


Figure 1 *A photograph and representative spectrum of photoluminescence from colloidal CdSe quantum dots excited by UV light. The absorption and consequent fluorescence, moves to higher energies and hence toward the blue end of the visible spectrum, as the particle size decreases*[27]*.*
http://upload.wikimedia.org/wikipedia/commons/5/57/CdSeqdots.jpg Credit: NASA.

not ascribe to nanotechnology, lacking these particular phenomena, but is classified under the heading *microtechnology*[5]. In regard to the fabrication of nanodevices, we find the "bottom-up" approach, where materials and devices are constructed from molecular components which self-assemble *via* molecular recognition, while in the "top-down" approach, nano-objects are built from larger entities, not involving control at an atomic level[6].

The plural forms "nanotechnologies" and "nanoscale technologies" thus refer to the many and various aspects, devices and their applications that have in common this scale of the *quantum realm*. Indeed, there are multifarious potential applications of nanoscale materials, including industrial and military uses, as attested by the investment of \$3.7 billion, by the US National Nanotechnology Initiative, \$1.2 billion by the European Union and \$ 750 million in Japan[1]. It may be that nanotechnology can provide advances in medicine, electronics, biomaterials, energy production and, as is the subject of this article, in agriculture and more broadly in the food industry. On the other hand, nanotechnology raises many of those same issues as when any new technology is inaugurated, *e.g.* concerns about the toxicity and environmental impact of nanomaterials[1], and their potential effects on global economics, in addition to speculation over potential doomsday scenarios ("grey goo"), most emphatically dramatised by the late Michael Crichton in his novel *Prey*[7]. The Royal Society's report on nanotechnology contains examples of some of the definitions and potential implications of nanotechnologies[8]. Commercial products, so far, are limited[1] to bulk applications of nanomaterials, rather than atomic scale synthesis, *e.g.* the use of silver nanoparticles as a bactericide, nanoparticle-based transparent sunscreens, and stain-resistant textiles based on carbon nanotubes. The aspects embraced by nanotechnology are broad, and there is much work and concern over the large-scale employment of engineered nanoparticles (ENMs) and their effects on the environment, agriculture, and plants, and on the humans who consume them directly. Moreover, as this short survey attempts to indicate, there is also now a considerable body of work on the applications of nanoscale technology to agriculture and the food industry.

Indeed, an *ACS Select* was recently published on this topic[9].Thus may be provided novel sensors intended to improve the quality and safety of food, along with methods of packaging that will amend the storage and delivery of foodstuffs.

According to the researchers and stakeholders, revolutionary advances can be anticipated during the next 10 – 15 years, principally through a convergence of nanotechnology, biotechnology and agricultural and environmental sciences, of which the following have been listed[9]:

- development of nanotechnology-based foods with lower calories and less fat, salt, and sugar while retaining flavour and texture;
- nanoscale vehicles for effective delivery of micronutrients and sensitive bioactives;
- re-engineering of crops, animals, and microbes at the genetic and cellular level;
- nanobiosensors for detection of pathogens, toxins, and bacteria in foods;
- identification systems for tracking animal and plant materials from origination to consumption;
- integrated systems for sensing, monitoring, and active response intervention for plant and animal production;
- smart field systems to detect, locate, report, and direct application of water;
- precision and controlled release of fertilisers and pesticides;
- development of plants that exhibit drought resistance and tolerance to salt and excess moisture; and
- nanoscale films for food packaging and contact materials that extend shelf life, retain quality, and reduce cooling requirements.

2. Nanotechnology in agriculture

2.1 Precision farming

Precision farming aims to maximise output (*i.e.* crop yields) while minimising input (*i.e.* fertilisers, pesticides, herbicides, water*, etc.*). Computers, global satellite positioning systems, and remote sensing devices are all employed in the monitoring of highly localised environmental conditions, so to determine whether crops are growing at maximum efficiency or any specific problems, and their precise location. The input of fertilisers and water use can be optimised, resulting in lower production costs and potentially greater production. The amount of waste from agriculture can also be reduced, further minimising its environmental impact. Real-time monitoring may be achieved through linking nanotechnology-enabled sensor devices with a GPS system. By dispersing nanosensors throughout a field, soil conditions and crop growth could be continuously monitored. A Wi-Fi system has been introduced in one of the Californian vineyards, Pickberry, in Sonoma County, for which the initial cost has been justified since it enables the best grapes to be grown, to produce finer wines, which are sold at a premium price[10].

2.2 Smart Delivery Systems

Many of the pesticides that were in widespread use during the second half of the 20th century, have been banned on account of their toxicity. As an alternative means to maintain adequate crop yields, integrated pest management systems have been introduced that employ a blend of traditional methods of crop rotation and biological pest control methods. However, it is thought that nanoscale "smart" devices might be employed, *e.g.* to identify plant health dysfunctions before they have advanced sufficiently to become visible to the farmer, and even to provide a remedial response to them. Such devices might therefore act both as an early warning system and as a curative. Chemical agents, such as fertilisers, pesticides and herbicides, might thus be delivered by targeted and controlled means, in fact similar to drug-delivery systems in nanomedicine. The deployment of these agents has been revolutionised through methods of encapsulation and controlled release, *e.g.* in formulations containing nanoparticles in the 100–250 nm size range with improved water solubility (thus increasing their activity). Alternatively, suspensions of 200–400 nm nanoparticles (nanoemulsions) – either water or oil-based – may be readily incorporated in a variety of media (gels, creams, liquids, *etc.*), with multiple advantages. The Primo MAXX® plant growth regulator, which if applied before the impacts of heat, drought, disease or traffic are manifest, has been shown to strengthen the physical structure of turfgrass, allowing it to cope with such stresses throughout the growing season[10].

Marketed under the name Karate®ZEON, is a rapid-release microencapsulated product containing lambda-cyhalothrin (a synthetic insecticide related to natural pyrethrins) which bursts, to discharge its contents, on contact with leaves[10]. A more targeted agent is the appositely named "gutbuster", which releases its active agent from an encapsulated form when it encounters alkaline environments, as occurs in the stomachs of some insects[10]. Smart fertiliser and pesticide delivery systems are being researched, employing nanoparticles, with the ultimate goal to release their contents, either slowly or quickly, in response to particular environmental changes, such as magnetic fields, heat, moisture, *etc.* Through such nanodevices, a more efficient use of water, pesticides, herbicides and fertilisers might be engendered, so to create a more environmentally friendly and less polluting method of agriculture.

Researchers at Cornell University have produced microscopic fluorescent probes or "nanobarcodes" with which to label multiple pathogens on a farm. The intention is to develop a portable on-site detector that can be used by non-specialists. Scientists at Purdue University developed a nanosensor that reacts with the hormone auxin (essential for root growth and the establishment of seedlings). An electrical signal is generated when the interaction occurs, so that, in principle, the concentration of auxin at various regions of the root can be determined. It is thus possible to ascertain whether auxin is absorbed or released by the surrounding cells, thus aiding an understanding of the way plant roots adapt to their environment, which is a critical factor especially in marginal soils[11]. Biotechnology and nanotechnology have been connected in the form of synthetic crystalline DNA sequences that are able to self-assemble into a collection of three-dimensional triangular forms. The crystals have small cohesive sequences ("sticky ends") that can specifically bind another molecule. A lattice structure can be formed, when multiple helices are attached through single-stranded sticky ends, which extends in six different directions, thus creating a three-dimensional crystal. It is thought that important crops might be improved by organising and linking carbohydrates, lipids, proteins and nucleic acids to these crystals[11]. Chemically-coated 3 nm diameter mesoporous silica nanoparticles (MSN), have been used to provide containers to deliver genes into plants, by a team at Iowa State University. The plant is activated by the coating to absorb the particles through its cell walls, where the genes are emplaced and activated very precisely, thus eliminating any undesirable effects of toxicity. DNA has been successfully introduced to tobacco and corn plants by this method[11].

2.3 Other developments in the agricultural sector due to nanotechnology

Nanotechnology can offer routes to added value crops or environmental remediation, for example, particle farming may provide nanoparticles by growing plants in defined soils, to be subsequently employed industrially. As an example, when alfalfa plants are grown in soil containing gold nanoparticles, the latter are absorbed *via* the plant roots and accumulate in the body of the plant. When the plants are harvested, the gold nanoparticles can be recovered by mechanical separation[12]. The US-based firm, Argonide, is employing 2 nm diameter aluminium oxide nanofibres (NanoCeram) in water purifying filters, which can remove viruses, bacteria and protozoan cysts from water that is contaminated with them[10]. The German chemical group BASF has targeted a substantial proportion of its $105 million 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 μm in size, in one of its plants outside Paris[10]. Altairnano are using a device termed "Nanocheck" which contains lanthanum nanoparticles that can absorb phosphates from aqueous environments, *e.g.* to prevent the growth of algae in ponds and swimming pools with a future market for commercial fish ponds, to reduce the currently high costs of removing algae from them[10]. Contaminated soil and groundwater may be "cleaned" by the action of iron nanoparticles, which can catalyse the oxidation of organic pollutants such as trichloroethene, carbon tetrachloride, dioxins, and PCBs to form simpler and less toxic carbon compounds. Iron oxide nanoparticles have been shown to be highly effective in binding and removing arsenic from groundwater, a significant health problem in West Bengal and Bangladesh, where there are naturally high concentrations of arsenic present in the soils and groundwater[10]. In the USA, there are of the order of 150,000 underground storage tank egresses, along with a considerable number of landfills, abandoned mines, and industrial sites that might be cleaned-up using nanoparticles[10].

2.4 Nanoparticles and recycling agricultural waste

Nanotechnology finds applications[11] in agricultural waste prevention, particularly in the cotton industry. Some of the cellulose or the fibres that arise when cotton is processed into fabrics and garments are either discarded as waste or they may be taken-up into making low-value products such as cotton wool or wadding. However, using an electrospinning method, 100 nm diameter cotton fibres can be produced, which are able to absorb fertilisers or pesticides very effectively, so permitting their later targeted application in agriculture. Cellulosic feedstocks are now regarded as a viable means for producing biofuels, and research is underway to nano-engineer enzymes for the simple and cheap conversion of cellulose from waste plant residues into ethanol. When rice husk is burned to produce thermal energy, a by-product is high-quality nanosilica, which can be processed in the fabrication of glass and concrete, thus converting a troublesome waste product into useful materials.

3. Nanotechnology in the food industry

That the potential for nanotechnology in the food industry is limited only by human ingenuity is made clear by the aforementioned recent ACS Select on the subject[9]. The widening prospect to design and operate on the nanoscale accords that more engineered nanomaterials (ENMs) will ultimately find their way onto our farms, into our supermarkets, onto our plates and into our bodies. There had been some lack of will to disclose their activities in "nanofood", but a number of companies have more lately been explicit in their intentions to introduce the technology, *e.g.* in smart packaging, on demand preservatives, and interactive foods. The latter concept centres around having thousands of nanocapsules containing flavour or colour enhancers, or added nutritional elements (such as vitamins), in the food, which would remain dormant until their release and activation was triggered by the consumer[10]. Thus, consumers would be able to modify food, according to their particular nutritional requirements or preferences. Kraft foods have established a consortium involving 15 different universities to research into applications of nanotechnology for the creation of interactive foods. The consortium further intends to develop smart foods, containing nanocapsules which will be ingested with food, but remain dormant until activated: thus, nutrients can be released to counter any deficiencies as detected by nanosensors. To be characterised as *nanofood*, it is necessary that nanotechnology methods or materials must feature at in the creation of the food at some point in its cultivation, production, processing, or packaging. It does not mean that the foodstuff will be created or modified at the atomic level, which for the foreseeable future will remain the stuff of science fiction.

3.1 Packaging and food safety

Food is packaged in films principally to prevent it from going dry, and to protect it from external moisture and oxygen. In the future, nanotechnology may provide smart packaging systems with the ability to mend small holes or tears, react to changes in particular environmental conditions, such as temperature and moisture concentration, and signal to the customer when the food has become contaminated. An "electronic tongue" is being developed for inclusion in packaging, with an array of nanosensors that are specific for the detection of gases that accompany the spoiling of food, which cause colour changes in the sensor strip – so providing an unambiguous signal that the food has "gone off". The Durethan KU2-2601 packaging film has been produced by Bayer Polymers, containing silica nanoparticles, with improved properties of weight, mechanical strength and heat resistance. The particles provide a highly effective barrier against the intrusion of oxygen, and the loss of water, so prolonging the life of foodstuffs.

When beer is stored in plastic bottles, a reaction occurs between the alcohol and the plastic, resulting in a greatly diminished shelf-life, such that shipping beer in this way is not practical, despite the advantages of reduced weight over glass bottles, and lower cost. However, a nanocomposite has been developed, containing clay nanoparticles, called Imperm, from which bottles can be made. The nanocomposite structure both reduces the loss of CO_2 from the beer and keeps oxygen out, extending the shelf-life to around 6 months[10]. Antimicrobial films have been produced by Kodak that can absorb oxygen from the contents of the package so lengthening the shelf-life of food. The nanobioluminescence detection spray contains a luminescent protein which specifically binds to the surface of microbes, *e.g.* salmonella and *Escherichia coli*. On binding, a visible glow is emitted, providing an instant signature of bacterial contamination, the degree of which is in proportion to the intensity of the glow. EU researchers in the Good Food Project have developed a portable nanosensor that can be used in field situations, *e.g.* on-farm, abattoir, during transportation, processing or at the packaging point. Thus, food can be tested for chemicals, pathogens and toxins there and then, avoiding the need to send samples away to analytical laboratories[10].

The BioFinger device, developed with funding from the EU, employs a cantilever, the tip of the which is coated with specific molecules that can bind to others, *e.g.* on the surface of bacteria, whereupon the tip bends and resonates. Since the cantilevers are incorporated on a disposable microchip, the device is easy to carry around[10]. By means of the "lotus effect" (lotus leaves are coated with nanoscale wax pyramids which cause water to form beads and run off them) a dirt-repelling packaging material has been fabricated at the University of Bonn, intended for use in abattoirs and meat processing plants. The bactericidal properties of silver nanoparticles are well known[13], and they are used to coat the inside of some washing machines, particularly those that run at temperatures well below the "boil wash". However, it has been shown that magnesium oxide and zinc oxide nanoparticles are highly effective at destroying microorganisms, which clearly are much cheaper to make, and it is thought they might revolutionise food packaging materials[10]. Radio Frequency Identification (RFID) technology is used in many areas of the food industry, *e.g.* for stock control in retail outlets, and to ensure better efficiency in the supply chain. The technology, first developed for military use over half a century ago, employs a tag with microprocessors with an antenna for the transmission of signals to a wireless receiver: thus, the journey of an item can be traced from the warehouse to the consumer, giving the advantage over bar codes, that line-of-sight is not necessary, and many hundreds of tagged-items can be read per second. A nanofood consortium has been created with the following aims: 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[10]. The Centre for Advanced Food Studies (LMC), which is an alliance of Danish institutions working in food sciences, proposed that the food science thematic priority in the Seventh Framework Programme (FP7) should address six specific areas[14]:

- basic understanding of food and feed for intelligent innovation;
- systems biology in food research;
- biological renewal in the food sector / biological production;
- technology development;
- nutrigenomics; and
- consumer needs-driven innovation and food communication.

It is believed by LMC that a focus on these fields would force an interdisciplinary and holistic approach, adding that possible risks, health, the environment and ethical issues should be incorporated into each of the priority areas. Following a foresight exercise on nanoscience, food researchers in Denmark hold the opinion that they are well placed to participate in international projects. Recommendations for significant increases in funding were made, and seven research areas were prioritised, as a result of the exercise, four of these LMC consider are relevant to food science: biocompatible materials; nanosensors and nanofluidics; plastic electronics; and nanomaterials with new functional properties.

3.2 Food processing

A critical feature in the area of "on demand" foods is the development of nanocapsules which are to be included in food to deliver nutrients to cells as necessary. Nanoparticles may also be added to existing foods so that nutrients are absorbed more effectively. In Western Australia, a major bakery has incorporated nanocapsules containing tuna fish oil (a source of omega-3 fatty acids) into bread: these have the advantage that the capsules only release their contents when in the stomach, so that the taste of fish oil, which some people find unpleasant, is avoided[10]. Nano-sized self-assembled liquid structures (NSSL) are employed, in the form of *ca* 30 nm diameter expanded micelles with nutrients or "nutraceuticals" contained within the aqueous interior, including lycopene, beta-carotene, lutein, phytosterols, CoQ10 and DHA/EPA. The particles have the trade-name, Nutralease, and allow the nutraceuticals to enter the bloodstream from the gut more easily than from normal foodstuffs. NSSL are marketed by Shemen Industries to deliver Canola Activa oil, which competes for bile solubilisation, and is claimed to reduce the body's cholesterol intake by 14%. 50 nm coiled nanoparticles, called nanocochelates, have been developed by Biodelivery Sciences International, for the enhanced delivery of nutrients such as vitamins, lycopene, and omega fatty acids, with no influence on the food's colour or taste. As a result of the above, the "super foodstuffs" concept is brought closer to becoming real, with potential manifold benefits, *e.g.* more energy, better cognitive functions, improved immune function, and anti-aging protection. A new product by the name of NanoCeuticals, which is a colloid (or emulsion) of particles of less than 5 nm in diameter, has been brought out by Royal BodyCare, who claim that it will scavenge free radicals, increase hydration and balance the body's pH. A nanoceramic has been marketed by the Oilfresh Corporation (USA) which, as a result of its large surface area, prevents the oxidation and agglomeration of fats in deep fat fryers, thus extending the useful life span of the oil. The amount of oil used in restaurants and fast food shops is thus reduced by half, and since the oil heats up faster, there is a further saving in the amount of energy used for cooking[10].

NovaSOL Sustain, developed by Aquanova (Germany), is a technology which incorporates two separate substances that are active for fat reduction (CoQ10) and satiety (alpha-lipoic acid) into micelles of *ca* 30 nm diameter, and is said to provide a novel approach to intelligent weight management. The NovaSol technology has been further employed to produce a vitamin E preparation, called SoluE, that does not cloud liquids, and a similar material containing vitamin C, called SoluC. Since the NovaSOL protects its contents from stomach acids, it can be used for the introduction of other dietary supplements[10]. The Woodrow Wilson International Center for Scholars in the USA 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[15]. A lifecycle analysis[16] has been made of nanocellulose, which is increasingly being used in food packaging and encapsulation applications.

Efforts have been made to provide a more stable environment from which to deliver eugenol, which is present in "oil of cloves", and is a popular preservative in the food industry, with antibacterial, antifungal and antioxidant properties. Normally, eugenol (Figure 2) is relatively sensitive to oxygen heat and light, which tend to degrade it, but when encapsulated as an inclusion complex in cyclodextrin (Figure 3), it is much more stable[17].

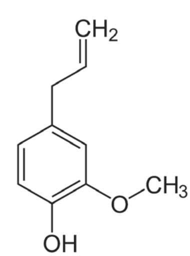
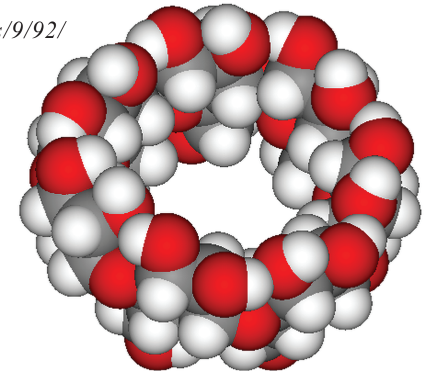


Figure 2 *Molecular structure of eugenol. http://upload.wikimedia.org/wikipedia/commons/8/86/Eugenol2.svg.*

Figure 3 *Space filling model of β-cyclodextrin. http://upload.wikimedia.org/wikipedia/commons/9/92/Beta-cyclodextrin3D.png.*



4. Potential environmental health and toxicological issues

From the ACS Select on nanotechnology in food and agriculture[9], we may draw attention to the following subjects. Despite the attractiveness of using QSAR approaches to the determination of the econanotoxicological effects of ENMs, the complexity of the real environmental situation, *e.g.* many different kinds of organism and of material types, renders the relationships difficult to apply because of a lack of reliable experimental data[18]. As an alternative, high-output screening combined with dynamic energy budget models is proposed[12]. Irrespective of the origin of the ENMs, *i.e.* whether they are deliberately introduced as part of an agricultural strategy, or present as contaminants, it is critical to know what effects they may have on the growth of plants. Thus, when wheat shoots were grown in sand that had been amended with silver nanoparticles, their growth was demonstrated to be stunted in a dose-dependent manner[19]. When *Arabidopsis thaliana* was exposed to CeO_2 nanoparticles at a concentration of 250 ppm, a significant increase in plant biomass was found, but as the concentration was increased to 500 – 2000 ppm, plant growth was decreased by up to 85% in a fashion that was dose-dependent[20]. Different effects were observed with In_2O_3 nanoparticles[20]. Although the environmental concentrations of ENMs are generally low, there is a risk that they may bioaccumulate in plants. Thus, it has been demonstrated that copper oxide nanoparticles will accumulate in maize plants, translocating from the roots to the shoots, and back again[21]. To explore the possibility of tropic transfer (movements of pollutants up the food chain), soil was inoculated with gold nanoparticles, and indeed, while the latter could be transferred to earthworms and thence to bullfrogs, the concentrations decreased by two orders of magnitude in each step[22]. It was shown that children may have the highest level of exposure to TiO_2 nanoparticles, which are in relatively high concentrations in "candy products"[23]. Silica ENMs were found to enter the gut epithelium, after digestion in the stomach, warning of a potential problem that requires further investigation[24].

Although nanoscale technology shows much promise in the food industry and in agriculture, its development must be made sustainably, and it is governments who will contribute substantially to this development[25], mainly through existing regulations. Notwithstanding that, during the past decade, much effort has gone into determining the environmental health and toxicological issues of ENMs, considerable uncertainly still remains, for which the following topics may be highlighted[9]:

- measurement and metrology of ENMs in complex matrixes;
- environmental fates and transformation of currently known ENMs and ever increasing number of new ENMs;
- nanobio interface between ENMs with human body and ecosystem species;
- exposure and full life cycle assessment;
- risk assessment and management of diverse uses of ENMs;
- safety by design; and
- sustainable nanomaterials and nanomanufacturing.

Nanoinformatics is an emerging field of research, for the design, data integration and communication of information regarding ENMs. Methods to predict the econanotoxicology of ENMs need major development and it appears probable that high-throughput, high-content screening methods will prove useful in assessing the safety of nanomaterials. Finally, I note a much cited review of the environmental and health effects of nanoparticles, of both natural and artificial origin[26].

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