Nanotechnology Applications for the Food Sector and Implications for Consumer Safety and Regulatory Controls

Dr. Qasim Chaudhry
Central Science Laboratory
Sand Hutton, York

The views expressed in this presentation must not be regarded as views of the UK Government
Known and Projected Applications

- Cosmetics
- Paints & coatings
- Catalysts & lubricants
- Security printing
- Textiles & sports
- Medical & healthcare
- Active coatings
- Food/ nutritional supplements
- Food packaging
- Agrochemicals
- Veterinary medicines
- Water decontamination
- Construction materials
- Electrical & electronics
- Fuel cells & batteries
- Paper manufacturing
- Weapons & explosives

~ 500 consumer products already available
The EU’s approach to converging technologies is different from that of USA, which is aimed at using them as a means to “enhance human performance”.

The EU approach is based on a balanced, concomitant assessment of the potential for successful innovation as well as any risks of the new applications.
CSL Reviews of Food Nanotechnology

- UK-Food Standards Agency projects on nanotechnology applications for the food sector
- Extensive searches of literature, company product literature and websites, patent databases.
- CSL database of nanomaterials manufactured and used in the UK: [http://nanotech.csl.gov.uk/](http://nanotech.csl.gov.uk/)
- The Woodrow Wilson inventory of nanotechnology consumer products: [www.nanotechproject.org/consumerproducts](http://www.nanotechproject.org/consumerproducts)
- Reports from The Institute of Nanotechnology (2006) [www.nanoforum.org](http://www.nanoforum.org); The Institute of Food Technologists (Weiss et al., 2006), and The Institute of Food Science and Technology [www.ifst.org/uploadedfiles/cms/store/ATTACHMENTS/ResponseFSA_NanotechnologiesT405app.pdf](http://www.ifst.org/uploadedfiles/cms/store/ATTACHMENTS/ResponseFSA_NanotechnologiesT405app.pdf).
Current and Projected Applications in the EU

- Nanotechnology applications in the EU’s food industry are currently at an elementary stage
- Current applications are mainly for food packaging, and delivery systems for nutraceuticals
- Most short-term applications are likely to be for high-value products, e.g. ‘active’ food packaging*
- Overall nanofood applications estimated at $410m in 2006 (food processing US$100m, food ingredients US $100m, and food packaging $210m), to reach $5.8 billion by 2012 (food processing $1,303m, food ingredients $1,475m, food safety $97m, and food packaging $2,930m )*

Nanotechnology Applications for Food and Nutritional Supplements

- Nanostructured ingredients and nutrient delivery systems (micelles, liposomes etc)
- Improved quality, texture, taste, less fat
- Enhanced delivery of nutrients/supplements

- Nanoencapsulated ingredients and additives
- Taste masking
- Protection from degradation
- Enhanced bioavailability

- Engineered nanoparticulated additives
- Enhanced bioavailability
- Antimicrobial action
- ‘Smart’, ‘Active’ and ‘Intelligent’ packaging
Example Applications for Food

• *Mars Inc.* US Patent US5741505 nanoscale inorganic coatings: Inorganic **nano-coating applied directly to a food product** to provide moisture or oxygen barrier to **improve shelf life** and/or flavour impact. Coating materials include **permitted additives** silicon dioxide (E551), magnesium oxide (MgO, E530) and titanium dioxide (E171). Applications include hard sugar confectionery, ready-to-eat cereals, biscuits, crisps.

• *BASF* US Patent US5968251 Production of carotenoid preparations in the form of coldwater-dispersible powders, and the use of the novel carotenoid pigments: Nanoparticulate **synthetic carotenoid** (‘lycopene’) dispersion claimed for a wide diversity of colouring properties associated with **improved bioavailability**. Applications include soft drinks, baking mixtures etc.
Examples of Nano-sized Carriers for Supplements

• **Novasol®** from Aquanova® (Germany) - a nano-micelle based carrier system for introduction of antioxidants in food and beverage products

• ‘**Nano-Sized Self-assembled Liquid Structures (NSSL)**’ from NutraLease Ltd. (Israel)

• **NanoCluster™** delivery system for food products from RBC Life Sciences® Inc. (USA).

• **BioDelivery Sciences International’s Bioral™** nanocochleate nutrient delivery system, for micronutrients and antioxidants. Phosphatidylserine carrier (~50nm) derived from soya bean (GRAS status)

### Example Applications for Nutritional Supplements

<table>
<thead>
<tr>
<th>Product</th>
<th>Application/ Claims</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Canola Active Oil</strong></td>
<td>NSSL-based nano micelle carrier for increased penetration of vitamins, minerals and phytochemicals</td>
</tr>
<tr>
<td>Shemen Industries, Israel</td>
<td></td>
</tr>
<tr>
<td><strong>Nanoceuticals™ Hydracel</strong></td>
<td>Claimed to lower the surface tension of drinking water (and hence increase solvent properties)</td>
</tr>
<tr>
<td>RBC Life Sciences® Inc. (USA)</td>
<td></td>
</tr>
<tr>
<td><strong>Nanoceuticals™ Slim Shake</strong></td>
<td>RBC’s NanoCluster™ delivery system to give CocoaClusters with enhanced flavour</td>
</tr>
<tr>
<td>Chocolate</td>
<td></td>
</tr>
<tr>
<td>RBC Life Sciences® Inc. (USA)</td>
<td></td>
</tr>
<tr>
<td><strong>Nanoceuticals™ Spirulina</strong></td>
<td>NanoClusters delivery system based food product</td>
</tr>
<tr>
<td>Nanoclusters</td>
<td></td>
</tr>
<tr>
<td>RBC Life Sciences® Inc. (USA)</td>
<td></td>
</tr>
</tbody>
</table>
### Example Applications for Nutritional Supplements

<table>
<thead>
<tr>
<th>Product</th>
<th>Application/ Claims</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nanoselenium green tea</strong></td>
<td>Claimed for enhanced bioavailability of selenium</td>
</tr>
<tr>
<td>Shenzhen Become Industry &amp; Trade Co., Ltd. (China)</td>
<td></td>
</tr>
<tr>
<td><strong>Nanoceuticals™ Microhydrin®</strong></td>
<td>Nanocolloidal silicate mineral, claimed to neutralise free radicals</td>
</tr>
<tr>
<td>RBC Life Sciences® Inc. (USA)</td>
<td></td>
</tr>
<tr>
<td><strong>Spray for Life® Vitamin Supplements</strong></td>
<td>Non-aerosol nanoceutical delivery system (NDS) for increased-bioavailability of vitamins through transmucosal administration</td>
</tr>
<tr>
<td>Health Plus International® Inc. (USA)</td>
<td></td>
</tr>
<tr>
<td><strong>Nutri-Nano™ CoQ-10</strong></td>
<td>Increased absorption of fat-soluble nutrients through conversion into water-soluble ~ 30 nm micelles</td>
</tr>
<tr>
<td>Solgar (USA)</td>
<td></td>
</tr>
</tbody>
</table>
## Example Applications for Nutritional Supplements

<table>
<thead>
<tr>
<th>Product</th>
<th>Application/ Claims</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nano Calcium/Magnesium</strong></td>
<td>Claimed for increased absorption and bioavailability of calcium/ magnesium</td>
</tr>
<tr>
<td>Mag-I-Cal.com (USA)</td>
<td></td>
</tr>
<tr>
<td><strong>Nanosiliceo Kapseln</strong></td>
<td>Nanoparticle mineral supplements (SiO₂, Mg, Ca)</td>
</tr>
<tr>
<td>Neosino (Germany)</td>
<td></td>
</tr>
<tr>
<td><strong>MesoZinc™</strong></td>
<td>Pure colloidal minerals</td>
</tr>
<tr>
<td><strong>MesoTitanium™</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Mesosilver®</strong></td>
<td></td>
</tr>
<tr>
<td><strong>MesoPlatinum® MesoPalladium™</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Meso-Iridium™</strong></td>
<td></td>
</tr>
<tr>
<td><strong>MesoGold®</strong></td>
<td></td>
</tr>
<tr>
<td><strong>MesoCopper®</strong></td>
<td></td>
</tr>
<tr>
<td>Purest Colloids, Inc. (USA)</td>
<td></td>
</tr>
<tr>
<td><strong>MaatShop™ Bio-Sim</strong></td>
<td>Food-grade diatomaceous earth, nanoized</td>
</tr>
<tr>
<td>MaatShop™ (USA)</td>
<td></td>
</tr>
<tr>
<td><strong>Nanoceuticals™ Silver 22</strong></td>
<td>Colloidal silver</td>
</tr>
<tr>
<td>RBC Life Sciences® Inc. (USA)</td>
<td></td>
</tr>
<tr>
<td><strong>Sovereign Silver™</strong></td>
<td></td>
</tr>
<tr>
<td>Natural-Immunogenics Corporation</td>
<td></td>
</tr>
<tr>
<td>(USA)</td>
<td></td>
</tr>
<tr>
<td><strong>Advanced Colloidal Silver</strong></td>
<td></td>
</tr>
<tr>
<td>Utopia Silver Supplements®, (USA)</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- Nano Calcium/Magnesium - Mag-I-Cal.com (USA)
- Nanosiliceo Kapseln - Neosino (Germany)
- MesoZinc™, MesoTitanium™, Mesosilver®, MesoPlatinum®, MesoPalladium™, Meso-Iridium™, MesoGold®, MesoCopper® - Purest Colloids, Inc. (USA)
- MaatShop™ Bio-Sim - MaatShop™ (USA)
- Nanoceuticals™ Silver 22 - RBC Life Sciences® Inc. (USA)
- Sovereign Silver™ - Natural-Immunogenics Corporation (USA)
- Advanced Colloidal Silver - Utopia Silver Supplements®, (USA)
Examples of Nanoclay-polymer composites

- Imperm® (Nanocor Inc): used in multi-layer PET bottles and sheets for food and beverage packaging to minimise the ingress of O2 and loss of CO2 from beverages.

- Duretham® KU 2-2601 (Bayer AG) uses Nanocor’s clay to produce a film with increased barrier properties in the plastic. The application is used where conventional PA is too permeable and EVOH (ethylene-vinylalcohol) coatings too expensive e.g. paperboard juice containers.

- Aegis® OX (Honeywell) a polymerised nanocomposite film contains a blend of active and passive nylon that incorporate active O2 scavengers and passive nanocomposite clay particles to enhance barrier properties.
Metal (oxide)-polymer nanocomposites

- Developed for antimicrobial or active packaging, abrasion resistance, UV absorption, strength
- Incorporation of UV absorbers (e.g. TiO$_2$) in plastics such as PS, PE, PVC.
- Incorporation of metals such as silver (Ag) and gold (Au) or oxides such as zinc oxide (ZnO), silica (SiO$_2$), alumina (Al$_2$O$_3$) and iron oxides (Fe$_3$O$_4$, Fe$_2$O$_3$)
- Natural antimicrobial action of silver has been utilised in a number of ‘active’ FCMs claimed to preserve the food materials within longer by inhibiting the growth of microorganisms
- Antimicrobial properties of nano zinc oxide and magnesium oxide have recently been discovered, which may be a cost-effective alternative to silver
Developments at R&D Stage

- Development of polymer nanocomposite films incorporating nanoparticles, nanosensors, or antigen detecting biosensors for ‘smart’ packaging to monitor condition of food, and traceability of food products.
- Development of ‘Electronic Tongue’ technology that is made up of sensor arrays to signal condition of the food.
- Development of nanostructured porous silicon BioSilicon™ (pSivida Australia) with potential food packaging applications to enable detection of pathogens, and variations of temperature during food storage.
- Development of next-generation packaging displays that include Radio Frequency Identification Display (RFID), as smart labels to assist quick and accurate distribution of foodstuffs with a limited shelf-life.
Example Patents (Food)

- Antibacterial \textit{wheat flour} containing \textit{silver nanoparticles}
- \textit{Nanoparticulated whey protein} for use as emulsifier, fat substitute, whitening and/or filling agents
- \textit{Chewing gum} containing hardly-soluble \textit{nano-calcium} salt and/or composite to promote mineralization of dental enamel
- \textit{Sweet, filled sweet or filled chewing gum} containing hardly-soluble \textit{nano-calcium} salt and/or composite to promote mineralization of dental enamel
- Active ingredient for application to fauna and flora, agriculture, horticulture, aquaculture, pet care and recreational gardening, comprises \textit{nanoparticles}
- Composition containing hydrophobic \textit{silicon nanoparticles} for control of insects, molluscs, mites
- Use of \textit{nanoparticulate sterols and sterol esters} as hypocholesterolemic additives for food
Example Patents (Food Contact Materials)

- UV barrier composition comprising **nano-titanium dioxide**, and polymer
- Antibacterial polyester film with coating layer of **silver nanoparticles**
- Refrigerator for use in preserving food in fresh state, comprising finish material containing antibacterial **nanosilver particles**
- Coated hollow container with a protective layer which includes **nanoparticles** to increase scratch resistance
- Gas and liquid barrier material comprising a matrix of thermoplastic polymer and **nanoparticulate zirconium and/or titanium phosphate**
- Coating composition for containers for storing light sensitive products comprising carrier dispersed with pigment having **UV and/or visible light absorber nanoparticles**
- Multilayer film with outer layer of polyamide containing dispersed **nano-scale filler particles** and at least one other polyamide layer without such particles
- Biodegradable **starch/clay nanocomposite films**
Potential Consumer Safety Issues

• Properties of nano-sized materials may differ widely from ‘conventional’ forms.

• Growing scientific evidence indicates that:
  • engineered free nanoparticles can cross cellular barriers, and may reach areas in the body where larger equivalents could have not reached
  • exposure to some engineered nanoparticles has been shown to cause increased production of oxyradicals that may lead to oxidative damage and inflammatory reactions


• Li et al. (2003) Ultrafine particulate pollutants induce oxidative stress and mitochondrial damage, Environmental Health Perspectives 111(4): 455-460.
Potential Consumer Safety Issues

Initial studies indicate that nanoparticles:

- > 300 nm - probably remain out of cells
- 70-300 nm can potentially enter cells but not the nucleus
- 70 nm or smaller can potentially enter cell nuclei*


- An in vitro study on human epithelial cell cultures using fluorescence labelled SiO₂ nanoparticles; study also found protein accumulation in the nuclei, impairment of DNA replication and transcription.
- SiO₂ is used as a food supplement. However, it is not known whether comparable effects will occur in vivo, through the ingestion route, and in the presence of other food matrices and materials.
Absorption of Nutrients Through the Gut

Image source:
www.uoregon.edu/~mdillon1/Energy%20Metabolism/Energy%20Metabolism.html
**Consumer Safety Concerns**

- Nanostructured ingredients and nutrient delivery systems
  - Can they also carry other foreign substances to the blood?

- Nanoencapsulated ingredients and additives
  - Can enhanced bioavailability of some additives lead to greater risks to a consumer’s health?

- Engineered nanoparticulated additives
  - What are the likely effects on GI tract function, other cellular functions in the body, and the gut microflora?
Regulatory Reviews


Regulatory Aspects

• Most nanotechnology applications for food/food contact materials would come under some approval process under the EU food laws

• Existing models for risk assessment should be applicable to nanomaterials but there are major gaps in information on hazard and exposure

• There are a number of uncertainties in relation to hazard, exposure and assessment of risks that might limit the scope and effectiveness of regulatory controls
  • Current legislation does not differentiate between ‘conventional’ and ‘nano’ forms of materials
  • Lack of knowledge of the effects of processes and products of nanotechnologies to inform adequate risk assessment
Current EU food legislation does not differentiate between ‘conventional’ and ‘nano’ forms of additives already approved for use in food.

There is a lack of clarity in the definition of novel foods under relevant regulations that may lead to uncertainty as to whether (and when) a food processed at nano-scale be considered novel food.

There are major gaps in knowledge in relation to:

- the extent of nanoparticle migration from food packaging
- the effects of nanoparticles on consumer health
Applications of nanotechnology are likely to bring enormous benefits to the food/health-food sector. Maintenance of quality and freshness, development of new tastes, flavours, textures, increased nutritional value, less salt, sugar, fat and preservatives, targeted nutrition for different lifestyles, improved, ‘active’, ‘intelligent’, ‘smart’ packaging materials; increased shelf life, better traceability and safety of food products.

There are uncertainties and concerns in relation to the safety of nanomaterials in food/supplements. A proactive approach is needed by the industry to test safety of materials and products before placing them on the market.

Gaps in knowledge have led to potential regulatory uncertainties. Industry self-regulation/best practice.

Consumers need to be involved/informed at the outset. Labelling of nano ingredients/additive? - at least for potentially high-risk applications.
Other Developments

- A review article ‘Applications and implications of nanotechnologies for the food sector’, (Chaudhry et al.) ready for publication

- A book ‘Outlook For Nanotechnologies In Food’, (Chaudhry et al. Eds), to be published by the Royal Society of Chemistry in 2008

---

**Assessment of Converging Technologies for the Food Sector**

Proposal full title: Assessment of Converging Technologies for the Food Sector

Proposal acronym: ACTFOODS

FP7 COOPERATION THEME 2: FOOD, AGRICULTURE AND FISHERIES, AND BIOTECHNOLOGY

Activity 2.2.5: Fork to farm: Food (including seafood), health and well being.

KBBE-2007-2-5-02 - Call: FP7-KBBE-2007-1

Type of Funding scheme: Small collaborative project

<table>
<thead>
<tr>
<th>Participant no.</th>
<th>Participant organisation name</th>
<th>Organisation short name</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Central Science Laboratory</td>
<td>CSL</td>
<td>UK</td>
</tr>
<tr>
<td>2</td>
<td>RIKILT Institute of Food Safety</td>
<td>RIKILT</td>
<td>The Netherlands</td>
</tr>
<tr>
<td>3</td>
<td>AZTi-Tecnalia</td>
<td>AZTI</td>
<td>Spain</td>
</tr>
<tr>
<td>4</td>
<td>Tubitak Marmara Research Centre</td>
<td>TUBITAK</td>
<td>Turkey</td>
</tr>
<tr>
<td>5</td>
<td>University of Bologna</td>
<td>UNIBO</td>
<td>Italy</td>
</tr>
<tr>
<td>6</td>
<td>A.N. Bakh Institute of Biochemistry of the Russian Academy of Science, Russia</td>
<td>INBI</td>
<td>Russia</td>
</tr>
<tr>
<td>7</td>
<td>Consumer's Association “The Quality Of Life”</td>
<td>EKPIZO</td>
<td>Greece</td>
</tr>
<tr>
<td>8</td>
<td>VTT – Technical Research Centre of Finland</td>
<td>VTT</td>
<td>Finland</td>
</tr>
<tr>
<td>9</td>
<td>University of Chester, Centre for Science Communications &amp; Environmental Quality &amp; Food Safety Research Unit</td>
<td>UCC</td>
<td>UK</td>
</tr>
</tbody>
</table>

Name of the coordinating person: Dr. Qasim Chaudhry

Coordinator Institution: Central Science Laboratory, sand Hutton, York United Kingdom Y041 1LZ

Coordinator’s Telephone Number: 0044 (0)1904 452584

Coordinator’s Fax Number: 0044 (0)1904 452111

Coordinator’s Email Address: q.chaudhry@csl.gov.uk
A workshop on

Applications and Implications of Nanotechnology for Food Contact Materials

30th October 2007

Central Science Laboratory
Sand Hutton, York YO41 1LZ
Tel: 01904 462584, Fax: 01904 462111, email: q.chaudhry@csl.gov.uk

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
<th>Presenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:30</td>
<td>Arrival, Registration and Coffee (Please report at the main reception on arrival)</td>
<td></td>
</tr>
<tr>
<td>10:00</td>
<td>Welcome and Opening Remarks</td>
<td>Prof. Mike Roberts Chief Executive CSL</td>
</tr>
<tr>
<td>10:05</td>
<td>Introduction and Background, Aims of the Workshop</td>
<td>Laurence Castle CSL</td>
</tr>
<tr>
<td>10:20</td>
<td>Current and Projected Applications of Nanotechnology for E.CMs</td>
<td>Qasim Chaudhry CSL</td>
</tr>
<tr>
<td>10:40</td>
<td>Potential Migration of Nanoparticles from Nanotechnology-derived E.CMs</td>
<td>Emma Bradley CSL</td>
</tr>
<tr>
<td>11:00</td>
<td>Current State of Knowledge With Regard to Toxicology of Engineered Nanoparticles</td>
<td>Ken Donaldson Edinburgh</td>
</tr>
</tbody>
</table>