ObservatoryNANO

BRIEFING No.1

AGRIFOOD

SEVENTH FRAMEWORK PROGRAMME

BIODEGRADABLE FOOD PACKAGING

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The volume of waste generated by the European agrifood sector is of increasing concern; in fact Europe's fruit and vegetable industries generate around 30 million tonnes of waste a year[1]. Numerous initiatives aimed at reducing agricultural waste (or finding novel uses for it) have been launched. For example the UK Government recently stated that within 10 years, 75% of all UK household waste should be recycled or composted[2].

Food packaging waste is predicted to increase as a result of an ever increasing demand for convenience food, and individual wrapping of fresh produce (such as fruit)[3]. Plastic packaging (useful for its water-tightness and rigidity) has been designed with little consideration for disposability or recyclability, resulting in concerns over the environmental impacts when they enter the waste stream. This BRIEFING outlines a promising area of nanotechnology that may contribute to the management of food packaging waste , adding value to the growing demand for biodegradable food packaging.

Nano adds value

Advances in nanomaterial research and processing technologies mean that natural polymers, such as sugars and proteins, can be combined with nanoclays and bio-based nanomaterials to create potentially non-toxic, biodegradable and biocompatible materials – which some have dubbed as "green nanocomposites".

Nanoprocessing (creating films, coatings, composites, and fibres) has improved the previously poor qualities of bio-based plastic to a level near to their fossil fuel derived counterparts. Additionally, the use of naturally occurring polymers mean that, in most cases, the material can be degraded (composted) or, in some cases, eaten (see Box 1).

Promising contributors to sustainability

Three promising overlapping areas of development in the field of biodegradable and edible bioplastics have been identified by the ObservatoryNANO:

(1) Bionanocomposites

When bioplastics are mixed with nanoclay particles, the resulting nanocomposites exhibit improved barrier properties compared with the pure bioplastic, and after their useful life can be composted and returned to the soil . Other nanomaterials can be utilised including nanoparticles, nanofibres and nanowhiskers[5,6].

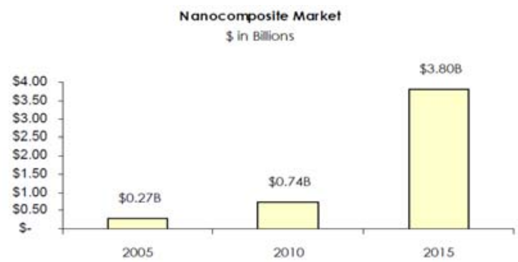
(2) Bio-based nanofibres

Many biopolymers such as chitosan, cellulose, collagen and zein (derived from corn) have been synthesised as nanofibres from various biopolymers using the electrospinning technique. In some cases these have superior properties to the traditionally cast polymer, including increased heat resistance.
In addition, mats of such nanofibres possess a

Box 1: Nanocomposites for packaging applications

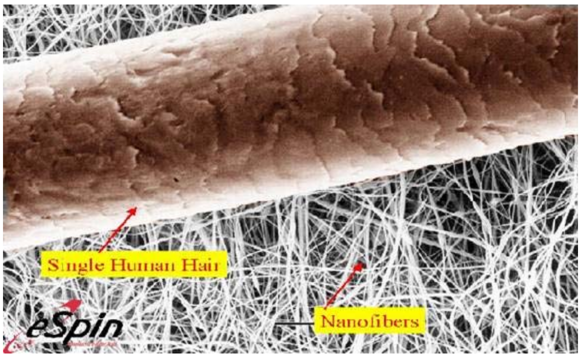
Nanocomposite materials currently used, or being developed, for the food packaging industry contain a polymer plus a nano-additive. Mostly nanoclay particulates are used; however, other composites containing nanoparticles, nanotubes or nanofibres are also being developed. Polymer nanocomposites containing nanoclay particulates are currently leading the food packaging market. However, bio-based nanocomposites (PLA-clay, cellulose nanofibres) and metal (oxide)-polymer composites are also being developed.

Nanocomposites are the fastest growing segment in the $40 billion polymer composite market and is estimated to more than double in size in the next four years. Nanocomposites based on Imperm® found their early application in multi-layer PET beer bottles used by Miller Brewing Co.



For bionanocomposites, the polymer or nano-additive can be derived from biomaterials sourced from plants. In most cases, the biomaterials can derived from readily available sources, e.g. cellulose from plant matter or sourced from the waste from the food manufacturing process (such as the pulp leftover from fruit juice production). On their own bioplastics have poor mechanical properties or poor water vapour barrier properties. This has meant that the use of such biodegradable options for food packaging has been restricted to card based packaging (using cellulose) where mechanical and barrier properties are of less importance. For wider uptake , in bottles, films, and moulded plastic packaging, these properties need to be improved.

highly nanoporous structure and can be used as support matrixes for additional functionality possessing as they do the lowest thermal conductance of all solids[6,7].



(3) Edible nano films

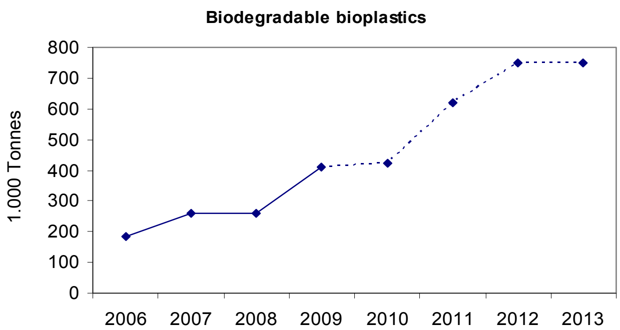
Edible films are layers of digestible material used to coat food (edible coatings) or as a barrier between food and other materials or environments (edible films). Bionanocomposites created from vegetable and fruit puree and cellulose nanowhiskers have been described in a recent review by de Azeredo[7]. Proteins that can be used include casein, whey, collagen, egg white and fish derived protein. Soya bean, corn and wheat protein also are candidates for edible films producing proteins[8,9].

Impacts

Economic and industrial impacts

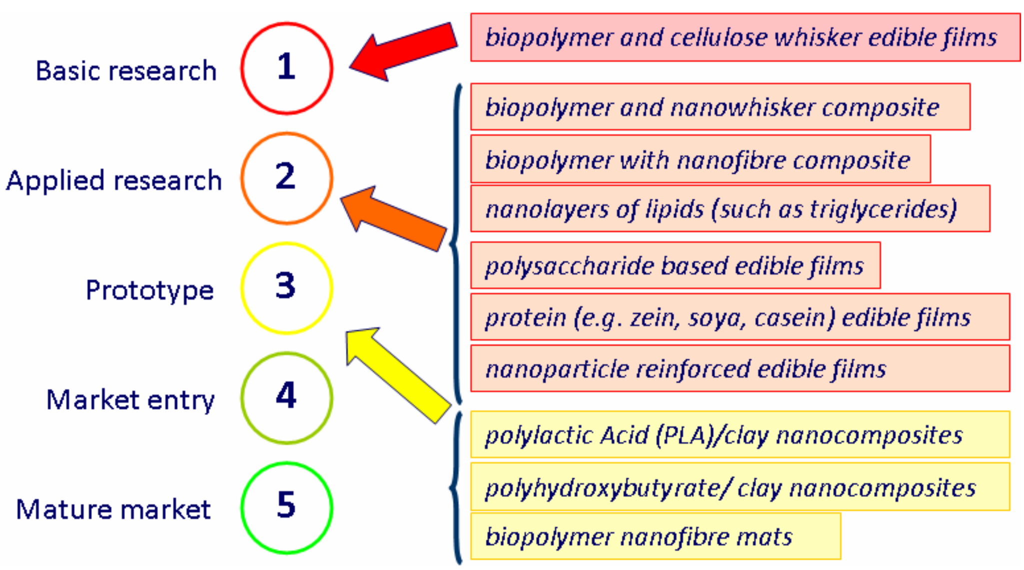
In its recent report entitled "World Bioplastics to 2013", Freedonia predicts that the global demand for bioplastics will rise by more than 400% by 2013 largely due to high crude oil and gas prices. Other factors include: consumer demand for more environmentally sustainable products; the increased production of certain bioplastics (notably polylactic acid (PLA)); and political and regulatory pressure to reduce non-degradable plastics[1].

Presently, the global market for biodegradable polymers exceeds €135 million and is expected to rise at an average annual growth rate of 12.6% to €244 million in 2010[10].



With regards to packaging, according to Economy Watch, the global food packaging market will reach €5.4 billion by the end of 2010 with a growth rate of 4.3%. The market for biodegradable packaging has been developing rapidly over the last decade with estimations suggesting an annual growth of greater than 20%.

It is difficult to determine the proportion of this growth which nanomaterials account for; however,



Technology Readiness Levels (TRL) providing a summary indication of the status of the various nanomaterials being developed in the food packaging in terms of route to market.

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three years ago fewer than 40 food packaging products containing nanoparticles were thought to be on the market in comparison to greater than 400 today. The growth in the industry is predicted to reach $20billion by 2020[11].

Societal Drivers

The use of packaging is predicted to increase due to the following drivers:

- Higher standards of living in western countries has led to the transportation of exotic foods over large distances leading to a need for more packaging to maintain freshness.
- The general trend towards urbanisation creates a greater distance between food producers (rural areas) and the consumer (urban areas).
- The increase in working families (both partners in work) coupled with the availability of refrigerators has led to a higher demand for convenience food, which increases packaging.

With this in mind, many national policies are focusing, not on reduction of packaging, but the management of it through sustainable sourcing of materials and increasing pressure to recycle or compost packaging waste.

Societal Impacts

The impacts on the EU citizen of **nano–enabled biodegradable packaging** will be a positive one, potentially providing greener and cleaner alternatives to fossil-fuel derived packaging materials.

This growth area of innovation could provide a solution to the management of the packaging waste, although it may also create opportunity costs in that a policy focus on **waste handling** rather than **waste reduction** may fuel an increase in packaging waste to unsustainable levels. A balance between these two policies should therefore be sought.

Challenges

The following challenges are of importance for nano-enabled biodegradable packaging:

- **Source management** there is a need to minimise use of agricultural land and forest[12] for the production of biomass for material manufacture. A promising solution lies in the use of bio-waste, such as from the fruit and vegetable industry (leftover pulp from fruit juice manufacture for example)[1].
- **Composting capacity.** If such innovations are truly going to replace (or at least be a major player against) fossil fuel derived packaging materials, a coordinated anticipation and planning for the compositing infrastructure is necessary
- **Regulations** are in place for packaging in the form of (EC) No 1935/2004 (Regulation on materials and articles intended for food contact) and the recent (EC) No 450/2009 (active and intelligent materials and articles intended to come into contact with food), but the uncertainty on the potential directives specific for nanomaterials, coupled with a call for a moratorium on nanotechnologies for the food sector (see the recent positioning of the European Parliament[13]) means that the food packaging industry remains cautious with respect to their use of nano-based materials.
- **Consumer perception** (especially on digestible packaging) has been shown to be cautious[14], thus early stage engagement with consumers (and consumer organisations and other NGOs) is necessary, not to educate them but to actually get design requirements based on their opinions of what is a suitable and acceptable technology to society.
- **Cost effectiveness** is key for this technology to compete with the incumbent fossil-fuel based plastic paradigm. A major bottleneck is the **rela-**

Valencia as a European hub for advanced food packaging

Valencia (ES) is a hub for polymer and packaging R&D with institutes such as ITENE (The Packaging, Transport and Logistics Research Centre), AIMPLAS (Technological Institute of Plastics) and many university departments involved in the field. ITENE coordinates a large number of research activities in the area of advanced food packaging coordinating FP7 NAFISPACK and were also involved in FP5 SUSTAINPACK.

Nanobiomatters, a medium sized firm is based in Valencia and the greater Valencia region. Over the past 6 years Nanobiomatters has developed R&D and production capabilities for nanoclay powder (Commercial Additive Plant of 2500t/year) and polymer-clay nanocomposite production (Commercial Extrusion Plant of 4000t/year). Commercial products are currently available, and with €4 million invested in development of its manufacturing facilities, and a diverse portfolio of nanobioplastics (including antimicrobial and gas scavenging functionalities), Nanobiomatters is rapidly becoming a major player in the field of biodegradable packaging.

These activities, the relationships with the local universities, and the emergence of firms such as Nanobiomatters makes Valencia a hub for nano-enabled packaging R&D.

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tively high production and processing cost[3]. Improved extrusion and additive processes are, however, allowing firms to create high performance materials. Therefore the bottleneck based on manufacturing cost is shifting to a more promising position.

EU Competitive Position

Europe is major contender in the production of knowledge and the coordination of research collaborations. This is illustrated in the EC funded SUSTAINPACK and NAFISPACK projects where large consortia of European Research Institutes collaborated with the food packaging industry to develop applications based on nanofibres and natural antimicrobial packaging respectively. The number of companies emerging around nano-enabled biodegradable packaging is, however, somewhat limited. Nanobiomatters (see p3) is one of the world leaders, especially with regards to scavenger and antimicrobial versions (BactiBlock and NanobioTer+) but the USA and Korea are alsocommercialising a number of processes especially in biodegradable nanocomposite films.

Summary

Bionanocomposites represent an exciting field with a number of application areas. European research and development is making major advances with research consortia such as NAFISPACK creating strong ties between research institutes and the food packaging industry.

At supply chain level companies are emerging, but face a number of challenges which will inhibit their growth against the incumbent non-biodegradable plastics manufacturer; policy incentives could be a first step in supporting such growth.

Nanotechnology adds value to the currently societally desirable bioplastic paradigm by making them stronger, water and gas impermeable, and adding functionalities such as antimicrobial effects. However, for the benefits to be harvested, a number of challenges must be addressed:

- Consumer and retailer perceptions on nanomaterials and their safety mean dialogue and engagement is necessary;
- Regulatory uncertainty around nanotechnology and labelling;
- Composting capacity, if biodegradable plastics are to replace the current non-biodegradable ones in an advantageous way;
- Balancing biomass production, crops developed purely for creation of materials, rather than food, may cause societal challenges including food shortages.

Contact

Douglas Robinson, douglas.robinson@nano.org.uk

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