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Nanotechnology and Opportunities for Agriculture and Food Systems

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Nanotechnology has emerged as one of the most innovative scientific fields in decades. Nanotechnology involves use of materials on an extremely small scale, usually 0.1 to 200 nanometers. One nanometer is equal to one thousandth of a micrometer or one millionth of a millimeter. For comparison, a living cell has dimensions of microns (thousands of nanometers). The physical, chemical and biological properties of materials at nano scale exhibit important differences when compared to those of micro and macro scales. Nanoparticles can be more chemically reactive and more bioactive than larger particles. Because of their very small size, nanoparticles may enter cells, tissues and organs easier than larger particles.

Nanoparticles exist in nature. Nanoclay, tomato carotenoid lycopene, many chemicals derived from soil organic matter, lipoproteins and viruses are a few examples of natural and biological nanomaterials with diverse structures and wide range of biological roles.

The National Nanotechnology Initiative (NNI), was formed in 2000. The NNI is a U.S. government research and development (R&D) initiative involving 20 departments and independent agencies. Its vision is to work toward "a future in which the ability to understand and control matter at the nanoscale leads to a revolution in technology and industry that benefits society." U.S. Department of Agriculture, a partner agency in the Federal NNI held a national planning workshop, "Nanoscale Science and Engineering for Agriculture and Food Systems," in Washington, D.C. on Nov. 18-19, 2002. Leading nanotechnology researchers and administrators from landgrant universities and nanotechnology program leaders from other federal agencies were among the participants of this workshop. The objective of the workshop was to identify nanotechnology opportunities with the potential to revolutionize agriculture and food systems and to develop a strategic plan with recommendations for implementation of a new program in nanotechnologies within the USDA. Nucleic acid bioengineering, smart treatment delivery systems, nanobioprocessing, bioanalytical nanosensors, nanomaterials and bioselective surfaces were identified as some of the potential research areas that would have a significant impact on agriculture. In 2003, USDA created a new program "Nanoscale Science and Engineering for Agriculture and Food Systems" under the National Research Initiative Program (NRI). Since then a number of research projects relevant to agriculture and food systems have been funded by the NRI program. Some of the topics that have been investigated in food and agricultural production systems include:

Food

- "Bio-selective surfaces" and "laboratory-on-a-chip" technology for early detection of pests, pathogens, trace chemicals, viruses, antibiotics and toxins.
- Integrated and rapid DNA sequencing technology to identify genetic variations and genetically modified organisms.
- Tracking integrity of food during production, transportation and storage.
- Delivery systems to reduce calories of food while retaining flavor, lowered fat, reduced salt, less sugar and improved texture.
- Delivery systems to enhance bioavailability of nutraceuticals, vitamins and nutrients in foods.
- "Personalized nutrition and nutrigenomics" approaches to meet specific health needs.
- Technologies for food packaging and food contact materials to assure quality and enhance shelf life (i.e. eliminate need for refrigerated storage). Nanoscale dirt-repellent coatings could have important applications at food production sites, in particular abattoirs and meat-processing plants.

Production Agriculture

- Technologies and processes to reduce crop and post-harvest losses.
- New breeding technologies.
- Tools for early and pre-disease detection, rapid diagnosis and prevention of diseases.
- Identity tracking of animals from birth to the consumers.
- Nutritional platforms for animal feeding that will alter food products (milk and meat) and enhance human health benefits.
- Technologies to reduce greenhouse gas emissions from livestock and manure management processes.
- Renewable energy production and distribution.
- "Smart field systems" to detect, locate, report and application of water only as needed and in required quantity.
- Precision and controlled release fertilizers and pesticides.

According to a study from Helmut Kaiser Consultancy completed in 2011, which evaluated the level of nano food research portfolio, the worldwide nanotech food market is expected to reach $20.4 billion by 2020. According to the same source, about 1,200 companies around the world are active in research and development in nanotechnology. USA is leading the technology followed by Japan and China.

Scientists take advantage of the unique properties of the nanomaterials to measure, control and manipulate matter. Currently, a lot of work is being carried out on nanosensors targeting improved pathogen detection in food systems. Many electronic companies have been investigating electrically conducting polymers. These same materials also can be used to manufacture sensors that can detect very low levels of molecular signals of spoilage and food-borne pathogens within minutes of exposure. For example, scientists are suggesting non-invasive bioanalytical nano-sensors could perhaps be placed in an animal's (i.e. cow's) saliva gland to detect a single virus before it has had a chance to multiply and develop disease symptoms. Another sensor application that nanotechnology would be helpful is "electronic tongue" that detects minute amounts of a wide range of chemicals. This sensor uses tiny electrodes coated with a conductive polymer. According to the researchers involved in the project, this device can detect parts per trillion concentrations of chemicals and costs about 50 cents to produce. It also is expected the tongue technology could potentially be incorporated into food packages such as meat wrappings and would change color when the meat is starting to spoil.

Nanotechnology is changing the packaging industry. For example, plastics manufactured with different nanostructures allow various gas and moisture permeability to fit the requirements of specific products such as fruits, vegetables, beverage and wine. As a result, shelf-life, flavor and color preservation of the products can be improved. Nanostructured films and packaging materials can prevent the invasion of pathogens and other microorganisms and ensure food safety. Nano-sensors embedded in food packages will determine whether food has gone bad or show its nutrient content. By adding certain nanoparticles into packaging material and bottles, food packages can be made more light- and fire-resistant with stronger mechanical and thermal performance and controlled gas absorption.

Some specific examples of nanotechnology applications in food industry are as follows:

- Use of nanoclays, nanopolymers, nanocavities and nanostrings as gas and UV barriers, anti-microbial surface development and breathable and multifunctional food packaging design.
- Nano-sized iron particles added to some nutritional drinks increase reactivity and bioavailability.
- Kitchenware, i.e. cutting boards manufactured with added nano-sized silver particles increase antibacterial properties.
- Starch nano-spheres added to food packaging have 400 times more surface area than natural starch particles. They are used as an adhesive to minimize water consumption and thus less time and energy to dry.
- Non-stick cooking equipment made with nano-ceramic coatings have enhanced functionality and durability.
- Nano-ceramic catalytic pellets are designed for prolonging freshness of frying oil while in use.
- Nano-silver and nano-carbon are used to coat the interior and the gasket of the refrigerator to prevent intrusion of bacteria from outside.
- Nano-silica is used as free flow aid for powdered ingredients in the food industry.

Nanotechnology is still an emerging technology. In spite of numerous potential benefits that nanotechnology offers, safety aspects of the application of this technology in food and agricultural industry and environment are not well known. Furthermore, consumers are not well informed about nanotechnology. Experiences from the genetically modified organism debate clearly indicate public support and consumer acceptance of this technology will depend on the behavior of institutions responsible for development and regulation of technological innovations and risk assessment. One way to secure public support for this technology is to dedicate resources to further research on widely shared goals such as clean and renewable energy and public health intervention to ensure development of healthy and nutritious foods and crops. Responsible industry practices, distribution of expertise and benefits, and availability of choices worldwide would help public acceptance of the technical innovations derived from nanotechnology and nanoscience. Currently, there are a number of on-going studies that attempt to detail, analyze and assess the potential problems and benefits, pitfalls, and known and unknown risks related to developments in nanoscience and technology. However, health, environmental and workers' health risk analyses, and a regulatory framework for nanotechnology and nanoscience are some of the issues that need to be further examined as the technology matures. Lack of regulatory harmonization also is an impediment for development of global strategies for commercializing products derived from nanotechnologies.