Asian Science
Volume 7 | Issue 2 | December, 2012 | 160-167

REVIEW PAPER

# A synoptical overview of nanotechnology for agriculture and health security

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**Key Words :** Nanotechnology, Current global population, Energy production, Computing

**View point paper :** Gautam, Virendra Singh, Vaishali and Priya, Tanu (2012). A synoptical overview of nanotechnology for agriculture and health security. *Asian Sci.*, **7**(2): 160-167.

The current global population is more than 6 billion with 50 per cent 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. Nanoscale science, engineering, and technology, which is more widely known using the novel term 'nanotechnology', is an emerging multidisciplinary field that can have enormous potential impact on our society. Globally, an estimated $9 billion per year is allocated to research and development in nanotechnology, with the expectation that this investment will lead to significant advances in a variety of applications including medicine, material science, computing and electronics, industrial manufacturing, environmental remediation, energy production, military applications, among others. The agricultural industries are no exception. So far, the use of nanotechnology in agriculture has been mostly theoretical, but it has begun and will continue to have a significant effect in the main areas of the food industry, development of new functional materials, product development, and design of methods and instrumentation for food safety and bio-security. The effects on society as a whole will be dramatic (Fig.1).

The term 'nano' is used as a prefix "nano" which is from the Greek word meaning "dwarf". Idea of nanotechnology given by K.Eric Drexter in 1979, also wrote a book in 1986, entitled as engine of creation: the coming era of nanotechnology. The term coined by Norio, Taniguchi in 1974. In more technical terms, the word "nano" means $10^{-9}$, or one billionth of something, For comparison, A leckocyctes has size of 10,000 nm, bacteria 1000-10,000, virus 75-100 nm, protein 5-50 nm, deoxynuclotude (DNA)~ 2 nm (width) and an atom ~0.1 nm.

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. There are two main approaches used in nanotechnology, bottom up approaches and top down approaches. The bottom up technique built or grows larger structure atom by atom or molecule by molecule. These techniques includes to chemical synthesis, self assembly and positional assembly. Top down approaches which means reducing the size of the bulk material structure to the nanoscale without atomic level control *eg*. Atomic layered depositions

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(ALD) technique, photonics applications in nano electronics and nano engineering such as opaque substance became transparent (Cu).

By various definitions of nanotechnology concluded in form of fundamental aspects: 1. research and technology development at the atomic, molecular, or macromolecular levels using a length scale of approximately 1 to 100 nanometers in at least one dimension; 2. the creation and use of structures, devices and systems that have novel properties and functions because of their small size; and 3. the ability to control or manipulate matter on an atomic scale (EPA, 2007).

**Nanotechnology applications for agriculture and food technology:**

**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.

**GPS for precision farming:**

Global positioning system is widely used in agriculture. It is space based, global based navigation system that provides reliable information about any location in all weathers and at all times and anywhere on the earth. Three essential parts; the space segment, the control segment, user segment.

Nanotechnology enabled devices will increase use of autonomous sensor linked into GPS system. These nanosensors could be distributed throughout field where the can monitor soil conditions and crop growth wireless sensors are already being used in certain parts of USA and Australia. GPS system making farmers to better decision for mapping yield, mapping variable rate planting suggesting variable optimum fertilizers, and field mapping for record and insurance purpose.

**Particle farming (For extraction of gold):**

Particle farming is a system, which yields nanoparticles for industrial use by growing plants in defined soil, absorb gold nanoparticles through their roots and accumulate these in their tissues.

**Types of nanomaterials:**

Nano-scale materials can occur in nature; both natural and manmade processes (such as volcanic activity or diesel combustion) can also give rise to nanometer-sized materials unintentionally. For the remainder of this paper, 'nano-scale materials' or 'nanomaterials' refer to engineered or manufactured nanomaterials that are produced intentionally using the approaches described above. Currently, these intentionally produced nanomaterials can be categorized as follows. (EPA, 2007)

**Carbon-based materials:**

Carbon-based materials composed mostly of carbon, typically in the form of a hollow sphere, ellipsoid, or tube. Spherical and ellipsoidal carbon nanomaterials are called fullerenes (e.g., buckyball), while the cylindrical forms are known as nanotubes. These nanomaterials are used in improved films and coatings, stronger and lighter materials, and in electronics.

**Metal-based materials:**

Metal-based materials include metal oxides (*i.e.*, titanium dioxide), nanogold, nanosilver, and quantum dots. A quantum dot is a closely packed semiconductor crystal made of a few hundred or thousands of atoms (Steigerwald *et al*., 1988). Varying its size changes the optical properties of the quantum dot, thus these are useful in tagging specific molecules or cells.

**Dendrimers:**

Dendrimers are nanosized polymers with surface that has numerous chain ends which can be tailored to perform specific functions such as catalysis. Three-dimensional dendrimers can have a hollow interior cavity which can be filled with specific molecules, thus these may be useful as carriers such as in controlled drug delivery.

**Composites:**

Composites are nanomaterials that are combined with larger, bulk-type materials to enhance the properties of traditional materials. Nanoscale structures and morphology are interfaced with bulk materials (e.g., clay) to give rise to a composite material (e.g., nanoclay) with improved characteristics (e.g., stronger, lighter, with better barrier properties).

In general, the unique properties of these various types of nanomaterials give them novel electrical, catalytic, magnetic, mechanical, thermal, or imaging features that are highly desirable for varieties of scientific and commercial applications.

**Agricultural production:**

Nanotechnology can contribute to enhancing agricultural productivity in a sustainable manner, using agricultural inputs more effectively, and reducing by-products that can harm the environment or human health. Nanotechnology-based biosensors deployed in crop fields and in the plants to monitor soil conditions, growth, and disease vectors, can expand the concept of precision farming in which productivity can be optimized while providing inputs (*i.e.*,fertilizer, pesticide, irrigation, etc.,) and conditions (*i.e.*, temperature, solar radiation) only in precise levels necessary (Joseph and Morrison, 2006). Similarly, nanotube sensors implanted in the skin of livestock animals can detect changes in hormone levels or unusual amounts of antibodies, thereby helping to optimize breeding procedures and to initiate veterinary interventions before the onset of diseases that can hamper growth (Scott, 2005). Similar to nanomedicine applications, pesticides and herbicides can be formulated with nanoparticles to enhance the effectiveness of the active ingredients and allow targeted delivery and release, thereby requiring less dosage per application and minimizing runoff of unutilized excess chemicals.

On the other hand, nanotechnology can also benefit from agriculture. Researchers in University of Texas – El Paso have shown that plants grown in gold-rich soil formed gold nanoparticles which can be isolated from its roots and shoots (Kalaugher, 2002). Other types of plants and growth media are also being investigated. This opens up the possibility of 'particle farming' in the future, wherein plants grown on medium rich in specific compounds are harvested for nanoparticles, rather than using the current conventional production techniques which are expensive and can be harmful to the environment.

**Enhanced fibre and rubber products:**

Electrospinning techniques have been developed to produce nanofibres from cellulose derived from scrap materials from current techniques of spinning cotton (Frazer, 2004). Carbon nanotube-based fibers have been synthesized which are 17 times stronger than Kevlar (Dalton *et al.*, 2003). Researchers at Clemson University in South

Carolina is developing carbon nanofibre fabrics that generate electrical charge from the motion of the wearer, possibly leading to charging of small electronic devices. Glass nanofibres that change in colour depending on thickness are being developed at MIT; when woven into clothing.This could enable the wearer to change the colour of their clothes on demand.

Natural rubber impregnated with nanoparticles has been developed by Cabot tyre manufacturing company in collaboration with Nanoproducts Corporation to enhance the strength and wear properties of automobile tyres. Nanoclay composites (made by Inmat and Nanocor companies) mixed with rubber are also used to create a better seal on the inside surface of tyres. These advances result in tyres that require less amount of rubber to make, plus they are lighter and cheaper and with longer useful life, thus reducing the burden on the environment from discarded tyres. A lightweight nanomaterial called aerogel, which is composed of nano-air bubbles in a silica matrix, is being looked at for incorporation into tyre treads or possibly replacing rubber entirely in making tyres.

**Environment:**

Developments in nano-bioprocessing can lead to conversion of agricultural waste into energy and other useful by-products, thereby transforming waste that can adversely impact the environment into valuable end-products (Moraru *et al.*, 2003). Nanotechnology processes are used in converting waste fibers from cotton spinning into biodegradable cellulose mats that can absorb pesticides and fertilizers. Nanomaterials have also been used in the remediation of agricultural lands and groundwater contaminated by farm run-off. Photocatalysis using nanoparticles can be used to degrade pesticides and to treat wastewater (Warad and Dutta, 2005). Nanoscale iron particles can be used to catalyze the breakdown and oxidation of organic compounds such as tricholoethene, dioxins and PCBs in contaminated groundwater, after which the nanoparticles are degraded into a harmless form of naturally-occurring iron found in the soil (Zhang, 2003). Lanthanum nanoparticles that absorb phosphates in aqueous environments can be used for clean-up of ponds and lagoons; these may also have applications in preventing algae growth in commercial fish ponds (Joseph and Morrison, 2006). Current research at Prairie Swine Centre is looking at using various types of nanoparticles to control gases emitted from swine manure slurry, thereby potentially reducing emissions of odour and gaseous contaminants to the environment (Asis and Predicala, 2006).

**Insect and pest management:**

These include insect pests management through the formulations of nanomaterials-based pesticides and insecticides, enhancement of agricultural productivity using bio-conjugated nanoparticles (encapsulation) for slow release of nutrients and water, nanoparticle-mediated gene or DNA transfer in plants for the development of insect pest-resistant varieties and use of nanomaterials for preparation of different kind of biosensors, which would be useful in remote sensing devices required for precision farming. Traditional strategies like integrated pest management used in agriculture are insufficient, and application of chemical pesticides like DDT have adverse effects on animals and human beings apart from the decline in soil fertility.

Dr Micaele Buteler and Weaver of Montana State University tested the use of nanostructured alumina (NSA) on two insects pests common in the milling, food processing and storage of dry grains.NSA may provide a cheap and reliable alternative to commercially available insecticidal dusts.

Karte ® ZEON's Capsulated product (lamda-cylothrin), which provides control over a broad spectrum of primary and secondary insect pest of cotton, rice, peanuts and soybeans.

Gutbuster an encapsulated product, which breaks open to release its contents only when it comes into contact with alkaline environments, such as the stomach of insects. Controlled release of pesticides, herbecides and fertilizer delivery system which can respond to environmental changes.

Therefore, nanotechnology would provide green and efficient alternatives for the management of insect pests in agriculture without harming the nature.

**Fertizers:**

Nanomaterials could even be used to control the release of the fertilizer such that the nutrients are only taken up by the plant, and not lost to unintended targets like soil, water or microorganism. In nanofertilizer, nutrients can be in form encapsulated by nanomaterial, coated with a thin protective film and delivered as emulsions or nanoparticles.

**Plant and animal health:**

Nanotechnology can help in diagnosis, treatment, and monitoring of diseases of crops and livestock to ensure timely intervention when necessary. Nanoparticles have been designed to adhere irreversibly to target pathogenic bacteria, reducing infectivity of foodborne enteropathogens in poultry products (Qu *et al*., 2005). Thin films and nanoemulsions have been used to prevent adhesion of bacteria on surfaces of equipment. Additionally, selected nanoparticles of magnesium oxide and zinc oxide were found to be highly effective at destroying microorganisms; coatings made from these nanomaterials can impart anti-microbial and biocidal properties on surfaces.

This application has important uses at food production sites, in particular abattoirs and meat processing plants (Joseph and Morrison, 2006). Nanoshells with attached antigens were designed to seek out cancer cells and bind with them; when illuminated with infrared light, the nanoshells are heated, raising the temperature of the bound cancer cells and destroying them (Scott, 2005). Non-invasive bioanalytical nanosensors are being developed that could be placed in an animal's salivary gland to detect the presence of pathogenic bacteria and viruses before these had a chance to multiply and develop disease symptoms that become visible to the farmer. These smart nanodevices will act both as a preventive and an early warning system and can also be used to deliver drugs and vaccines in a controlled and targeted manner.

**Virus as nanomaterial:**

Viruses are simple and cellular interties, reproduce only within living cells because they are obligate intracellular parasites. All viruses have composed of a nucleic acid genome surrounded by a protein capsid. The nucleic acid of virus can be RNA or DNA, single stranded or double stranded, linear or circular. Capsid may have helical, icosahedral or complex symmetry. They are constructed of protomers that self assembly through non covalent bonds.

TMV has created great interest in the material sciences community since it is a robust in its native for that means it a good candidate for chemical modification indeed it is being used as template for the synthesis of CdS, PbS and metal clusters.

Plant and bacteria viruses are other types of viruses that are non pathogenic to animal that make them amenable for use in material sciences. They have been genetically and chemically modified for broad uses from vaccine to nanomaterials (Table 1).

For the genetic manipulation of the TMV coat protein for the deposition of nanoparticles, first of all use to U1 strain of TMV as parental construct for the creation of TMV1cys, TGT codon into TMV coat protein at 3'position through PCR based mutagenesis mutation technique. Now recreation of TMV1cys and generate infectious RNA transcripts, inoculate infectious RNA transcripts in *Nicotine tobaccum,* inoculated plant harvested at 20 days.

Reverse transcriptase PCR followed by sequencing was used to confirm and maintenance TGT codon into coat protein ORF purified virus. Fluorescent labeling of TMV1cys virion transcription of codon region of virus genome in *Nicotine tobaccum*. Fabrication of patterned capture surfaces. Containing single standard DNA complement to 5' end of TMV genomic RNA was fabricated. Specially selective assembly of TMV non templates via hybridization (separate protocol)

In this way we can say that ability of TMV1 cyst to function as a template for the deposition of nano particles, metal cluster like gold, platinum etc. Points for note here, genetic manipulation in virus (virus hybrid) does not change biological fitness of virus. Ability of TMV1 cys to function as template for the deposition of nanoparticles.

**Food manufacturing and processing :**

Nanotechnology can be applied in the food industry through precise manipulation of food molecules to create healthier, tastier, and safer food products. Nanoscale materials and techniques have been used in the development of novel and functional foods and in safe processing and handling of food (Moraru *et al*., 2003). Nanotube membranes were used in the separation of food biomolecules with functional value (e.g., proteins, vitamins, minerals, flavour and nutraceuticals) (Lee and Martin, 2002). Nano-based filters were also used for removing undesirable compounds from foods and beverages as well as in the purification of biofuels (*i.e.*, ethanol).

Nanoparticles are also being used to advance the concept of functional, 'on-demand' foods, wherein nanocapsules store flavours and nutrients inside food and are released at designated organs in the body when needed

**Table 1 : Description of landmarks uses of TMV in nanotechnology as nanomaterial for humankind**

| Microbes | Used as | Scientist | Year |
|---|---|---|---|
| TMV | Template for synthesis opf cds, pbs, fe203 and metal clusters | Shenton, W. *et al.*, Bittner, A.M *et al.*, | 1999 |
| TMV | Can function as an efficient template for controlled deposition of silica | Royston, E. *et al.*, | 2006 |
| TMV | Template for the fabrication of nanosized rod and dumble shaped gold particles | London, P.B *et al.*, | 2007 |
| M13Phase | As a phase display for expression of small peptides and antibodies | Arap, *M.A* | 2005 |
| CCMV | Incapcolation of iron oxide particles | Liepold *et al.*, | 2005 |
| CMP | Nano scaffold as single enhancement for micro array | Soto, C.M *et al.*, | 2009 |
| TMV | Nano scale protein assemblies from asercular per mutant of TMV | Dedeo, M.T *et al.*, | 2010 |

by the consumer (Moraru *et al*., 2003). Nano-encapsulation of nutrients is also being looked at as a means to deliver more efficiently to cells or organs those nutrients such as vitamins, omega fatty acids or compounds that are degraded by normal digestive processes. Nanospheres can used to encapsulate functionalized DNA fragments and can be effective delivery vehicles for oral immunization to treat food allergies (Roy *et al*., 1999).

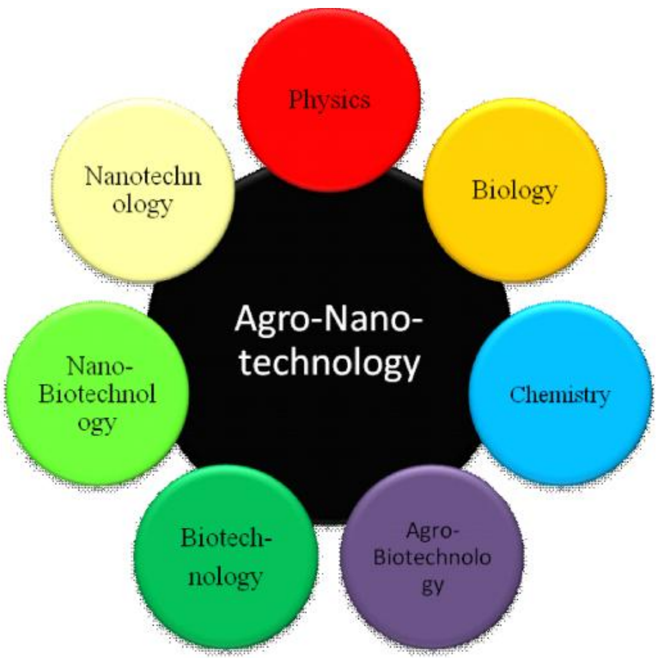


**Fig. 1 : Nanotechnology is interdisciplinary science, integrate with various sciences for Agro-nano technology**

## Food packaging:

Various packaging materials have been developed using nanotechnology to ensure safe handling of food items, to extend the shelf-life of food products, and to address the environmental burden from non-biodegradable packaging materials currently used in the food industry. Composite materials with silicon nanoparticles used for packaging were found to be more airtight, thus preventing food decay and extending the shelf-life of food products (Moore, 1999). Nanocomposite foam of potato starch and calcium carbonate has been developed; this material is lightweight and biodegradable, hence it can be used to replace polystyrene 'clam shells' currently used widely in the fast-food industry (Stucky, 1997).

Nanocomposite plastic can be manufactured with better strength and barrier properties (*i.e.*, permeabilities to various gases and moisture); as a result these materials can fit the requirements of specific products such as fruits, vegetables, beverage and wine, thus improving the preservation of flavour and colour of the product and extending their shelf-life. Plastics with incorporated nanomaterials were developed to have the required mechanical and barrier properties to replace the more expensive bottles and cans currently used for beers. Research using nanotechnology is being done not only to modify the permeation behaviour and the mechanical, thermal, chemical, and microbial properties of packaging materials but also to incorporate nanobiosensors to detect microbiological and biochemical changes in food items (Moraru *et al*., 2003).

## Nanofilteration and water purification used to clean ground water:

US company "Argenoide" is using 2 nm diameter aluminium oxide nanofibres (Nano Ceram) as a water purifier. Filter made from these fibers can remove viruses, bacteria and protozoan cyst from water. The French utility company "Generals desEaux" has also developed nanofilteration technology. Onedo developed ultrafilteration system with holes of 0.1 microns in size for water purification.

## Electrospining in cotton industry:

It is estimated that from harvesting cotton to finalizing over 25 per cent cotton fiber is lost to scrap of waste. At Cornell university in USA , a technique called electrospining has been developed that's make good use of the scrap material.

## Food safety and security:

Nanotechnology applications in the food industry is also contributing towards addressing the increasing consumer awareness of food safety and security concerns. Chip-based micro-arrays have been developed for rapid detection of biological pathogens in food. Quantum dots have been used for rapid detection of *E. coli* and other food-borne pathogens (Su and Li, 2004). Researchers are looking at nanobiosensors for detecting contamination in water supplies, food materials, and agricultural products. Biosensors have a biological component that reacts to changes in substances or presence of specific cells, and then produce a signal in a linked transducer.

Nanobiosensors can be designed to detect changes in the food, presence of pesticides and possibly genetically modified crops within the food system. Similar to the concept of the 'electronic nose', researchers are developing an 'electronic tongue' with sensors comprised of small electrodes coated with a polymer to detect small amounts of a wide range of chemicals, such as gases released when food is spoiled (Gardner, 2002). This electronic sensor strip can potentially be incorporated into food packages, which will change in colour when the food product is no longer fit to consume. Nanobarcodes (*i.e.*, cylindrical nanoparticles of varying width) can be used in tagging and tracking of food and agriculture products (Warad and Dutta, 2005) (Fig. 2). Nanoscale monitors can also be linked to recording and tracking devices to monitor temperature and other conditions to which the food items are exposed to from the food processing plant to the consumer (Scott, 2005).

**Smart packaging system and packaging film :**

The primary purpose of food packaging films is to prevent contents from drying out and to be protecting them from moisture and oxygen e.g. Bayer polymers developed Durethan KU2-2601 (packaging film).

**Detection of food contamination:**

Agro micron has developed the nanobioluminacense

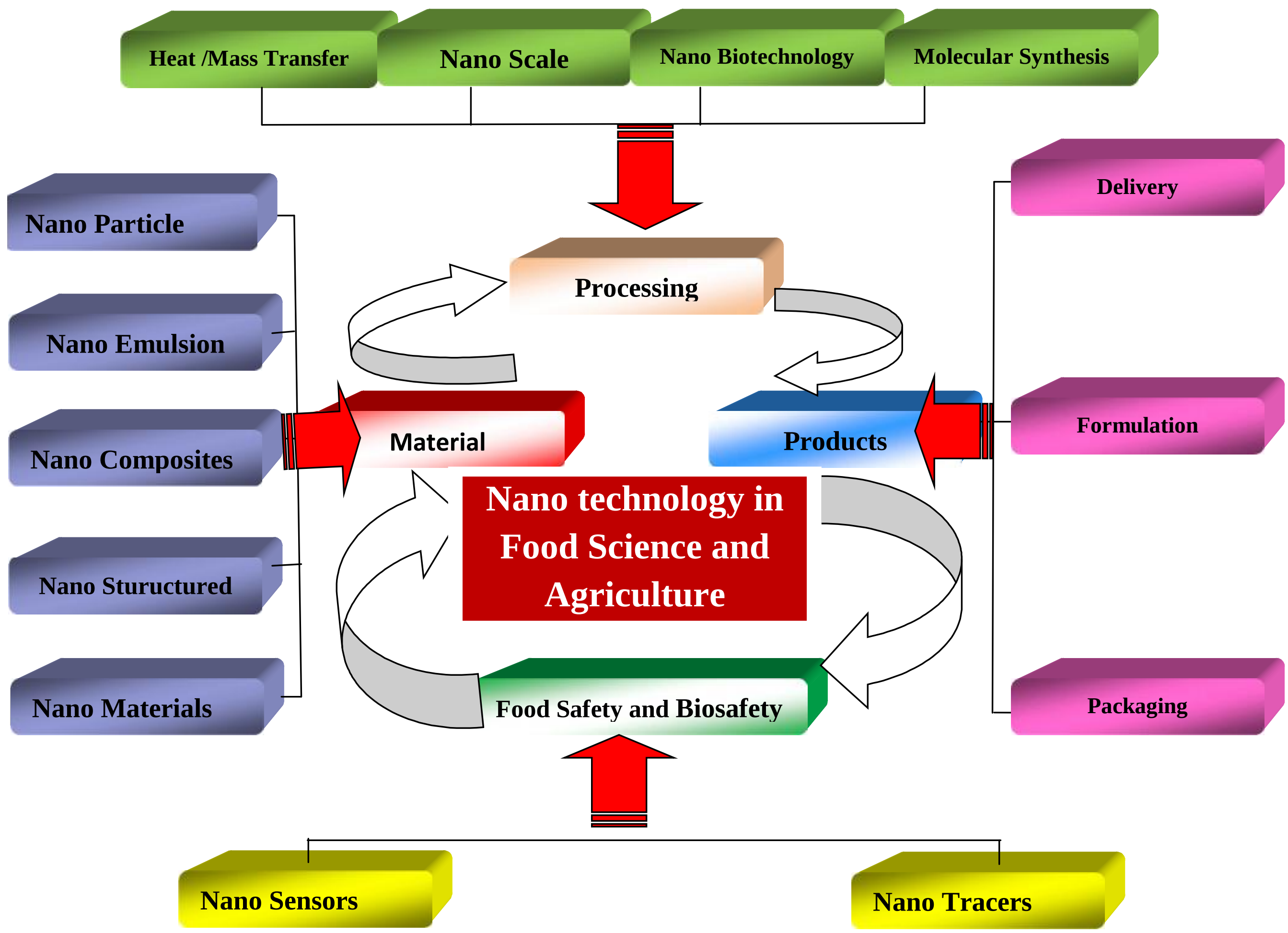


Image source: Moraru C.I *et al.*, Nanotechnology. A new frontier in Food Science "Food Technology", 2003,57,24-29

**Fig. 2 :** **Cyclic relationship of materials, techniques and processing, products and food safety and biosafety aspects of nanotechnology for food sciences (Health security) and agriculture**

detection spray which contains lumination protein that have been engineered to bind the surface of micro such as *Salmonella typhomurium* and *E. coli* when bound it emits a visible glow, thus allowing easy detection of contaminated food and beverages.

**Good food sensor:**

EU researcher in good food project have developed portable monosensor to detect chemicals , pathogens and toxins in food . The project is also developing a device using DNA biochips to detect pathogens.

**Application of nanotechnology in food industry:**

Nanofoods do not means automatically modified food or the food produced by nano machines. Instead nanofoods are the foods that are the produced process of packaged using techniques and tools based on nanotechnology.

**Packaging and food safety:**

Modifying the permeation behavior of foils, increasing barrier properties (mechanical, chemical, and microbial), improving mechanical and heat-resistance properties developing antimicrobial and anti fungal surfaces and sensing as well as signaling microbiological and biochemical changes.

**Terrorist attack on fruit supply:**

A researcher group at university of Leeds in UK has determined that nanoparticles of zinc oxide and magnesium oxide highly effective at destroying micro-organisms.

**Nanosensor for food market:**

Small nanosensors also being use by Honeywell to monitor grocery store in Minnesota this technology help us to identify which have expiring date. USA leading 1$^{st}$ position followed by Japan and European Union securing 3$^{rd}$ position in the world. In developing world, China's share of academic publications in nanoscale science rose from 7.5 per cent in 1995 to 18.3 per cent in 2004, taking country from 5$^{th}$ to 2$^{nd}$ place in the world, however, India now focus on applications.

**Advance nano particle and material in agriculture:**

Nano materials working in wide spectrum and dynamic way, application of nano materials by different ways. In 2008, thousands of peoples got stick as a result of melanine contamination in dairy products from china. Na Li and his group, of University of Miami have designed path to detect melamine in milk using gold nanoparticles. In presence of melamine, the mixture changes from pink to blue. On the other hands, Prof Harold Craighead and his colleagues of Cornell University have developed a nanoscale resonators that can detect prions (Bovine Spongiform Encephalopathy) in human at amounts lower than what could be detected to date. Nanocor sells a product called imperm, a nanocomposite of nylon and nano clay. That can be used in plastic bottles to improve the gas barrier properties of the bottles and extend product shelf life. Beer can keep normal for as long as 30 weeks compare keep in normal plastic bottles for 11 months.

Potential of nano particles have intelligent for good and fresh packaging. Nanosensors could indicates temperature, freshness, ripeness and contaminates or pathogens right on packages. Kinect sells food storage containers that contain silver nano particles, which are antimicrobial, to keep foods fresher longer. Sherman Industries of Israel sells Canola active oil, which's uses nanodrops to encapsulate and carry vitamins, minerals or phytochemicals which would not dissolve in the oil. Nanosciences helps to reduces oil in all types fast food. Sunnyvale California, has created nanoporous ceramic pellets that can added to the frying oil to prevent oil molecules from clumping together while in use. Dr. Jeremy Tzeng from Clemson University uses the nanoparticles added to chicken feed and mimic cell surfaces inside the chicken. These nanoparticle react as pathogen disabling nanoparticles to keep chicken healty. The tiny pathogens (germs) get confused and bind to the particles instead of real cells then flush out as they go through the digestive system-keeping chickens safer and healthier for human consumption.

**Societal effects:**

Coming nanotechnologies in the agricultural field seem quiet promising. However, the potential risks in using nanoparticles in agriculture are no different than those in any other industry. Through the rapid distribution of nanoparticles to food products – whether it be in the food itself or part of the packaging – nanoparticles will come in direct contact with virtually everyone. The environmental group ETC (Action Group on Erosion, Technology and Concentration) is deeply concerned with the implications and regulation of nanotechnology used in food. Currently, there are none. Their main concern is that of the unknown. In a publication in November 2004, the ETC stated that "the merger of nanotech and biotech has unknown consequences for health, biodiversity and the environment". Since there is no standardization for the use and testing of nanotechnology, products incorporating the nanomaterials are being produced without check.

**Conclusion:**

The ability for these materials to infiltrate the human body is well known, but there is really no information on the effects that they may have. While there is no evidence of harm to people or the environment at this stage, nanotechnology is a new and evolving area of study that could cause a great deal of harm due to its still ambiguous chemical properties. With the current application and advancements soon to come, nanotechnology will have a great impact on the direction that agriculture will take. Scientists are blazing a trail for a new technology and looking at every possible avenue to improve upon current methods in every possible field. In the field of agriculture, there are still many possibilities to explore and a great deal of potential with up-coming products and techniques.

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**Received :** *17.08.2012;* **Accepted :** *02.12.2012*