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Review of Potential Use, Benefits and Risks of Nanosensors and Nanotechnologies in Food

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Subject review

Usage of nanotechnology in food with all of its possible different applications has potential to significantly change today's ways of food manufacturing and packaging as well as to alter fundamental functionality of food. Application of nanotechnology in food increases food safety, allows better delivery of new functional ingredients and extends product life. Food nanotechnology implies nanotechnology application in food package manufacturing and nanotechnology application directly to food products. Production of nanopackages implies usage of nanosensors for detection of contaminants and pathogens, nanosensors for product tracking and control, nanoparticles for improvement of mechanical properties and biodisintegration of a package. New food ingredients in food can be delivered by means of colloids, liposomes, nanoemulsions or nanolaminats, thus transforming food products into health preparation or a medicine. Increased research in the field of nanofood application and a possible nanofood mass production can perhaps lead to health risk for consumers; hence it is important to pass new scientifically based regulations which will define usage of food nanotechnology.

Pregled potencijalnih primjena, koristi i rizika od nanosenzora i nanotehnologija u hrani

Pregledni članak

Upotreba nanotehnologije u području hrane sa svojim mogućim raznovrsnim primjenama ima mogućnost da uvelike promijeni ne samo dosadašnji način proizvodnje i pakiranja već transporiranja i čuvanja hrane. Upotrebom nanotehnologija u hrani povećava se sigurnost hrane, omogućuje kvalitetnija dostava novih funkcionalnih sastojaka pomoću hrane, te produljuje vijek trajanja proizvoda. Pod pojmom nanotehnologije u hrani podrazumijeva se primjena nanotehnologija u proizvodnji pakovina za hranu i primjena nanotehnologija izravno na prehrambene proizvode. U proizvodnji nanopakovina upotrebljavaju se nanosenzori za detekciju patogena i kontaminanata, nanosenzori za sljedivost i kontrolu proizvoda, nanočestice za poboljšavanje mehaničkih svojstava i biorazgradivosti pakovine, te nanočestice antibakterijskih svojstava. Dostava novih sastojaka u hranu obavlja se pomoću koloida, liposoma, nanoemulzija ili nanolaminata, čime prehrambeni proizvod postaje zdravstveni preparat ili lijek. Povećanje istraživanja primjene nanohrane nose sa sobom i moguće opasnosti od uzimanja nanohrane po zdravlje potrošača, te će se morati donijeti znanstveno utemeljeni propisi koji će definirati upotrebu nanotehnologija u hrani.

1. Introduction

Nowadays it is easy to imagine food mixture that can change taste as needed or desired by a consumer, activate antibodies and change food color if bacteria are detected thus marking food unsuitable for eating. This is made possible thanks to nanotechnology. According to [1], nanotechnology refers to a set of technologies which manipulate, produce and control materials within dimensions of 1nm up to 100 nm. Nanoscience studies/researches phenomena and manipulation of materials in an atomic, molecular and macromolecular scale in which material attributes are significantly different in comparison to a big, normal (macro) scale [2]. Nanoscience is a derivative of a multidisciplinary approach to nanomaterials from basic natural sciences like physics, chemistry, biotechnology and engineering.

Materials on the nano-scale, the so-called nanomaterials, whether biological or artificial, have unique and new properties that sometimes significantly differ from the same materials on the macro scale. In a macro world there are many types and subtypes of technology (e.g. food production technology, electrical power production technology, building technology), thus it is important to understand that nanotechnology includes not only one technology but it implies all technologies used on the nano-scale (1-100nm). According to [3], due to their size, behavior and properties of nanomaterials are placed between the property of nuclear quantum effects (quantum physics) and conventional properties of a macro world, where laws of classical physics apply. It is this area that scientists around the world are especially interested in. Nanotechnology application in food is a bit slow and it is mainly focused on specific areas, while nanotechnology applications in other areas of industrial production (e.g. microelectronic industry, pharmaceutical industry) are well recognized in future applications.

Potential (and current) nanotechnology application in food will be described in this paper, as well as their potential impact on human body and the necessity to bring future nanofood regulation. Introduction into nanotechnologies is followed by Chapter 2 which presents current and possible nanotechnology application, food packaging and ICT (Information and Communication Technology) in food. Chapter 3 gives a summary of nanofood potential health risk and Chapter 4 brings an overview of nanofood regulations.

2. Current and possible nanotechnology applications in food

According to [4], nanofood is defined as food that is produced, processed or packaged with use of nanotechnology techniques or tools. Nanotechnology application in food has great possibilities in the areas of food safety, disease control, new tools for molecular and cell biology, new ways of entering useful dietary additives, new ways of detecting pathogens, etc.

Although in [4-5] and other sources nanofood and its application is classified in many ways, for a better and simpler overview of nanotechnologies in food there is a need to introduce terms such as nanotechnology in food packaging and nanotechnology in food products. Exact classification is almost impossible since the areas of the aforementioned terms overlap (as can be seen in Table 1).

2.1. Nanotechnologies in food packaging and food contact materials

Research of nanotechnology applications in food is most advanced in food packaging and food contact materials [6]. The basic goal of this application is to enhance food safety and extend product life which then includes nanomaterials with antibacterial properties, nanosensors for microorganisms and chemical detection, nanosensors for measuring the inner atmosphere and materials for extension of product life.

Table 1. Areas of nanotechnology application in food packaging and food products

Tablica 1. Područja primjene nanotehnologija u pakovinama i prehrambenim proizvodima

Nanotechnologies in food packaging and food contact materials / Nanotehnologije u pakovinama i materijalima u dodiru s hranom	Nanotechnologies in food products / Nanotehnologije u prehrambenim proizvodima
- food safety/sigurnost hrane - “smart materials” – disease control / “pametni materijali” – kontrola zaraze - extension of product life / produljenje vijeka trajanja proizvoda - environmental protection / zaštita okoliša	- food safety / sigurnost hrane - disease control / kontrola zaraze - extension of product life / produljenje vijeka trajanja proizvoda - methods of production / načini proizvodnje - food supplements / dodaci hrani

2.1.1. Nanosensors

Food packages equipped with nanosensors are designed for control of inner and external conditions of food products [7]. Nanosensors in food packages can be divided into nanosensors for detection of atmospheric impacts (external conditions) and nanosensors for microorganisms and chemical detection inside the package (internal condition). Every sensor smaller than 1000 nm is considered to be a nanosensor.

Nanosensors for detection of external conditions

By decreasing dimensions, a great advancement in the development of computer technology enables potential application of sensors in food which will log all atmospheric impacts on the product, from the factory to the final customer. For example, if micro- or nanosensors for temperature, moisture or other measurement devices are added to freshly picked fruit, then while receiving fruit salespersons would be able to read data to check freshness of fruit and conditions fruit was transported in [8], and based upon these data they could make a decision either to take or to refuse the goods in question. This kind of sensors is being developed [9], and for data transmission cheap radio frequency identification (RFID) tags are used, which are very flexible, small and almost invisible, but still much greater than 1000 nm.

Nanosensors for detection of internal condition

Another two kinds of nanosensors in food can be recognized on the nano-scale depending on the type of detection. These are chemical nanosensors and nanobiosensors [10]. Chemical sensors and biosensors are produced in a similar way by putting chemical or bacterial detector (reagents) on the probe, which in reaction with the targeted chemical element or bacteria causes a change on the nanosensor output. Similarly to [11], Figure 1 shows an example of nanobiosensor mode of operation.

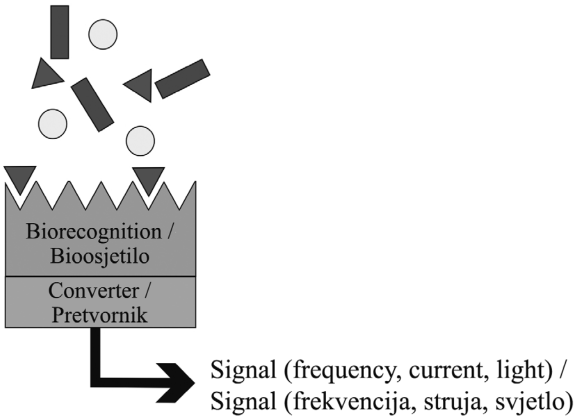

Figure 1. Mode of operation of a biosensor

Slika 1. Princip rada biosenzora

Optical nanosensors have potentially greatest application with chemical detection or biodetection [12]. In reaction with chemical or biological reagents they change their color. According to [13], optical nanosensors are produced in two ways – by thermal suppression or chemical erosion. Both of these ways give optical threads with probe peak size around 30-40 nm.

Usage of nanosensors in food packaging will result in so-called “smart materials”. This kind of food package could detect unsafe bacteria in the product (e.g. salmonella) and change the color of a package (marking that the food product in question is not safe for consumption). Detection of a chemical element within the package is also possible [14], so in that way it is possible to detect a high concentration of oxygen which is the cause of package strapping or breaking.

Logging and processing of data gathered by nanosensors

The greatest benefit would be accomplished by logging data from external and internal nanosensors, which will result in traceability and safety of such food and in that way the concept “from farm to fork” can be fully incorporated.

Results of chemical [11] or bio [10] nanosensors detection must be transferred to the mainframe computer for the purpose of processing.

Wireless data transfer from food sensors can be done by many protocols, but the cheapest and the most explored way is data transfer via radio frequency identification tags (RFID). RFID tags are electronic chips that transfer high frequency signals, that can be read from the distance of a few meters and during reading they do not need to be in the sight of the reader [8]. They usually consist of an electronic chip for data logging and processing, modulation and demodulation of the signal and other parts of specific functions (e.g. antenna or signal converter).

Three types of RFID tags can be found:

- active RFID tags: have a battery and can send data independently or store data in memory,
- passive RFID tags: do not have a battery and for data transmission they require external power supply (usually a reader), which induce data transfer,
- BAP (battery assisted passive) tags: have a battery, require external power supply for data transfer and have a large range of reading.

Two scenarios for RFID tags application in food packages are:

1. Usage of active RFID tags which will be incorporated in the food product package material and in combination with a great number of nanosensors or microsensors they will log data from sensors. In that way, without any doubt or error, any discontinuity in transport or a warehouse (high temperatures, package strapping, high bacteria concentration, etc.) can be determined. This way is in use in some drugs packages [15].
2. Usage of passive or BAP RFID tags on packages in combination with nanosensors or microsensors and sending data to the RFID reader and/or mainframe computer. Food packaged with these RFID tags must be under constant supervision of RFID reader [16].

The most difficult problem in realization of both scenarios whereby a great number of sensors are used on a small surface will be a very large number of single signals, or the so-called information fusion [17]. Correct reading of signals and processing of information fusion from different sensors represents a kind of a problem which explorers in other areas confront [18-19]. Due to a great number of food products, signal detection and processing from this kind of products in big supply chains (supermarkets or warehouses) may require more computers connected in the computational grid.

The benefits from exploring this and other ICT technologies in food processing and packaging are enormous because it will be possible to view product traceability [20], food safety of products [21] and potential food-borne epidemics. The fact that usage of this kind of technology will not increase the price of food because RFID tags are very cheap [22] is another important factor for future development. At the moment, the smallest micro RFID tags are approximately 50 x 50 μm or 50000 x 50000 nm [23].

2.1.2. Nanopackaging that extends product life

Nanopackaging with extended material properties

Production of nano polymer plastics which are very thick on the nano-scale is developing today [24]. The result of this is impermeability of compounds from packagings to the product itself preventing thereby oxidation or reaction of a product to packaging and maintaining the original properties of the product. The final result is extended product life [25]. Nanoclays, nanonylons or nanotubes are usually used for production of nano polymer plastics. They are all placed on the inner wall of packaging or added during package production. Nanoclay, nanonylon or nanotubes improve mechanical stability of the package and decrease reaction of the package material and food product. Moreover, additional nanoparticles (e.g. nano silver, nano sensors), can be added to this type of material and then the package could have antibacterial, nano sensor or similar characteristics [26]. Great attention is given to exploration and production of nanopackage material which could, by adding nanoparticles in biopolymers, gain better characteristics than polymer in way of solid mechanics and food preservation but could still be biodegradable [25].

These types of "new" plastic materials are already applied in some products and we are most familiar with production of plastic bottles which, by adding nanoparticles, become harder than the glass and reaction of plastic and liquid, which decrease product life in the past, is minimized. Product life of beer in a new bottle is increased for six months.

Nanopackagings with antibacterial characteristics

There are two ways packagings with antibacterial characteristics develop:

1. Chemical compounds or antibodies can be added to packaging material and they can be released if, in combination with nanosensors, microbes, bacteria or virus is detected. This implies that release is caused by some event.
2. What happens more frequently is that nanometals and/or nanometal oxides with antibacterial activities are added to packaging materials like nano silver, nanozink, nano magnesium dioxide, nano titanium dioxide and others which have great antibacterial characteristics [27]. These nanopackagings are not designed to release antibacterial materials; on the contrary, the whole package has antibacterial characteristics throughout the entire product life. The most known and most frequently used compound is nano silver. In its natural form silver is a metal with antibacterial characteristics. In the past there were lots of examples referring to usage of silver for food preserving, e.g. a silver coin put in milk to increase its shelf life.

Nano silver consists of particles of silver with 2–20 nm in diameter and the smallest viruses, like rhinovirus, are 25 nm, as shown in Figure 2.

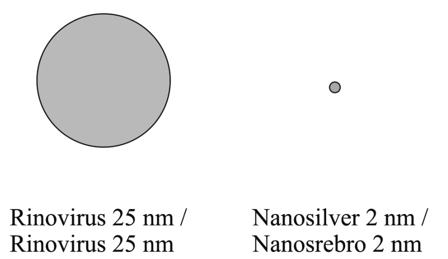

Figure 2. Comparison of sizes of Rhinovirus and a particle of nano silver

Slika. 2. Usporedba veličine rinovirusa i čestice nanosrebra

Three mechanisms of silver effect are detected in [28] and other references:

1. Catalytic Oxidation - Atomic (nascent) oxygen adsorbed onto a bed of silver atoms or ions in solution reacts readily with the sulfhydryl (H) groups surrounding the surface of bacteria or viruses to remove the hydrogen atoms (removed as water) causing the sulfur atoms to form an R-S-S-R bond; respiration is blocked and the bacteria expire.
2. Reaction with Bacterial Cell Membranes - There is evidence that silver ions may attach to surface radicals of bacteria, impairing cell respiration by blocking its energy transfer system and stopping in that way normal action of a cell and its propagation. It should be noted that mammalian cells are not affected by silver because the protective cell walls block entry of large ions such as silver.
3. Connection with DNA of contagious organisms for the purpose of stopping unwinding of DNA spiral. It is still unknown how silver connects with DNA without breaking conjunctions that hold the spiral together. The studies show that this connection stops division of the spiral which is the basic step for cellular propagation.

Studies also show that silver mostly prevents the growth of bacteria by deactivation of enzyme metabolism of bacteria which leads to destruction of cell membranes and it disables its reproduction. It is believed that the viruses are destroyed by nano silver, because silver particles cause the collapse of the protective protein shell of the virus, which prevents it from multiplying. Some viruses are immune to nano silver.

Nanomaterials in food production that are mostly present in today's market are nanoparticles in food contact materials. Their usage is mostly antibacterial. The most frequently used nanoparticle is nano silver which is already applied in food contact materials (e.g. cutting boards, freezers, baby bottles, cutlery, etc.).

2.2. Nanotechnologies in food products

Nanotechnologies that are applied directly in food products are usually part of delivery systems of functional ingredients (drugs, vitamins, antibiotics, antioxidants, aromas, proteins, etc.) which are key components of a wide range of industrial products like pharmaceutical, cosmetics or nutrition products. Functional ingredients can be found in different shapes, so that they can be found in different polarity (polarized, non-polarized or amphiphilic), in different shape (solid, fluid or gas) or in different molecular weight. Functional ingredients are not commonly used in their basic shape. Because of that the most common way is that they are included in some kind of a delivery system.

A delivery system must perform several tasks [29], i.e.:

1. Serve like a vehicle which carries functional ingredients to a specific place of action,
2. Must protect a functional ingredient from chemical or biological decomposition during the transport,
3. Must be able to control release of a functional ingredient such that an ingredient is released progressively or that release is caused by some event (e.g. decrease of pH, increase of temperature, contact with a chemical, etc.),
4. A delivery system must be compatible with other product attributes (look, texture, taste and product life).

Several delivery systems are developed and ways/things like colloids, biopolymer matrix, emulsions, lipids and others are used as carriers for transport.

2.2.1. Colloids

According to [30], a colloidal system is a system of two or more components (solvent and solution) in which one component is evenly dispersed within the whole volume of the other component. The size of particles in nano colloids ranges between 1 and 100 nm (milk is an example of a natural colloidal system where particles of lactose are around 1 nm).

Nanoparticles like nano silver, nano gold, nano biopolymers and others are added to the product and are dispersed throughout the whole product volume. Major advantages of colloidal systems are that they are formed spontaneously, they are thermally stable and transparent. A disadvantage of colloidal systems is a need for a large amount of solvents for their formation, which can result in problems with taste, price of production and legality (exceeding the maximum level).

2.2.2. Liposomes

Liposomes are created from polar lipids plentiful of which can be found in nature, most of them being phospholipids in soy or eggs. Liposomes are spherical, polymolecular aggregates with a bilayer shell configuration [31]. Depending on the preparation method, liposomes can be single or multilaminant, i.e. they can have one or more double-layered shells. Liposomes vary in dimensions from 20 nm to few hundreds μm. They can carry many functional ingredients in their interior. A charged ionic cluster, resolved in water, can be put inside liposomes because polar lipid charges are used in creation of liposomes. They are usefully used for encapsulation and provide microenvironment in which proteins can continue to act without any outside influence. According to [32], liposomes are successfully used to increase shelf life of dairy products by encapsulating lactoferrin, a bacteriostatic glycoprotein as well as nisin Z, an antimicrobial polypeptide.

2.2.3. Nanoemulsions and nanoencapsulation

Emulsion is a compound of two fluids which cannot be mixed (e.g. water and oil). It is an unstable compound which is soon after mixing divided into basic ingredients. Emulsifier is needed to make such compound stable. Emulsifier is a substance which disperses one fluid into another in small droplets. Emulsions with droplet size less than 100 nm to 500 nm is caused by usage of a microfluidizer. These kinds of emulsions are called nanoemulsions. Functional edible ingredients are added inside the droplet and delivery systems can be made in two ways [29].

a) Usage of multiple emulsions can make systems with new encapsulation and delivery characteristics. Most frequent examples are oil-in-water-in-oil (O/W/O) and water-in-oil-in-water (W/OW). Functional food components could be encapsulated within the inner water phase, the oil phase, or the outer water phase, thereby making it possible to develop a single delivery system that contains multiple functional components. This technology could be used to separate two aqueous phase components that might adversely react with each other if they were present in the same aqueous phase. This way of encapsulation makes it possible to deliver functional ingredients to three different target areas (e.g. mouth, stomach and intestine) with only one product.

b) Usage of multilayered emulsions can make new delivery systems. Delivery systems in multilayered emulsions usually consist of an oil droplet surrounded with a nanometer thin layer (shell) of different polyelectrolyte. These layers are formed by using a layer-by-layer (LbL) electrostatic deposition method that involves sequential adsorption of polyelectrolytes onto the surfaces of oppositely charged nanoparticles. A sequence method of oil droplet LbL encapsulation is shown in Figure 3. This method can be repeated thus making emulsions with three or more layers.

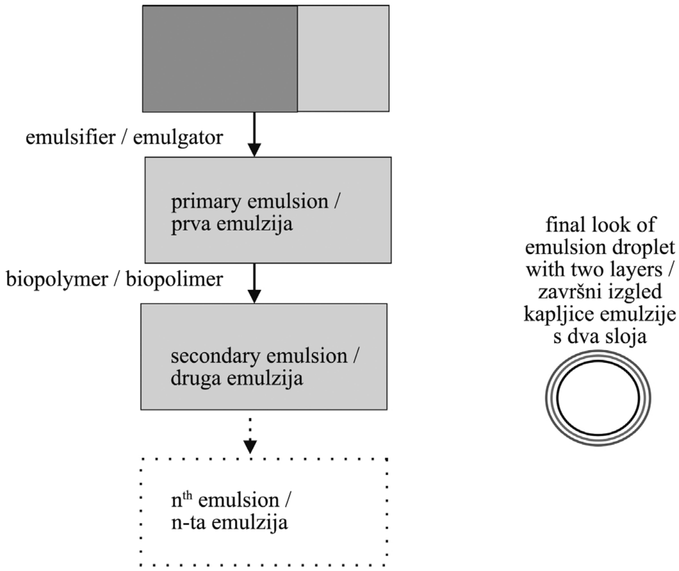

Figure 3. An example of multiple encapsulation in nanoemulsion

Slika 3. Primjer višeslojne enkapsulacije u nanoemulziji

It is possible to develop so-called smart delivery systems by developing special nanolayers into which functional ingredients are added. Functional ingredients added in layers and inside the core of a multilayered delivery system can be released as an answer to a specific event. Two possibilities are predicted:

a) Total breakup of a shell – in a specific event all layers are broken and all ingredients are released.

b) Gradual release – in a specific event only one layer is broken and another event will break the second layer.

In the future consumers themselves could control release of some ingredients. For example, if a biopolymer shell under the influence of certain microwaves can be broken, then a consumer can add to food, by a microwave oven, a certain taste, vitamins, drugs or some other ingredients. Ultimate result will be multiple encapsulations of different functional ingredients which can be released by a consumer depending on his/her health or dietary needs (drugs, vitamins, etc.). This production technology would use food ingredients (proteins, polysaccharides, etc.) and process production (homogenization and mixing) which are commonly used in production of food product emulsion. A thin line between food and drug will be fully broken with this food production. An example of conditioned shell break and ingredients release is shown in Figure 4.

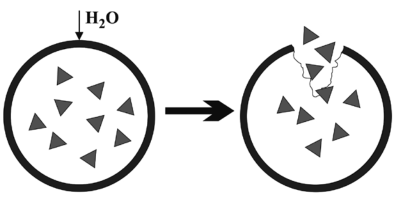

Figure 4. Shell breakdown –contact with water as the trigger

Slika 4. Pucanje ljuske - okidač je dodir s vodom

2.2.4. Biopolymer matrix – nanolaminates

Nanolaminates are [31] nanomaterials which are added directly to the surface of food in order to provide food safety, add functional ingredients and protect food from atmospheric influence (air, UV, temperature, moisture, etc.). In this way products can have extended shell life and freshness. Basic conditions for food enveloping with nanolaminates are safe consumption of nanolaminates and no change of taste of the basic food product. Nanolaminates usually consist of two or more layers of nanometer dimensions which are physically or chemically attached to each other. Different forces of attraction are used as ways of "bonding" and it is usually a result of electrostatic attraction of oppositely charged layers. Materials which can be used for creation of nanolaminates are polyelectrolytes (proteins, polysaccharides), charged lipids (phospholipids, surfactants), and colloidal particles (micelles, vesicles, droplets)

The procedure for developing nanolaminates is very similar to the procedure of shell encapsulation in nanoemulsions with all benefits and disadvantages offered by that way of functional ingredient delivery. Polyelectrolyte with oppositely charged particles is commonly added to every layer of functional ingredients and in that way it strongly spans advantageous layer as shown in Figure 5.

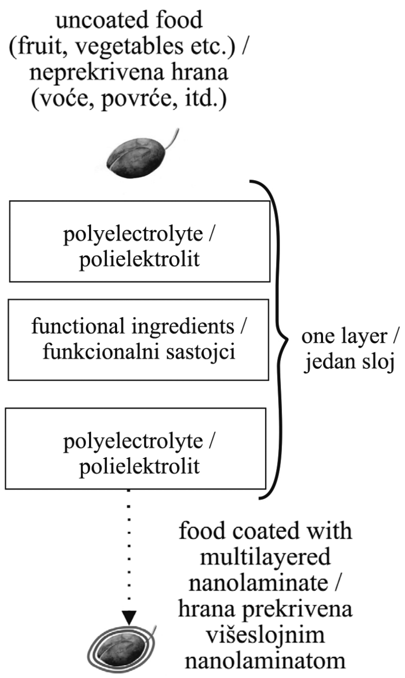

Figure 5. Principle of nanolaminates creation

Slika 5. Princip nanošenja nanolaminata

3. Possible dangers from nanofood

Research in the application of nanotechnology has become more and more interesting, while at the same time a study on the impact of nanotechnology on environment and human health lags behind a little. Since there are many nanotechnology applications in food, for each new method of application a new research on the impacts on human health should be carried out, which takes several years of research.

Possible greatest dangers from food nanotechnologies are:

With their huge surface area, nanoparticles in food can have an impact to human body or to environment.

It is possible that some nanometal or nanoparticle, which in normal size does not have a toxic impact, shows that impact on the nano-scale because of this huge surface area [33].

The example from Figure 6 shows the easiest way to explain what surface effects of nanoparticles are. Imagine a cube of 1x1 m page size; let us calculate its surface area. The size is 6^2 m. Imagine now that the same volume is filled with smaller cubes with the length of 0.5 m page sizes and then set them to form again a cube of one volume meter. Let us calculate a new total surface area of a cube which is made up of cubes whose page size is 0.5 m. 0.5 x 0.5 x 6 = 1.5 m^2, which is the surface area of one smaller cube, and 1.5 x 8 (number of cubes) = 12 m^2, the total surface area. From this simple calculation it is shown that if you reduce the length of the page for 2, at the same time the size of the control surface area will increase by 2. Now imagine nanoparticles in the form of a cube and with the length of the page of 1 nm.

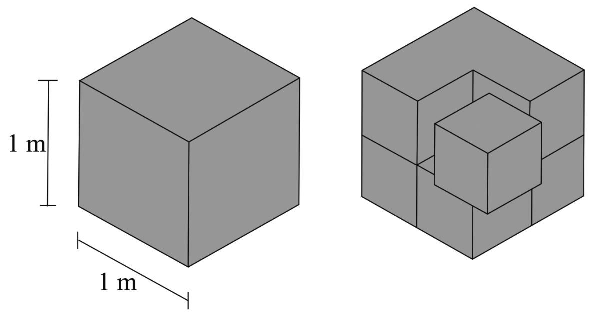

Figure 6. Display of various surfaces of cubes of the volume 1 m^3

Slika 6. Prikaz različitih površina kocaka volumena 1 m^3

Unknown nanoparticles effect to organisms

As already mentioned, research in the field of nanotechnologies and their impact on human body cannot follow research of nanotechnology applications.

- mass and the number of particles can be calculated when they are in their basic shape (nanopowder), but measurement of free nanoparticles in a biological medium for the purpose of defining dose exposure can be accomplished with difficulty, because the required equipment has not been fully developed. Also, concentrations are very often under the limit of instrument detection or the parameter is hard to measure.
- metal nanoparticles show migration of chemical elements from nanoparticles.

Studies show different results of exposure to same the nanomaterial [34-36]. Different conclusions were drawn: from those that nanoparticles in food are safe with minor side effects to those that the same nanoparticles are dangerous to liver and some other organs. Because of that, scientists have shown initiative to make a research database so that all results can be independently confirmed. This kind of database will be useful for connection of different research teams working on similar projects.

Among other questions, one question arises as to whether it is possible that smallest nanoparticles (size 1 – 5 nm), after intake in human body, freely pass the body between organs and if it is true, will certain nanoparticles retain in one organ until it becomes a threat to health.

The impact of nanometals on organism is mostly explored. To get a broader vision of how much effort and time should be taken to research a single nanometal impact, it suffices to say that dozens of researches are needed for one nanometal. It is possible, with all researches, that the impact on health from a particular nanoparticle is shown afterwards after a long exposure, as it was the case with DDT [37-38] or heavy metals.

In their preliminary studies of potential risks from nanomaterial application in food world's leading food agencies and food institutes (EFSA, FSA, FDA, FSAI, BfR and others) [39-41] agreed that the existing knowledge is not enough to make specific conclusions. Furthermore, nanomaterials, which in normal size do not have a harmful effect, must be researched because of their small size and huge surface area. Specific risk assessments on the case by case scenario should be made and they should be based on research (when those researches are completed and made available).

4. Food laws and nanotechnologies in food

Professor Staffan Skerfving, chairman of the European food safety authority working group on nanotechnologies, claims that it is currently impossible to detect chemical nanoparticles in food [42].

Possible problems in nanofood application are best shown in nonexistent law acts that will regulate this application. If some material is approved for usage in food, then the same nanomaterial can be used in food or feed without special permission or labeling on food package (in which nano sign will be marked).

European Union leads the way in forming laws for nanofood application. European Commission has acknowledged guidelines providing [43]:

- a list of EU laws and directives which will be mostly used and applied during making laws for nanomaterials and nanotechnologies application,
- which researches in the field of environment, health and security must be done to provide support for a new legal frame,
- which gaps in security and nanotechnology knowledge must be filled in, in cooperation and collaboration of institutes and research teams.

In near future, adoption of a series of EU laws can be expected. These laws will regulate nanofood market and offer protection to consumers. Countries outside the EU are lagging behind with preparation of law directives referring to nanotechnology or maybe they will not regulate nanotechnologies in food [44] at all in spite of warnings from the academic community.

5. Curent and future developments

The definition of nanotechnology says that it is a technology of materials ranging between 1 – 100nm. But potential usages and terms nano are also used for technologies extending the limit of 100 nm (up to 1000 nm). Nanotechnology treatment and materials are already used in some food packagings and in food contact materials. This kind of products can be found on the USA, China, Japan and South Korea markets and the study carried out in 2007 on the territory of Great Britain and the EU [6] shows that this kind of products are found in a very small quantity. Assessments show that in few years direct nanoparticles application in food production and food packaging will be conducted in practice. New delivery systems of functional ingredients, antibacterial characteristics and smart packaging have a potentially wide application in food production with all benefits and potential disadvantages. There are two great challenges that have to be addressed by the European Commission and all European inhabitants: could a lack of knowledge on nanoparticles impact on human body and connected consumers concern slowly stop nanofood application in the EU, at least until researches are over, and could the EU afford banning usage of a new technology which has not been scientifically proved as harmful. Stagnation in research of potential nanotechnologies applications in food would be caused by banning and the result will be European stagnation in that field. The ultimate result will be import of knowledge and patents for nanofood processing.

It cannot be claimed with certainty either that nanotechnologies are fully safe for health or that they are harmful. Since in potential nanofood application many technologies and materials can be found, it is expected that some of nanotechnologies will be found unsuitable for human diet so acceptable tolerant daily intakes should be found. Consumers will have the ultimate judgment about nanotechnologies application in food, and they will decide how much and in what way food will be nano modified. Because of that it is crucial to educate consumers, approximate the way of production and nanofood function and introduce them with all benefits nanofood can offer not just as a means for taste or conservation but as a drug and a delivery system of important ingredients for organism. According to some estimates, in the whole world there are more than 600 products which have nano characteristics, which includes food contact materials with 80% of the mentioned number. The number of products is constantly increasing.

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REFERENCES

[1] HOCHELLA, M. F. Jr.: *Nanoscience and Technology: the Next Revolution in the Earth Sciences*, Earth and Planetary Science Letters 2002; 203(2): 593-605.

[2] CHONG KEN, P.: *Nano Science and Engineering in Solid Mechanics*, Acta Mechanica Solida Sinica 2008; 21(2): 95-103.

[3] HE, J-H.; WAN, Y-Q.; XU L.: *Nano-effects, Quantum-like Properties in Electrospun Nanofibers*, Chaos, Solitons & Fractals , 2007; 33(1): 26-37.

[4] TIJU, J.; MORRISON, M.: *Nanotechnology in Agriculture and Food 2006*, Nanoforum report, Available at: http://www.nanoforum.org/dateien/temp/nanotechnology%20in%20agriculture%20and%20food.pdf (Accessed on:19 September 2009).

[5] Friends of the Earth, Out of the Laboratory and on to Our Plates: *Nanotechnology in Food & Agriculture*, 2008. Available at: http://www.foeeurope.org/activities/nanotechnology/Documents/Nano_food_report.pdf (Accessed on: 6 October 2009).

[6] CHAUDHRY, Q.; SCOTTER, M.; BLACKBURN, J.; BRYONY, R.; BOXALL, A.; CASTLE, L.; AITKEN, R.; WATKINS, R.: *Applications and Implications of Nanotechnologies for the Food Sector*, Food Additives & Contaminants: Part A 2008; 25(3): 241-258.

[7] PATOLSKY, F.; LIEBER, C. M.: *Nanowire Nanosensors*, Materials Today 2005; 8,(4): 20-28

[8] VERGARA, A.; LLOBET, E.; RAMÍREZ, J.L.; IVANOV, P.; FONSECA, L.: *Zampolli et al. An RFID Reader with Onboard Sensing Capability for Monitoring Fruit Quality*, Sensors and Actuators B: Chemical 2007; 127(1): 143-149.

[9] YANG, B.; BURAK, A.; QIAO, L.; METIN, S.: *Compliant and Low-cost Humidity Nanosensors Using Nanoporous Polymer Membranes*, Sensors and Actuators B: Chemical 2006; 114(1): 254-262.

[10] GÖPEL, W.: *Nanosensors and Molecular Recognition*, Microelectronic Engineering 1996; 32(1-4): 5-110.

[11] KAMPERS, F.: Nanotechnologies for Food, *Proceedings of the Nanotech Northern Europe 2008 conference*, Copenhagen, Danmark, September 23-25, 2008

[12] CULLUM, B. M.; VO-DINH, T.: *The Development of Optical Nanosensors for Biological Measurements*, Trends in Biotechnology 2000; 18(9): 388-393.

[13] CULLUM, B. M. In: JAMES, A. S.; CRISTIAN, I. C.; KAROL, P.: *Dekker Encyclopedia of Nanoscience and Nanotechnology*, Taylor & Francis 2004: 2757-2768.

[14] LIU, S.;YUAN, L.; YUE, X.; ZHENG, Z.; ZHIYONG, T.: *Recent Advances in Nanosensors for Organophosphate Pesticide Detection*, Advanced Powder Technology 2008; 19(5): 419-441.

[15] CYPAK: *Intelligent Pharmaceutical Packaging*, The Compliance Connection. Available at: http://www.cypak.com/Static/21/5 (Accessed on: 29 September 2009.).

[16] ABAD, E.; ZAMPOLLI, S.; MARCO, S.; SCORZONI, A.; MAZZOLAI, B.; JUARROS, A. et al.: *Flexible Tag Microlab Development: Gas Sensors Integration in RFID Flexible Tags for Food Logistic*,Sensors and Actuators B: Chemical 2007; 127(1): 2-7.

[17] NACHOUKI, G.; QUAFAFOU, M.: *Multi-data Source Fusion*, Information Fusion 2008; 9(4): 523-537.

[18] XIONG, N.; SVENSSON, P.: *Multi-sensor Management for Information Fusion: Issues and Approaches Information Fusion 2002*; 3(2): 163-186.

[19] RUHM, K. H.: *Sensor Fusion and Data Fusion – Mapping and Reconstruction*, Measurement 2007; 40(2): 145-157.

[20] ABAD, E.; PALACIO, F.; NUIN, M.; GONZÁLEZ DE ZÁRATE, A.; JUARROS, A.; GÓMEZ, J.M.; MARCO, S.: *RFID Smart Tag for Traceability and Cold Chain Monitoring of Foods: Demonstration in an Intercontinental Fresh Fish Logistic Chain*, Journal of Food Engineering 2009; 93(4): 394-399.

[21] TAJIMA, M.: *Strategic Value of RFID in Supply Chain Management*, Journal of Purchasing and Supply Management 2007; 13(4): 261-273.

[22] WU, N.C.; NYSTROM, M.A.; LIN, T.R.; YU, H.C.: *Challenges to Global RFID Adoption*, Technovation 2006; 26(12): 1317-1323.

[23] Hitachi: world smallest RFID: News releases, Available at: http://www.hitachi.com/New/cnews/030902.html (Accessed on: 29 September 2009)

[24] DE AZEREDO, H.M.C.: *Nanocomposites for Food Packaging Applications*, Food Research International 2009, 42(9): 1240-1253.

[25] SORRENTINO, A.; GORRASI, G.; VITTORIA, V.: *Potential Perspectives of Bio-nanocomposites for Food Packaging Applications*, Trends in Food Science & Technology 2007; 18(2): 84-95.

[26] ISHIZU, K.; TSUBAKI, K.; MORI, A.; UCHIDA, S.: *Architecture of Nanostructured Polymers*, Progress in Polymer Science2003; 28(1): 27-54.

[27] BIGNOZZI, C. A.; DISSETTE, V.; ALFREDO, C.; GIACOMO, C.; DELLA VALLE, R.: F*unctional Nanomaterials with Antibacterial and Antiviral Activity*, US20080269186 (2008).

[28] DAVIES, L. R.; ETRIS, S. F.: *The development and functions of silver in water purification and disease control*, Catalysis Today 1997; 36(1): 107-114.

[29] WEISS, J.; TAKHISTOV, P.; MCCLEMENTS, J.: *Functional Materials in Food Nanotechnology*, Journal of Food Science 2006; 71(9): 107-116.

[30] LYKLEMA, H.: *Introduction to Colloid Science*, Fundamentals of Interface and Colloid Science 2005; 4(1): 1-16

[31] CHEN, H.; WEISS, J.; SHAHIDI, F.: *Nanotechnology in Nutraceuticals and Functional Foods*, Food Tech 2006; 60(3):30–6.

[32] TAYLOR, T.M.; DAVIDSON, P.M.; BRUCE, B.D.; WEISS, J.: *Liposomal Nanocapsules in Food Science and Agriculture: Critical Reviews in Food Science and Nutrition 2005*; 45(7-8): 587-605.

[33] FSAI (Food Safety Authority of Ireland): *The Relevance for Food Safety of Applications of Nanotechnology in the Food and Feed Industries*. Available at: http://www.fsai.ie/assets/0/86/204/b81b142b-9ef7-414c-9614-3a969835b392.pdf, (Accessed on: 21 August 2009).

[34] HUSSAIN, S.; HESS, K.; GEARHART, J.; GEISS, K.; SCHLAGER, J.: *In Vitro Toxicity of Nanoparticles in BRL 3A Rat Liver Cells*. Toxicol In Vitro, 2005; 19(2): 975-983.

[35] MAYR, M.; MIN, J. K.; WANNER, D.; HOPFER, H.; SCHROEDER, J.; MIHATSCH, M.J.: *Argyria and Decreased Kidney Function: Are Silver Compounds Toxic to the Kidney?*, American Journal of Kidney Diseases 2009; 53(5): 890-894.

[36] DRAKE, P. L.; HAZELWOOD, K.J.: *Exposure-Related Health Effects of Silver and Silver Compounds: A Review*, Annals of Occupational Hygiene Advance Access 2005; 49(7): 575-85.

[37] RABELLO, M. N.; BEÇAK, W.; DE ALMEIDA, W.F.; PIGATI, P.; UNGARO, M.T.; MURATA, T., et al.: *Cytogenetic Study on Individuals Occupationally Exposed to DDT*, Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis 1975; 28(3): 449-454.

[38] YÁÑEZ, L.; BORJA-ABURTO, V. H.; ROJAS, E.; FUENTE, H.; GONZÁLEZ-AMARO, R.; GÓMEZ, H. et al.: *DDT Induces DNA Damage in Blood Cells. Studies in Vitro and in Women Chronically Exposed to this Insecticide*, Environmental Research 2004, 94(1): 18-24.

[39] EFSA (European food safety authority): *Draft Opinion of the Scientific Committee on the Potential Risks Arising from Nanoscience and Nanotechnologies on Food and Feed Safety*. Available at: http://www.efsa.europa.eu/EFSA/efsa_locale-1178620753812_1211902361968.htm (Accessed on: 3 October 2009).

[40] FDA (Food and Drug Administration): Nanotechnology: A Report of the U.S. Food and Drug Administration Nanotechnology Task Force. Rockville, Maryland. Available at: http://www.fda.gov/ScienceResearch/SpecialTopics/Nanotechnology/NanotechnologyTaskForceReport2007/default.htm (Accessed on: 4 October 2009).

[41] FSA (Food Standards Agency), A Review of Potential Implications of Nanotechnologies for Regulations and Risk Assessment in Relation to Food. Available at: http://www.food.gov.uk/multimedia/pdfs/nanoregreviewreport.pdf (Accessed on: 20 August 2009).

[42] EU Food Law weekly 2008; 364:1-4.

[43] COMMISSION OF THE EUROPEAN COMMUNITIES, 2008: Regulatory Aspects of Nanomaterials. Available at: http://osha.europa.eu/en/riskobservatory/communication_regulatory_aspects_nanomaterials (Accessed on: 5 October 2009).

[44] CHAU, C-F.; WU, S-H.; YEN, G-C.: *The Development of Regulations for Food Nanotechnology*, Trends in Food Science & Technology 2007; 18: 269-280.