Env. Biodiv. Soil Security **Vol. 2,** pp. 155 - 174 (2018)

Nanobiotechnology for Plants: Needs and Risks

Neama Abdalla[1], Mohamed I. Ragab[2], Miklós Fári[3], Hassan El-Ramady[4], Tarek Alshaal[4], Nevien Elhawat[5], Mohammed Elmahrouk[6], Abdelnaser Elzaawely[7], Tamer Elsakhawy[8], Alaa El-Dein Omara[8] and Hussein Taha[1]

[1]Plant Biotechnology Dept., Genetic Engineering Division, National Research Center, Giza, Egypt (hussein.taha2@yahoo.com)

[2]Horticulture Department, Faculty of Agriculture, Ain Shams University, Shoubra Elkheima, Cairo, Egypt (Email: mohamedragab99@hotmail.com)

[3]Agricultural Botany, Plant Physiology and Biotechnology Dept., Debrecen Univ., Debrecen, Hungary (E-mail: fari@agr.unideb.hu)

[4]Soil and Water Sciences Dept., Faculty of Agriculture, Kafrelsheikh Uni., Kafr El-Sheikh, Egypt (alshaaltarek@gmail.com; ramady2000@gmail.com)

[5]Biological and Environmental Science Department, Faculty of Home Economics, Al-Azhar University, Cairo, Egypt (Email: adel.nevien@yahoo.com)

[6]Horticulture Dept., Faculty of Agriculture, Kafrelsheikh Uni., Kafr El-Sheikh, Egypt (E-mail: threemelmahrouk@yahoo.com)

[7]Agricultural Botany Dept., Faculty of Agriculture, Tanta University, Tanta Egypt (E-mail: elzaawely@agr.tanta.edu.eg)

[8]Agriculture Microbiology Dept., Soil, Water and Environment Research Institute (SWERI), Sakha Agricultural Research Station, Agriculture Research Center (ARC), Egypt (E-mails: alaa. alaa.omara@yahoo.com; drelsakhawyg@gmail.com)

NANOTECHNOLOGY has been revolutionized penetrating all sectors in our life through the nanoscience as an essential science for a wide range of technologies. Amazing achievements resulted from this nanotechnology including all agricultural fields such as plant nutrition and crop productivity, energy sector, food sector, and plant biotechnology. A conjugation between plant biotechnology and nanotechnology has been produced an important science called plant bio-nanotechnology. Several fields have been invaded through different nanobiotechnology applications in agriculture including (1) the nanotechnology of encapsulated agro-chemicals, (2) the monitoring of different environmental stresses and crop conditions using nanobiosensors, (3) the improvement of crop production and ameliorating plants against diseases and (4) solution several environmental problems. The crop productivity also could be improved using some new agro-chemicals (e.g., nanofertilizers and nanopesticides). These agro-chemicals are very effective in delivering encapsulating nanomaterials and then enhancement the productivity of crops as well as the suppress plant pests and diseases and protecting the environment from pollution. On the other hand, nanoparticles could enter the food chain *via* different nano-agrochemicals or nano-processed foods. Therefore, many approaches including uptake of nanoparticles by plants, entry and bio-distribution of nanoparticles into the food chain are needed before using of different bionanotechnological tools in agro-production sector. Further new regulations should be created or re-built for new approaches in plant bionanotechnology. Therefore, this review will focus on our needs and risks in the plant nano-biotechnology.

Keywords: Plant bionanotechnology, Nanobiotechnology, Agrochemicals, Nanomaterial regulations, Agronanobiotechnology.

*Corresponding author e-mail: neama_ncr@yahoo.com
DOI:10.21608/JENVBS.2018.6711.1041

Introduction

Several attempts have been done to identify and define the nanobiotechnology including some books, reviews and original articles (e.g., Homaee and Ehsanpour 2016; Sarmast and Salehi 2016; Kaushik and Dixit 2017; Prasad and Aranda 2018). It could be defined the nanobiotechnology as the science of studying the biotechnology of organisms at nanoscale. In other words, the nanobiotechnology (i.e., bio-nanotechnology or nanobiology) is referring to the study of the intersection between both the biology and the nanotechnology. This science is important for a wide range of several applications in many fields including agriculture, industry and medicine. Nanobiotechnology field also allows studying different conjugated sciences including molecular biotechnology, nanotechnology, chemistry, biology and engineering sciences (Jha and Prasad 2016; López-Valdez and Fernández-Luqueño 2018). Several nanoparticles and nanomaterials have been used in different biotechnological purposes, where the size of nanoparticles used in agriculture in general ranges from 5 to 200 nm (Ghormade et al. 2011). The issue of the biological methods for metallic nanoparticles production using plants as biofactories has received considerable critical attention and are eco-friendly and high efficient methods (Barman et al. 2014; Kuppusamy et al. 2016). On the other hand, there are many applications of nanobiotechnology in agricultural sector including nano-encapsulated fertilizers (Chhipa 2016; Chhipa and Joshi 2016; Dubey and Mailapalli 2016; Khan and Rizvi 2017; López-Valdez and Fernández-Luqueño 2018) and pesticides (Kah et al. 2014; Chhipa 2016; Chhipa and Joshi 2016; Dubey and Mailapalli 2016; Khan and Rizvi 2017; Abd-Elsalam and Prasad 2018) as well as nanoparticles mediated genetic material delivery in plants (Hatami et al. 2016; Siddiqi and Husen 2017a; Tripathi et al. 2017a). Furthermore, some delivery of mesoporous nanoparticles mediated DNA and proteins in plants have been proved (Rai et al. 2015; Chung et al. 2016; Rajan et al. 2017).

Food security is a major area of interest within the field of global security and a great challenge faces the increase in global crop production to meet out the extreme increase in the global population. Therefore, crop productivity is of paramount importance in both forms the qualitative and quantitative of foods. So, the nanobiotechnology has a serious mission in improving crop production as reported in many studies (e.g., Balaure et al. 2017). These studies focus on the transfer of response of protein and other chemical complexes mediated by certain nanoparticles into the plant cells (Brandelli 2015; Rai et al. 2015; Álvarez et al. 2016; Sarmast and Salehi 2016). Therefore, further investigations in the nanobiotechnology are needed to offer promising prospects in improving the production and management agricultural crops as well as the production of transgenic plants (Bhau et al. 2016; Misra et al. 2016; Balaure et al. 2017; Siddiqi and Husen 2017a). Furthermore, the crop productivity also could be enhanced through using the nanobiotechnology by applied nano-encapsulated pesticides and fertilizers, nanoremediation for soil and water, and nanosensors.

Concerning plant nanobiotechnology, it refers to the nanofabrication, biosystem and applications of bionanotechnology for plants (Abdalla et al. 2016). Therefore, plant tissue culture using nanoparticles or the plant bionanotechnology could be considered promising tools, where many investigations have been conducted *in vitro* using nanoparticles of metals/ metalloids or metal oxides like selenium (Domokos-Szabolcsy et al. 2012, 2014; El-Ramady et al. 2014, 2015, 2016a, b), titanium dioxide (Safavi 2014; Cox et al. 2017), silver oxide (Raman et al. 2015; Tomankova et al. 2015; Homaee and Ehsanpour 2015, 2016; Cox et al. 2017), copper oxide (Nair et al. 2014; Rahmani et al. 2016), zinc oxide (Rahmani et al. 2016; Javed et al. 2017) etc. Furthermore, many benefits have been gained from the utilization of nanoparticles in *in vitro* researches including (1) improving multiplication rate (Siddiqi and Husen 2017b), (2) eliminate the contamination (Martínez-Fernández et al. 2015; Wang et al. 2015; Singh and Lee 2016; Fernandes et al. 2017), (3) rooting induction of hard rooting plants (Domokos-Szabolcsy et al. 2012, 2014), (4) ameliorating stresses such as drought and salinity (Tripathi et al. 2017b) and (5) enhancing plant growth under low concentrations of nanoparticles (Capaldi Arruda et al. 2015; Abdalla et al. 2016; Gil-Díaz et al. 2016a, b; Siddiqi and Husen 2017b).

Therefore, this review will focus on plant nanobiotechnology and its importance for the productivity of crops. The needs and risks of plant nanobiotechnology will be lso highlighted.

Nanobiotechnology: an emerging global issue

In light of recent events in nanotechnology, it is becoming extremely difficult to ignore the existence of nanoscale materials and their main component of biological systems including protein molecules, DNA molecule width, immune system component and many other cell component (Jyoti and Tomar 2017). By understanding the functions and advantages of this biological nanomolecules, researchers began to simulate this system by converting materials used in their researches in nano scale and studing their effect on biological systems (Vestergaard et al. 2015; Tripathi et al. 2019). Nanobiotechnology expresses integration between nanotechnology and biological systems in particular into molecular biology and cell biology and classified as a novel and exciting field of research. Due to the global challenges and problems, the bionanotechnology could be considered a crucial global issue. Nanobiotechnology may help the universe in dealing with different global challenges including environment, food, energy and security (Vestergaard et al. 2015; Abd-Elsalam and Prasad 2018). Therefore, it could be gained the inevitable fruits from utilization and exploitation of resources through the bionanotechnology including nanoencapsulation (Cano-Sarabia and Maspoch 2016), nanobiosensing and nanobionalyses (Vestergaard and Tamiya 2015; Jyoti and Tomar 2017). Several scientific articles and books have been published regarding the bionanotechnology and its applications (e.g., Vestergaard et al. 2015; Sarmast and Salehi 2016; Kaushik and Dixit 2017; Prasad and Aranda 2018). Therefore, it could be concluded that, the bionanotechnology is comprising both nanotechnology and biotechnology focusing on many fields like the pharmaceutical, environmental, agricultural, medicinal, energy and food (Vestergaard and Tamiya 2015). It also includes the study of nanotechnology for plants (besides bacteria and fungi), animals and humans.

Concerning the plant bionanotechnology, it covers the biosynthesis of nanoparticles using plants (including lower plants) and different uses for the therapeutic and diagnostic platform technologies. These plants have several benefits regarding the biological methods in tailoring nanoparticles including sustainable, cost-effective, simplicity, resource efficient and ecofriendly nature (Jha and Prasad 2016). The significance of bionanotechnology will be appeared in facing the global problems and challenges under different levels including the environment, energy, food, pharmaceutical and medicinal fields.

Nanobiotechnology for crop productivity

There is no doubt that, a growing pressure on the agricultural resources including food, energy, land and water due to the growing human population necessitating a need for different innovative technologies to improve and conserve crop productivity (Khan and Rizvi 2017). This reflects a serious challenge facing the increase in global crop production to meet out the extreme increase in the global population. The productivity of crops is of paramount importance in both forms the qualitative and quantitative of foods. So, the nanobiotechnology has a serious mission to improve the production of crops (Balaure et al. 2017), where the crop productivity could be promoted through using the nanobiotechnology by applied nano-encapsolated pesticides and fertilizers, nanoremediation for soil and water as well as nanosensors. So, a great revolution in all agricultural fields has been achieved depending on the bio/nanotechnology including the production and protection of crops (**Fig. 1**). In the agriculture, there are several applications for nanobiotechnology including nano-encapsulation of both fertilizers (Chhipa 2016; Chhipa and Joshi 2016; Dubey and Mailapalli 2016; Khan and Rizvi 2017; Mikhak et al. 2017; Petosa et al. 2017; Sarlak and Taherifar 2017; Subramanian and Thirunavukkarasu 2017) and pesticides (Chhipa 2016; Chhipa and Joshi 2016; Dubey and Mailapalli 2016; Khan and Rizvi 2017; Sarlak and Taherifar 2017) as well as nanoparticles mediated genetic material delivery in plants (Hatami et al. 2016; Siddiqi and Husen 2017a; Tripathi et al. 2017a).

For enhancement the efficiency of amendments that should increase contact of fertilizer with plant leading to increase in nutrient uptake, minimize of particle size, resulting in increased number of particles per unit of weight and specific surface area of a fertilizer that should increase contact of fertilizer with plant leading to increase in nutrient uptake (Liscano et al. 2000). The particles below 100 nm as nanoparticles could make plants use fertilizer more efficiently, more environmentally friendly through hamper of pollution and dissolve in water more effectively thus increase their absorption and distribution(Joseph and Morrisson 2006). Therefore, nanotechnology such as using nanoscale fertilizer may offer new techniques to be used for crop management. The efficient use of nano-scale microelements was reported by many authors including titanium (Hasanpour et al. 2015; Singh and Lee 2016; Tan et al. 2017) silicon

(Siddiqui et al. 2014; Ashkavand et al. 2015; Sabaghnia and Janmohammadi 2015; Qados and Moftah 2015; Liu et al. 2015; Wang et al. 2015; Mahdavi et al. 2016) silver (Seghatoleslami et al. 2015; Almutairi 2016) iron (Martínez-Fernández et al. 2015; Pourjafar et al. 2016) zinc (Seghatoleslami and Forutani 2015; Soliman et al. 2015). The previous reports also described the role of nanomaterials in ameliorating biotic stress in plant habitat.

Nanocapsules for efficient delivery agrochemicals

As mentioned before, many agrochemicals could be delivered through encapsulation process. This encapsulation could be defined as a process in which enveloping or surrounding a material with nano-scale another material to protect it from the extraneous conditions (Cano-Sarabia and Maspoch 2016; Schoebitz and Belchí 2016; Sarlak and Taherifar 2017). Several fields have been used or applied the encapsulated materials such as the agriculture, foods, textiles, paints, pharmaceuticals, printing applications and several other industries (Prasad et al. 2014; Sarlak and Taherifar 2017). This encapsulation process also includes the material of the core could be confined within capsule walls for a specific period of time and the material of core also could be released either gradually through the capsule walls *via* the diffusion or when the external conditions will be activated the capsule walls to melt, break, or dissolve (Sarlak and Taherifar 2017). In agriculture, the exapmles for the core could be included insecticides, herbicides, drugs, perfumes, biocides, vitamins, pheromones, fertilizers, pesticides, microbicides, whereas the examples for the shell or carriers includes polysaccharides (dextrin, chitosan, starch, gums and alginates), proteins (gelatin, lecithin, legumin and albumin), fats, liposomes, polymeric nanoparticles, biopolymers, organogels, dendrimers, solid nanoparticles, emulsions-base systems and metal-organic particles (Cano-Sarabia and Maspoch 2016).

Concerning the nanoencapsulation, it could be defined as the packaging technology for nanoparticles in different forms including the solid, liquid or gas, where the active substrace called the core and the secondary material is named as the matrix or shell (Sakao et al. 2013; Cano-Sarabia and Maspoch 2016; Schoebitz and Belchí 2016). These nanocapsules may range from 1 to 1000 nm in their size, where this nanoscopic size represents the main reason for the large surface area of them. Regarding the main benefits of encapsulation process, they include

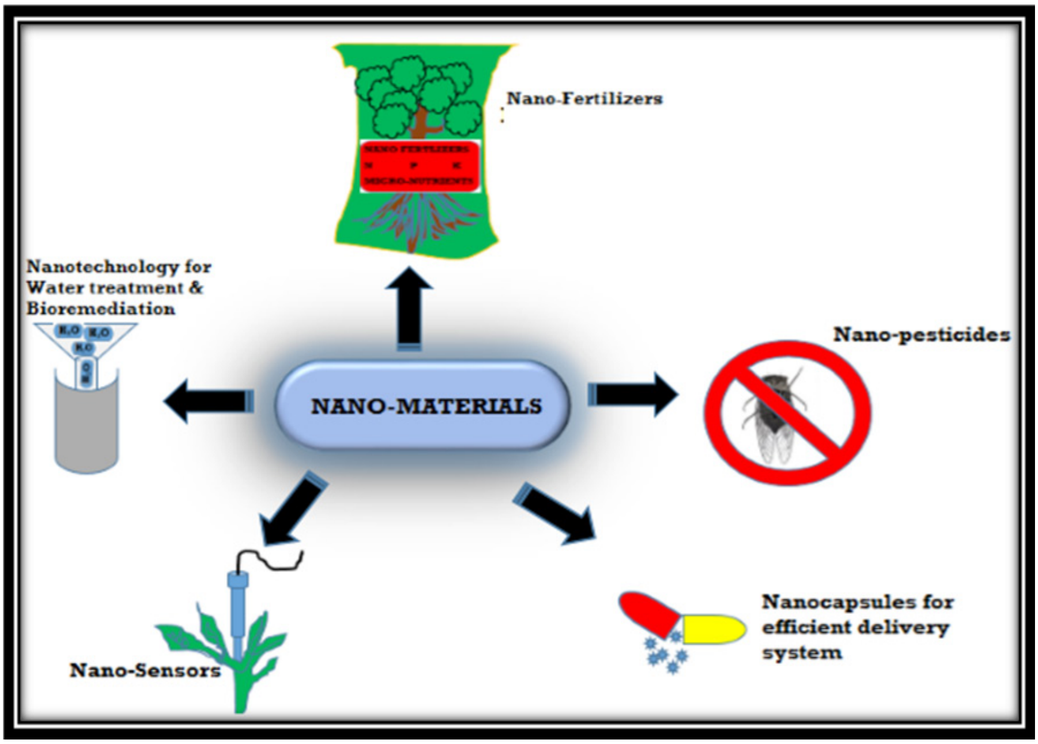

Fig. 1. Several applications for nanomaterials in the agriculture including nano-encapsulation of both fertilizers and pesticides, water treatment, nanobiosensors and nanoencapsulates for efficient delivery system

(1) increasing the stability through the protection of the encapsulated against any environmental deactivation, (2) the safe handling for toxic materials, (3) the conversion of liquids to free flowing solids, (4) the separation of incompatible materials, (5) masking organoleptic properties such as color, taste, odor of substances and (6) controlled and targeted release of encapsulated active compounds (Đordevic et al. 2015; Cano-Sarabia and Maspoch 2016; Khan et al. 2017). Concerning the nanoencasulation of fertilizers, it could be achieved through (1) encapsulating the nutrients by nanoporous material, (2) coating the nutrients with a thin protective film, or (3) delivering the nutrients as emulsions at nanoscale dimension level (Monreal et al. 2016; Khan et al. 2017).

Regarding the nanopesticides, encapsulated nanopesticides are very active method in delivering the active ingredients of pesticides as well as suppress the plant pests and pathogens in a smaller dose of chemical substances. It could be also encapsulated the active ingredients of the nanopesticides in nanocapsules, which have the tolerance against the environmental conditions (Monreal et al. 2016; Khan et al. 2017). Furthermore, there are many nanoformulations could be used in increasing the solubility of the poor soluble active ingredients to be more effective and slow release as well as protecting these ingredients from the premature degradation (Khan et al. 2017). It is worth to mention that, several metal/metaloids or metal oxides have been used in plant protection against pests and pathogens *in vitro* (**Table 1**) including silver (Jo et al. 2009; Cvjetko et al. 2017), copper (Esteban-Tejeda et al. 2009; Chhipa and Joshi 2016), sulphur (Rao and Paria 2013), zinc (Ahamed et al. 2011; Chhipa and Joshi 2016) and silicon (Chhipa and Joshi 2016). The mode of action regarding the utilization of nanotechnology includes both toxicity of nanoparticles for pests and pathogens and the delivery of encapsulated nanomaterials to pesticides (Monreal et al. 2016; Khan et al. 2017). Phytotoxicity resulted from nanoparticles under *in vitro* experiments in different conditions also was and still one of the most issues related to nanomaterials and their effects on plants (**Table 2 and Fig. 2**).

TABLE 1. Some effects of nanoformulations or nanoparticles on some pest and pathogens in *in vitro* experiments

Nanoparticles (NPs) (formulation details)	Pest or pathogen	General effects	Reference
Ag NPs (suspension, 20–30 nm)	**Fungi:** *Bipolaris sorokiniana*; *Magnaporthe grisea*	Antifungal activity inhibited formation of fungal colonies	Jo et al. (2009)
Ag NPs (solution 100 ppm and 7 – 25 nm)	**Fungi:** *Spaherotheca fusca*	Inhibited growth of powdery mildew	Lamsal et al. (2010)
Ag NPs (solution, 10 ppm)	**Fungi:** *Fusarium culmorum*	Inhibited spores growth	Kasprowicz et al. (2010)
Ag NPs (solution, 10 ppm)	*Anopheles subpictus; Culexquinquefasciatus*	Pediculocidal and larvicidal	Jayaseelan et al. (2011)
Ag NPs (MS media, 35 nm)	**Bacteria:** Not identiefied	Removing bacterial contaminants	Safavi et al. (2011)
Ag NPs (MS media, 35 nm; solution 20-200 ppm)	**Bacteria:** *Bacillus sp.* **Fungi:** *Penicillium sp.*	Antimicrobial and hormetic effect at 50 mg l^{-1} Ag NPs	Spinoso-Castillo et al. (2017)
Zn NPs (suspension, 50 nm)	**Bacteria:** *Salmonella typhimurium*	Antibacterial and preservative agent	Tayel et al. (2011)
Cu NPs (encapsulated in soda lime glass powder, 30 nm)	**Bacteria:** *Escherichia coli*, *Micrococcus luteus*	Antibacterial and antifungal	EstebanTejeda et al. (2009)

On the other hand, there is a promising issue for nanotechnology representing in the use of the nanoparticles-based delivery systems due to the genetic transformation of plants. As well known, it could be produced the transgenic plants as a great tool and comprehensive useful in agricultural researches. As well known also, it could be carried out gene transfer using *Agrobacterium sp.* As well as the application of physical and chemicals techniques (electroporation, microprojectile, etc). Therefore, it could be applied the nanoparticles-mediated gene transfer methods in the direct transfer of DNA into the cells. These methods are better efficacy and have the stable integration as well as the rapid expression for the transgenic process using nanoparticles (Rai et al. 2015; Khodakovskaya and Lahiani 2016; Shukla et al. 2016; Pacheco and Buzea 2017). These nanoparticles could be conjugated with nucleic acid developing the methodology of gene transfer in plants and improving the efficacy, stability and accuracy of transgenic process making it less time-consuming (Burlaka et al. 2015; Rai et al. 2015; Elahian et al. 2017). Therefore, it could be concluded that, the encapsulation of nanomaterials could be considered the best method in delivering different agro-chemicals or different agricultural active ingredients in more efficient manner.

Nanobiosensors

Nanosensors or nanobiosensors are emerging as promising tools for the applications in agriculture and food production. These nanobiosensors offer significant improvements in selectivity, speed and sensitivity compared to traditional chemical and biological methods. Nanosensors can be used for determination of microbes or pathogens, contaminants and food freshness **(**Joyner and Kumar 2015; Bazin et al. 2017; Bhat et al. 2017; Kurbanoglu et al. 2017; Lee et al. 2017; Ray et al. 2017**)**. A detection technique that takes less time and that can give results within a few hours, that is simple, portable and accurate and does not require any complicated technique for operation so that even a simple farmer can use the portable system. If autonomous nanosensors linked into GPS system for real-time monitoring can be distributed throughout the field to monitor soil conditions and crop, it would be of great help. Nanosensors have the arrangement like ordinary sensors, but their production is at the nanoscale. Therefore, nanosensor can be defined as an extremely small device than can bind to whatever is wanted to be detected and send back a signal. These tiny sensors are capable of detecting and responding to physicochemical (sensors) and biological signal (biosensors), transferring that response into a signal or output that can be used by humans. Compared

TABLE 2. Phytotoxicity resulted from nanoparticles under in vitro experiments in different conditions.

Nanoparticles (NPs) and their details	Plant used	General effects	Reference
Silica NPs (47 nm) (solution 10-100 ppm)	*Arabidopsis thaliana*	Toxic effects on plant cells, inhibited cell growth and negative affect on photo-synthetic efficiency	Cabello-Hurtado et al. (2016)
Ag NPs (17 nm) (solution 20-60 ppm)	Wheat	Callus cells exposure to Ag NPs or Ag ions may cause similar results and stress as well	Barbasz et al. (2016)
Ag NPs (20 nm) (solution, 2-20 ppm)	Potato	AgNPs may have a higher toxicity more than the equivalent mass of Ag ions	Homaee and Ehsanpour (2016)
Ag NPs (20 nm) (solution: 2-20 ppm)	Potato	Enhanced explants growth, AgNPs exhibited stronger toxicity than $AgNO_3$ at 10 and 20 mg l^{-1}	Homaee and Ehsanpour (2015)
Ag NPs (20 nm) (solution: 5 -50 ppm)	Mung bean	Increase in proline and lipid peroxidation level due to cellular damage and oxidative stress	Nair and Chung (2014)
CuO NPs (30 nm) (solution: 20 -500)	Mung bean	At 500 mg l^{-1} a decrease in root growth and increase in oxidative stress	Nair et al. (2014)
CuO NPs (53 nm) (solution: 500 – 1500 ppm)	*Brassica nigra*	Increase at low concertation 20 mg L^{-1} nonenzymatic anti-oxidative, phenolics flavonoids	Zafar et al. (2017)

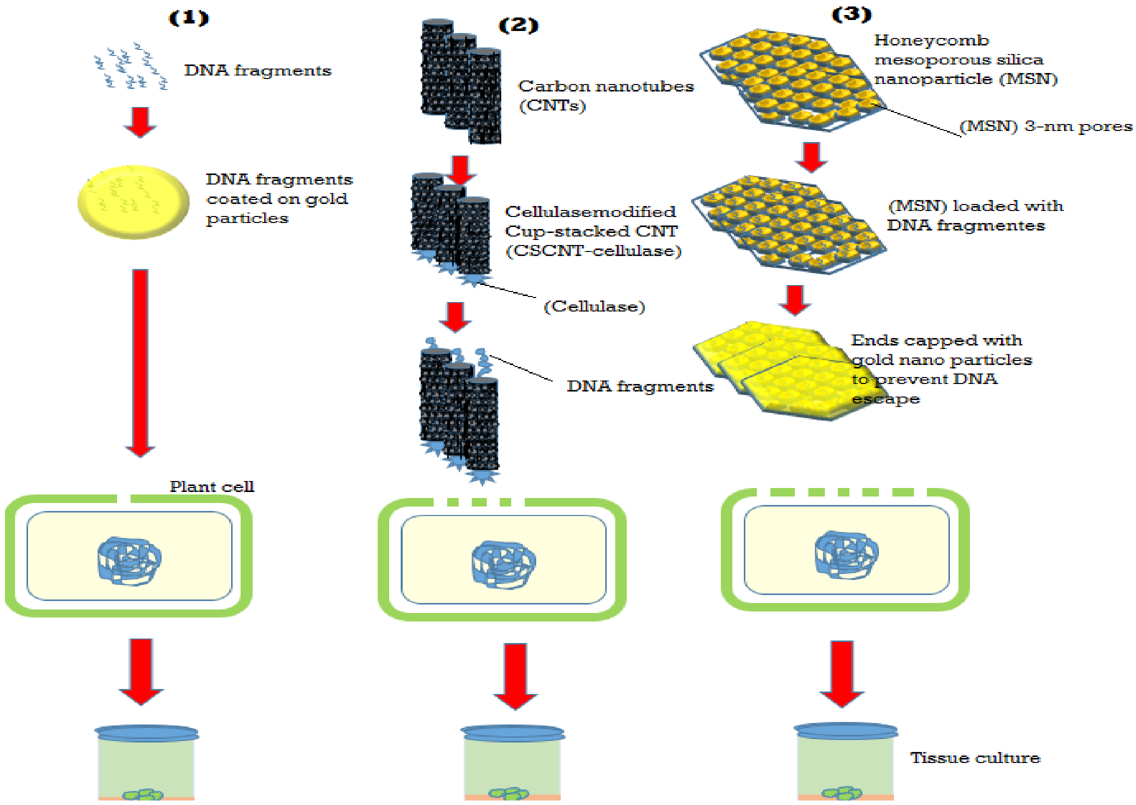

Fig. 2. Using plant tissue culture in bionanotechnology through three cases: (1) coating of DNA on gold nanoparticles and then direct DNA transfer, (2) using carbon nanotube (CNTs) with immobilized cellulase, which can serve as an efficient DNA delivery system for plant cells and (3) surface-functionalized silica nanoparticles can be also used in delivering DNA into plant cells and tissues through a honeycomb mesoporous silica nanoparticle (MSN) system with 3-nm pores that can transport DNA and chemicals into isolated plant cells and intact leaves (Sources: Torney et al. 2007; Fouad et al. 2008; Rashid and Lateef 2016).

with traditional sensors and their shortcomings, nanosensors have several advantageous properties, such as high sensitivity and selectivity, near real-time detection, low cost and portability and other necessary attributes which are improved by using nanomaterials in their construction (Lu and Bowles 2013).

Furthermore, nanobiosensors are getting applications in different industries other than food and agriculture, but recently many sensors have been developed after considering its importance (Jyoti and Tomar 2016; Kashyap et al. 2017). In the field, nanobiosensors can detect the presence of plant viruses and other crop pathogens and the level of soil nutrients (Brock et al. 2011). Nano-biosensors also allow the more quantification and rapid detection of bacteria and viruses, thereby increasing the safety of the food for the customer (Jyoti and Tomar 2016). For monitoring the impacts of agricultural pollutants on biological and ecological health, some researchers use nanosensors (Ansari et al. 2016). These nanosensors also can use in increasing the crop productivity and reducing land burden, through electrochemically functionalized single-walled carbon nanotubes with either metal nanoparticles or metal oxide nanoparticles and metal oxide nanowires and nanotubes for gases such as nitrogen oxides, ammonia, sulfur dioxide, hydrogen sulfide and volatile organics (Ramnani et al. 2016; Abegaz et al. 2017). In the field also, significant contributions of nanobiosensors research including the potential to radically alter the way sensors are designed, constructed and implemented (Al-Garawi et al. 2016; Kök 2016). Biosensor design showed good compatibility between membranes and enzymes without a change of the conformation of the enzyme molecule and binding always takes place outside the enzyme active centers (Bäcker et al. 2017). Therefore, the development of sensors/ biosensors depends on specific interactions makes atomic forcespectroscopy (Shuai et al. 2017). Therefore, it could be concluded that, the nanobiosensors are very important tools nowadays in the modern agriculture and day by day the farmers can not improve their production without these anobiosensors.

Plant nanobiotechnology: needs and risks

The traditional methods of agricultural process including classical mineral fertilization, plant disease monitoring, determination of plant needs and irrigation times have a lot of problems which affect negatively the environmental systems. For example the use of mineral fertilizers such as nitrogen and phosphorous mineral forms and its leakage through surface water cause drastic changes in ecosystems starting from food nutritioning and blooming. Also, the transformation between fertilizer forms resulting from microbial activities and environmental conditions may cause the emission of some nitrogen forms to the air. So, it is required to search for new tools for efficient use of macro- and micro-elements (Delgado et al. 2016; Negm and Eltarabily 2016; Gamajunova 2017; Motesharezadeh et al. 2017). Nanobiotechnology introduces a good solution for most previous problems. It can provide efficient delivery systems and tools for encapsulation of mineral fertilizers. Even though this new scientific advance has been extensively used, health and environmental concerns are emerging among scientists and scholars. Apprehension is mounting regarding human health and the effects associated to the new technology. Because of its small size, nanomaterials have unique properties and could penetrate into human cells, causing inflammatory responses and oxidative stress (**Fig. 3**; Schmidt 2009). Some scholars imply that nanoparticles could have similar influence or toxicity in the human body as asbestos (Austin and Lim 2008). There is not sufficient information to precisely understand the environmental effects of nanotechnology. It is reported that, there is a close relation between potential pathways for engineered nanoparticles into the natural systems and potential environmental risks associated with emerging nanotechnologies (Dawson 2008). Preliminary studies on animal have shown potential toxicity of nanomaterials for liver, kidneys, and immune system. Additionally, the effects of exposure to engineered nanoparticles may be dissimilar from the effects induced by naturally occurring nanoparticles. The toxicity and influence of nanoparticles in the environment depend on their size, type, charge, etc. Additionally, the influence of nanoparticles on the environment depends also environmental factors, i.e., humidity, temperature, wind flow rate, the nature of light, etc. However, properties of nanomaterials including small size and large surface allow easy dispersion and bonding in the environment and with human tissues. One way in which nanomaterials enter the environment and humans is through agriculture sector (Rico 2015; Cai et al. 2017). Nanoparticles strongly interact with soils. Nanomaterials enhanced plant foods nd pesticides are able to disperse into soil, water and atmosphere, to bond more strongly with pollutants and carry them through soil and water (Sastry 2012; Cai et al. 2017). Exposure to nanofertilizers and nanopesticides, can contribute to health hazards (Sastry 2012). Migration of nanoparticles incorporated in food material to human has also a great and high risks (Berekaa 2015; Sharma et al. 2015; Geary et al. 2016). In other words, direct exposure of consumers to nanomaterials poses a serious problem to human health. Nanoparticles can enter the human body through the skin, respiratory system or digestive system (**Fig. 3**). However, as long as the nanoparticles remain bound, exposure is limited or very low. Health impact and safety regarding the application of nanomaterials was reported in detail by Teow et al. (2011), Samet (2014), Costa (2016) and Musazzi et al. (2017).

As mentioned before, the nanobiotechnology is the science, which belongs the study of nanomaterials, nanoparticles and nanosensors in agriculture, food, biology, environment and medicine as well as the nanomedicine including the diagnostics, therapy, imaging and drug development (**Fig. 3**). Hence, the bionanotechnology combines both of nanotechnology and biotechnology in order to develop the synthesis of nanomaterials in biological and environmental friendly manner. It could be used the principles and techniques of nanoscale to biosynthetize different nanoparticles from living or non-living biosystems under the umbrella of nanobiotechnology (Srivastava and Kowshik 2015; Parveen and Rao 2016; Vena et al. 2016; Nordmeier et al. 2017). In general, there are two approaches in production of nanoparticles including the bottom-up and the top-down approach. Concerning the methods for nanoparticles production, they include biological, chemical and physical methods. Several organisms including unicellular and multicellular such as bacteria, fungi, actinomycetes, algae and yeast, have been used to synthesize inorganic nanomaterials extracellularly and intracellularly (Sharma et al. 2015; Park et al. 2016; Parveen and Rao 2016; Prasad et al. 2016; Roy et al. 2016; Dorcheh and Vahabi 2017) and higher plants as well (Benakashani et al. 2016; Siddiqi and Husen 2017a; Yuan et al. 2017).

On the other hand, many applications of industrial biotechnology have been reported in the last few decades including (1) remediation the environmental pollution, (2) reduction of atmospheric CO_2 level as well as greenhouse gases emissions and (3) production nanomaterials using biological agents like microbes and biomolecules (Dorcheh and Vahabi 2017). Furthermore, the application of many different nanomaterials resulted from the biological agents in large scale production is called the industrial nanobiotechnology. This science could be characterized by the ability to produce and improve of interested nanomaterials depending on both bioinformatics tools and biotechnology (Buzea and Pacheco 2017; Dorcheh and Vahabi 2017). It is also reported that, plant virus particles could be considered as nanoparticles and could be used in bionanotechnology (Parveen and Rao 2016; Sarmast and Salehi 2016; Khan and Rizvi 2017).

Several microorganisms have the ability to biosynthesize a large amount of inorganic nanoparticles in the environement ranging from the precious metals to the magnetic materials, e.g., Au, Ag, Ba, Cu, Cr, Co, CdS, Fe_3O_4, Fe_3S_4, Mn, Se, TiO_2, Zn (Sharma et al. 2015; Prasad et al. 2016; Buzea and Pacheco 2017). Like other lower plants, higher plants could be also used them to produce nanparticles even through some plant organs like rice husks (for silica nanoparticles) or plant extracts as listed below:

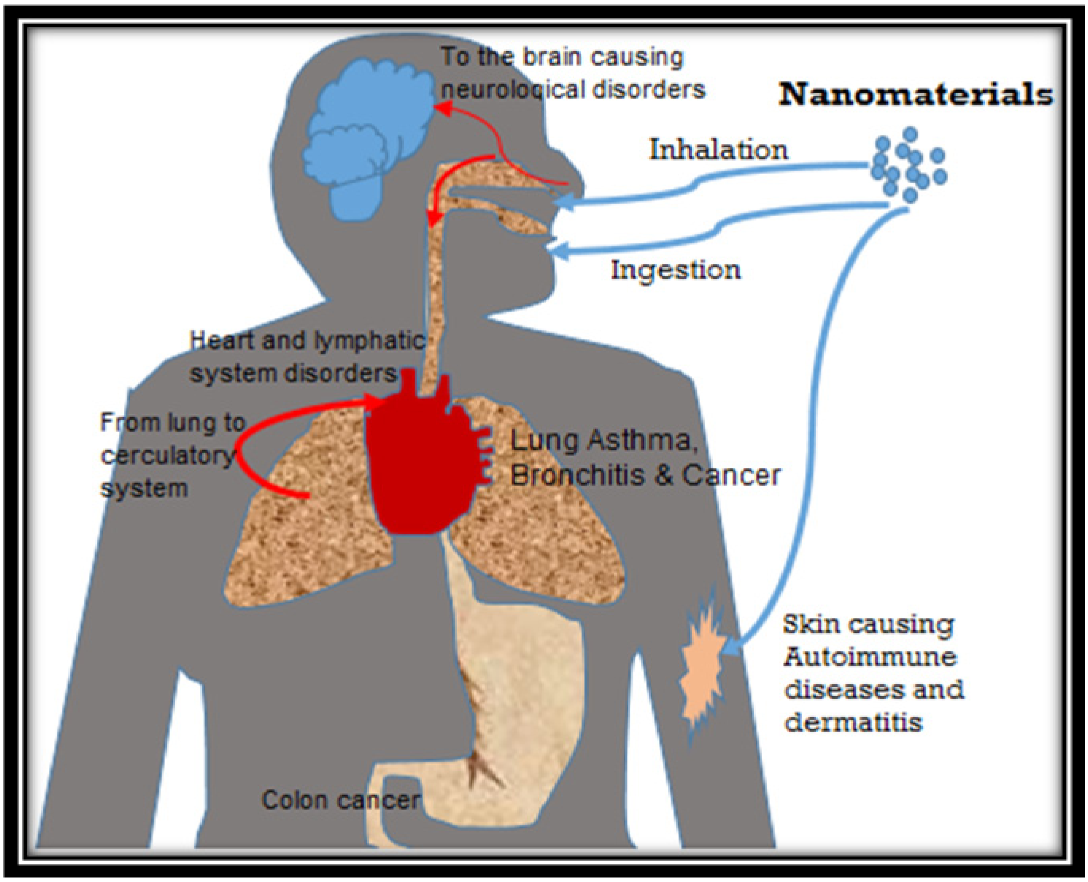

Fig. 3. Nanomaterials or nanoparticles can be penetrated or inhaled or ingested by human causing several troubles in all organs of human body including brain, heart, lung, lever, colon, etc. So, there is an essential need to conduct many investigations in frame the bionanotechnology for plants and humans as well.

(1) Au nanoparticles: some plants like *Medicago sativa*, *Aloe vera*, black tea, *Camelia sinensis*, *Cinnamomum camphora*, *Citrus paradisi*, *Coriandrum sativum*, *Hibiscus rosasinensis*, *Magnolia kobus*, *Psidium guajava*, *Sesbania drummondii*,

(2) Ag nanoparticles: Medicago sativa, *Aloe vera*, *Capsicum annum*, *Helianthus annus*, *Hibiscus rosasinensis*, *Jatropha curcas* (latex), *Lawsonia inermis* (from henna leaves), *Rhizophora mucronata*, *Solanum torvum*, *Syzygium cumini*, *Terminalia chebula*, *Tribulus terrestris*, *Vinca rosea*

(3) Cu nanoparticles: Medicago sativa, *Brassica juncea*, *Helianthus annus*, *Calotropis procera*

(4) TiO_2 nanoparticles: Annona squamosa

(5) FeO nanoparticles: Medicago sativa (Buzea and Pacheco 2017).

Several reports have been published about the risks and hazards of nanoparticles in the environment, posing different risks to ecological systems (e.g., Hegde et al. 2016; León-Silva et al. 2016; Patil et al. 2016; Servin and White 2016; Hou et al. 2017; Lu et al. 2017; McGillicuddy et al. 2017; Yang et al. 2017; Lou et al. 2018). Therefore, it must be stressed that, nanoparticles have side effects on the environment and human being. These nanparticles could be produced as well known from the natural (volcanic eruptions or natural aerosol particles from dust storms or from forest fires) and anthropogenic activities (human industrial activity like smoke from cigarettes, using of fossil fuels, the vegetation combustion and ultrafine-nanoparticle emissions in automobile traffic). So, it is very important to pay attention to public views regarding new technologies in agro-production during the product development stages and different risks of adverse as well as unintended consequences with nanotechnology (Wigger 2017; Zuverza-Mena et al. 2017). Due to using of nano-agrochemicals in agro-production, the health of several farmers will be at risk, where the nanofertilizers and nanopesticides may be easily dispersed into soil, water and atmosphere (Tripathi et al. 2017a). Hence, several nanoparticles may enter the food chain *via* these nano-agrochemicals or through nano-processed food, raising the risks and hazards as well as the nanotoxicity in agroecosystems (Mattsson and Simkó 2017). Therefore, the analysis of life cycle, the uptake of nanoparticle by plants, the entry and bio-distribution into the food chain, etc need a thorough investigation before these tools are used as products in agro-production sector (Holden et al. 2016; Kumar et al. 2016; McClements 2017; Rizwan et al. 2017).

Concerning the regulations for nanoparticles, it should be evaluated the risk assessment of manufactured nanoparticles and the risk management activities as well (Mattsson and Simkó 2017). For the regulatory purposes, the risk assessment of nanoparticles requires knowing more information about the exposure time, the potential hazard and the dose used as well as the kind of nanoparticles, the possible changing in nanoparticles and its properties over time in the environment (Bicho et al. 2016; Dekkers et al. 2016; Priester et al. 2017). Despite of accepted progress in developing the risk assessment of nanoparticles, there are still several open questions concerning the fate and behavior of nanoparticles in different environments (Schulte et al. 2016; Mattsson and Simkó 2017). It could be concluded some regulations regarding agro-production according to the European Parliament: (i) legislation on food additives (Regulation: EC no. 1333 /2008, Art 12), (ii) information for consumers (Regulation: EU no. 1169 /2011, e.g. Art 18), (ii) cosmetic products (Regulation: EC no. 1223 /2009, e.g. Art 13 (1), (vi) biocidal products (Regulation: EU no. 528/2012, e.g. Art 19 (1), (v) food for infants (Regulation: EU no. 609/2013, Art 9 (2) as reported by Lee and Stokes (2016). Many studies have been published concerning the regulatory purposes for the risk assessment of nanoparticles such as Dekkers et al. (2016), Hegde et al. (2016), Lee and Stokes (2016), Feijoo et al. (2017) and Mattsson and Simkó (2017). It is worth to mention that, it could maximize the benefits from the bionanotechnology in different plant fields. It must be stressed that, new regulations should be found to protect not only the human health but also the environment. Therefore, it should be also stressed on the evaluation of risk assessment of engineered nanoparticles application in all sectors including agriculture, energy, healthcare, transport, information and communication technologies.

Conclusion

Several challenges face humankind including the insecurity in enegry, food, water and land. This challenge will be increased day by day necessitating the need for innovative solutions such as the nanotechnology and bionanotechnology. It is well known that, there are many applications of nanotechnology in the agriculture and food sector as well. Concerning the potential of nanotechnology in the agriculture, it includes (1) increase the global production of foods, (2) improvement the productivity of crops, (3) protection of cultivated plants against diseases, (4) monitoring or detecting plant diseases, (5) enhancement food quality and (6) minimizing the loss in natural resources. Concerning the bionanotechnology, many applications conjugate between biotechnology and nanotechnology including the nanotechnology of encapsulated agro-chemicals, the monitoring of different environmental stresses and crop conditions using nanobiosensors, the improvement of crop production and ameliorating plants against diseases and solution several environmental problems. So, it could be used plant bionanotechnology for *in vitro* propagation of economic plants. Furthermore, it could be also carried out more investigations including the interaction between nanoparticles and plant responses, the understanding nanonutrient or element toxicity symptoms, toxic concentrations and producing biofortified crops, using of nanoparticles in remediation of multi-pollutants from soil and safety of plant nano-biotechnology (i.e., evaluation the risks associated with the transfer of nanoparticles through food chain). Therefore, it will be possible to perform a complete and scientifically sound risk assessment of the application of engineered nanoparticles in all industrial and public sectors, including agriculture, healthcare, transport, energy, materials, information and communication technologies.

Acknowledgments

Authors thank the outstanding contribution of EFOP-3.6.2-16-2017-00001 Research of complex rural economic and sustainable development, elaboration of its service networks in the Carpathian basin. The research was financed by the Higher Education Institutional Excellence Programme of the Ministry of Human Capacities in Hungary, within the framework of the biotechnology thematic programme of the University of Debrecen 20428-3/2018/ FEKUTSTRAT.

References

Abdalla N. A., H El-Ramady, É Domokos-Szabolcsy and H Taha (2016). Review on plant nanobiotechnology. *The International Annual Meeting of German Society for Plant Nutrition for "From model plants to crops and crop systems" Hohenheim Uni., Stuttgart, 28-30 September 2016* Germany.

Abd-Elsalam K. A. and R. Prasad (2018). Nanobiotechnology Applications in Plant Protection. *Nanotechnology in the Life Sciences Series,* https://doi.org/10.1007/978-3-319-91161-8, Springer International Publishing AG, part of Springer Nature

Abegaz B W., T. Datta and S M. Mahajan (2017). Sensor technologies for the energy-water nexus – A review. *Applied Energy* (In press)

Al-Garawi Z S., G E. Kostakis and L C. Serpell (2016). Chemically and thermally stable silica nanowires with a β-sheet peptide core for bionanotechnology. *J Nanobiotechnol* **14:**79. DOI: 10.1186/s12951-016-0231-8

Almutairi, Z. M. (2016). Influence of Silver Nano-particles on the Salt Resistance of Tomato (Solanum lycopersicum) during Germination. *International Journal of Agriculture & Biology,* **18**(2).

Álvarez S P, N E López, J M Lozano, E A R Negrete and M E S Cervantes (2016). Plant Fungal Disease Management Using Nanobiotechnology as a Tool. In: R. Prasad (ed.), *Advances and Applications Through Fungal Nanobiotechnology, Fungal Biology,* DOI: 10.1007/978-3-319-42990-8_8, Springer International Publishing Switzerland.

Ansari M.I. H, S Hassan, A Qurashi, F A Khanday (2016). Microfluidic-integrated DNA nanobiosensors. *Biosensors and Bioelectronics,* **85:** 247-260

Ashkavand, P., Tabari, M., Zarafshar, M., Tomášková, I., & Struve, D. (2015). Effect of SiO2 nanoparticles on drought resistance in hawthorn seedlings. *Forest Research Papers,* **76**(4): 350-359.

Austin, R. H., & Lim, S. (2008). The Sackler Colloquium on promises and perils in nanotechnology for medicine. *Proceedings of the National Academy of Sciences,* **105**(45): 17217 17221.

Bäcker M, C Koch, S Eiben, F Geiger, F Eber, H Gliemann, A Poghossian, C Wege, M J. Schöning (2017). Tobacco mosaic virus as enzyme nanocarrier for electrochemical biosensors. *Sensors and Actuators B: Chemical,* **238:** 716-722

Balaure P C, D Gudovan, I Gudovan (2017). Nanopesticides: a new paradigm in crop protection. In: A M GRUMEZESCU (Ed.), *New Pesticides and Soil Sensors,* 129-192. Elsevier Inc., Academic

Press, http://dx. doi.org/ 10.1016/ B978-0-12-804299-1.00005-9

Barbasz A., B. Kreczmer and M. Ocwieja (2016). Effects of exposure of callus cells of two wheat varieties to silver nanoparticles and silver salt ($AgNO_3$). *Acta Physiol Plant* **38:** 76. DOI: 10.1007/s11738-016-2092-z

Barman G, Maiti S, Laha JK (2014). Biofabrication of gold nanoparticles using aqueous extract of red tomato and its use as a colorimetrixc sensor. *Nanoscale Res Lett* **8:**181.

Bazin I, S A. Tria, A Hayat, J-L Marty (2017). New biorecognition molecules in biosensors for the detection of toxins. *Biosensors and Bioelectronics,* **87:** 285-298.

Benakashani F., A.R. Allafchian and S.A.H. Jalali (2016). Biosynthesis of silver nanoparticles using *Capparis spinosa* L. leaf extract and their antibacterial activity. *Karbala International Journal of Modern Science,* **2** (4): 251-258.

Berekaa, M. (2015). Nanotechnology in Food Industry; Advances in Food processing, Packaging and Food Safety, *Int.J.Curr. Microbiol.App.Sci* **4**(5): 345-357

Bhat S S, A Qurashi, F A Khanday (2017). ZnO nanostructures based biosensors for cancer and infectious disease applications: Perspectives, prospects and promises. *TrAC Trends in Analytical Chemistry,* **86:** 1-13.

Bhau B. S., P. Phukon, R. Ahmed, B. Gogoi, B. Borah, J. Baruah, D. K. Sharma, and S. B. Wann (2016). A Novel Tool of Nanotechnology: Nanoparticle Mediated Control of Nematode Infection in Plants. In: D. P. Singh et al. (eds.), *Microbial Inoculants in Sustainable Agricultural Productivity,* DOI: 10.1007/978-81-322-2644-4_16, Springer India

Bicho R. C., T Ribeiro, N P. Rodrigues, J J. Scott-Fordsmand, M J.B. Amorim (2016). Effects of Ag nanomaterials (NM300K) and Ag salt ($AgNO_3$) can be discriminated in a full life cycle long term test with *Enchytraeus crypticus*. *Journal of Hazardous Materials,* **318:** 608-614.

Borgnia, M., S. Nielsen, et al. (1999). „Cellular and molecular biology of the aquaporin water channels." *Annu. Rev. Biochem*. **68**: 425-458.

Brandelli A. (2015). Nanobiotechnology Strategies for Delivery of Antimicrobials in Agriculture and Food. In: M. Rai et al. (eds.), *Nanotechnologies in Food and Agriculture,* DOI 10.1007/978-3-319-14024-7_6, Springer International Publishing Switzerland

Brock DA, Douglas TE, Queller DC, Strassmann JE (2011). Primitive agriculture in a social amoeba. *Nature;* **469** (7330): 393–396.

Burlaka O M., Y V. Pirko, A I. Yemets and Y B. Blume (2015). Application of Carbon Nanotubes for Plant Genetic Transformation. In: O. Fesenko, L. Yatsenko (eds.), *Nanocomposites, Nanophotonics, Nanobiotechnology, and Applications,* Springer Proceedings in Physics 156, DOI 10.1007/978-3-319-06611-0_20, Springer International Publishing Switzerland

Buzea C. and I Pacheco (2017). Nanomaterial and Nanoparticle: Origin and Activity. In: M. Ghorbanpour et al. (eds.), *Nanoscience and Plant–Soil Systems, Soil Biology* **48,** DOI: 10.1007/978-3-319-46835-8_3, Springer *International Publishing* AG

Cabello-Hurtado F., M D Lozano-Baena, C Neaime, A Burel, S Jeanne, P Pellen-Mussi, S Cordier and F Grasset (2016). Studies on plant cell toxicity of luminescent silica nanoparticles (Cs_2[Mo6Br14]@SiO_2) and its constitutive components. *J Nanopart Res* **18:**69. DOI: 10.1007/s11051-016-3381-6

Cai K, A Z. Wang, L Yin and J Cheng (2017). Bio-nano interface: The impact of biological environment on nanomaterials and their delivery properties. *Journal of Controlled Release,* doi: 10.1016/j.jconrel.2016.11.034

Cano-Sarabia M and D Maspoch (2016). Nanoencapsulation. In: B. Bhushan (ed.), *Encyclopedia of Nanotechnology,* DOI: 10.1007/978-94-017-9780-1, Springer Science + Business Media Dordrecht

Capaldi Arruda S C., A L. D Silva, R M Galazzi, R A Azevedo and M A Z Arruda (2015). Review Nanoparticles applied to plant science: *A review. Talanta* **131:** 693–705. http://dx.doi.org/10.1016/j.talanta.2014.08.050

Chhipa H, Joshi P (2016). Nanofertilisers, nanopesticides and nanosensors in agriculture. In: Ranjan S, Dasgupta N, Lichtfouse E (eds.) *Nanoscience in food and agriculture 1, Sustainable Agriculture Reviews,* Vol. 20. Springer, pp 247–282. doi:10.1007/ 978-3-319-39303-2

Chhipa H. (2016). Nanofertilizers and nanopesticides for agriculture. *Environ Chem Lett,* DOI: 10.1007/s10311-016-0600-4

Chung Ill-M, I Park, K Seung-Hyun, M Thiruvengadam and G Rajakumar (2016). Plant-Mediated Synthesis of Silver Nanoparticles: Their Characteristic Properties and Therapeutic Applications *Nanoscale Research Letters* **11:** 40. DOI: 10.1186/s11671-016-1257-4.

Costa A. L. (2016). Applying Safety by Molecular Design Concepts to Nanomaterials Risk Management. In: F. Murphy et al. (eds.), *Managing Risk in Nanotechnology, Innovation, Technology, and Knowledge Management*, DOI 10.1007/978-3-319-32392-3_10, Springer International Publishing Switzerland

Cox A., P. Venkatachalam, S. Sahi, N. Sharma (2017). Silver and titanium dioxide nanoparticle toxicity in plants: A review of current research, *Plant Physiology et Biochemistry,* **110:** 33-49. doi: 10.1016/j.plaphy.2016.05.022.

Crane R.A., T.B. Scott (2012). Nanoscale zero-valent iron: Future prospects for an emerging water treatment technology, *Journal of Hazardous Materials* **211–212:** 112-125.

Cvjetko P., A Milošić, A-M Domijan, I V Vrček, and B Balen (2017). Toxicity of silver ions and differently coated silver nanoparticles in *Allium cepa* roots. *Ecotoxicology and Environmental Safety,* **137:** 18-28.

Dawson, N. G. (2008). Sweating the small stuff: Environmental risk and nanotechnology.

Dekkers S, A G. Oomen, E A.J. Bleeker, R J. Vandebriel and S W.P. Wijnhoven (2016). Towards a nanospecific approach for risk assessment. *Regulatory Toxicology and Pharmacology,* **80:** 46-59.

Delgado A, M Quemada and F J. Villalobos (2016). Fertilizers. In: F.J. Villalobos, E. Fereres (eds.), *Principles of Agronomy for Sustainable Agriculture,* DOI 10.1007/978-3-319-46116-8_23, Springer International Publishing AG

Domokos-Szabolcsy E, L Marton, A Sztrik, B Babka, J Prokisch and M Fari (2012). Accumulation of red elemental selenium nanoparticles and their biological effects in Nicotinia tabacum. *Plant Growth Regul* **68:** 525–531. DOI: 10.1007/s10725-012-9735-x

Domokos-Szabolcsy E., Abdalla N., T. Alshaal, A. Sztrik, L. Márton and H. El-Ramady (2014). *In vitro* comparative study of two Arundo donax L. ecotypes' selenium tolerance. *International Journal of Horticultural Science* 2014, **20** (3–4): 119–122.

Dorcheh S K and K Vahabi (2017). Biosynthesis of Nanoparticles by Fungi: Large-Scale Production. In: J.-M. Mérillon, K.G. Ramawat (eds.), *Fungal Metabolites, Reference Series in Phytochemistry,* DOI: 10.1007/978-3-319-25001-4_8, Springer *International Publishing Switzerland*

Đordevic V., B Balanc, A Belscak-Cvitanovic, S Levic, K Trifkovic, A Kalusevic, I Kostic, D Komes, B Bugarski, V Nedovic (2015).Trends in Encapsulation Technologies for Delivery of Food Bioactive Compounds. *Food Eng Rev* **7:** 452–490. DOI: 10.1007/s12393-014-9106-7

Dubey A. and D. R. Mailapalli (2016). Nanofertilisers, Nanopesticides, Nanosensors of Pest and Nanotoxicity in Agriculture. In: E. Lichtfouse (ed.), *Sustainable Agriculture Reviews, Sustainable Agriculture Reviews* **19**: 307 – 330. DOI: 10.1007/978-3-319-26777-7_7, Springer International Publishing Switzerland

Elahian F, S Reiisi, A Shahidi and S A Mirzaei (2017). High-throughput bioaccumulation, biotransformation, and production of silver and selenium nanoparticles using geneticallyengineered Pichia pastoris. *Nanomedicine: Nanotechnology, Biology and Medicine*, **13** (3): 853-861.

El-Ramady H. R., N. A. Abdalla, T. A. Alshaal, N. Elhawat, É. Domokos-Szabolcsy, J. Prokisch, A. Sztrik and M. Fári (2014). The presentation entitled: Nano-selenium: from *in vitro* to micro farm experiments. *The international Conference „Biogeochemical Processes at Air-Soil-Water Interfaces and Environmental Protection" for the European Society for Soil Conservation, Imola–Ravenna,* Italy 23-26 June 2014. DOI: 10.13140/2.1.2260.4481.

El-Ramady H., T. Alshaal, N. Abdalla, J. Prokisch, A. Sztrik, M. Fári and É. Domokos-Szabolcsy (2016a). Selenium and nano-selenium biofortified sprouts using micro-farm systems. *Proceedings of the 4th International Conference on Selenium in the Environment and Human Health, Sao Paulo,* BRAZIL, 18–21 October 2015, pp: 189 – 190. (Eds.) G. S. Bañuelos, Z.-Q. Lin, L. R. G. Guilherme and A. R. dos Reis. CRC, *Taylor & Francis Group, London*, UK, DOI: 10.13140/RG.2.1.1065.9925

El-Ramady, H., É. Domokos-Szabolcsy, T. A. Shalaby, J. Prokisch and M. Fári (2015). Selenium in agriculture: water, air, soil, plants, food, animals and nanoselenium. In: E. Lichtfouse (ed.), *Environmental Chemistry for a Sustainable World* Vol. 5 (CO_2 sequestration, biofuels and depollution), pp: 153 – 232. DOI 10.1007/978-3-319-11906-9_5.

Springer Berlin

El-Ramady, H., N. Abdalla, H. S. Taha, T. Alshaal, A. El-Henawy, S. E.-D. A. Faizy, M. S. Shams, S. M. Youssef, T. Shalaby, Y. Bayoumi, N. Elhawat, S. Shehata, A. Sztrik, J. Prokisch, M. Fári, É. Domokos-Szabolcsy, E. A. Pilon-Smits, D. Selmar, S. Haneklaus and E. Schnug (2016b). Selenium and nano-selenium in plant nutrition. *Environ Chem Lett,* **14** (1):123–147. DOI: 10.1007/s10311-015-0535-1

Esteban-Tejeda L, Malpartida F, Esteban-Cubillo A, Pecharroman C, Moya JS (2009). Antibacterial and antifungal activity of a soda-lime glass containing copper nanoparticles. *Nanotechnology* **20:**505701

Feijoo S., S. González-García, Y. Moldes-Diz, C. Vazquez-Vazquez, M.T. Moreira (2017). Comparative life cycle assessment of different synthesis routes of magnetic nanoparticles. *Journal of Cleaner Production,* **143:** 528-538.

Fernandes J. P., C. M R. Almeida, F Andreotti, L Barros, T Almeida, A P. Mucha (2017). Response of microbial communities colonizing salt marsh plants rhizosphere to copper oxide nanoparticles contamination and its implications for phytoremediation processes. *Science of The Total Environment* (In Press) http://dx.doi.org/10.1016/j.scitotenv.2017.01.015

Fouad M., N Kaji, M Jabasini, M Tokeshi and Y Baba (2008). Nanotechnology meets plant biotechnology: carbon nanotubes deliver. *Twelfth International Conference on Miniaturized Systems for Chemistry and Life Sciences October 12 - 16, 2008, San Diego, California,* USA, pp: 227 – 229.

Gamajunova V (2017). Sustainability of Soil Fertility in the Southern Steppe of Ukraine, Depending on Fertilizers and Irrigation. In: D. Dent and Y. Dmytruk (eds.), *Soil Science Working for a Living,* DOI 10.1007/978-3-319-45417-7_14, Springer International Publishing Switzerland

Geary S M., A S. Morris and A K. Salem (2016). Assessing the effect of engineered nanomaterials on the environment and human health. *Journal of Allergy and Clinical Immunology,* **138** (2): 405-408.

Gerdini F. S. (2016) Effect of nano potassium fertilizer on some parchment pumpkin(Cucurbita pepo) morphological and physiological characteristics under drought conditions, *Intl J Farm & Alli Sci.* **5** (5): 367-371

Ghormade V, Deshpande MV, Panikar KM (2011). Perspectives for nano-biotechnology enabled protection and nutrition of plants. *Biotechnol Adv* **29:**792–803.

Gil-Díaz M., S. Diez-Pascual, A. González, J. Alonso, E. Rodríguez-Valdés, J.R. Gallego, M.C. Lobo (2016). A nanoremediation strategy for the recovery of an As-polluted soil. *Chemosphere,* **149:** 137-145

Gil-Díaz M., S. Diez-Pascual, A. González, J. Alonso, E. Rodríguez-Valdés, J.R. Gallego, M.C. Lobo (2016b). A nanoremediation strategy for the recovery of an As-polluted soil. *Chemosphere,* **149:** 137-145.

Hasanpour, H., Maali-Amir, R., and Zeinali, H. (2015). Effect of TiO2 nanoparticles on metabolic limitations to photosynthesis under cold in chickpea. Russian Journal of Plant Physiology, **62**(6): 779-787.

Hatami M., K Kariman, M Ghorbanpour (2016). Engineered nanomaterial-mediated changes in the metabolism of terrestrial plants. *Science of The Total Environment,* **571:** 275-291.

Hegde K., S K Brar, M Verma, R Y. Surampalli (2016). Current understandings of toxicity, risks and regulations of engineered nanoparticles with respect to environmental microorganisms. Nanotechnol. *Environ. Eng.* **1**:5. DOI: 10.1007/s41204-016-0005-4

Holden P.A., Gardea-Torresdey, J.L., Klaessig, F., Turco, R.F., Mortimer, M., Hund-Rinke, K., et al. (2016). Considerations of environmentally relevant test conditions for improved evaluation of ecological hazards of engineered nanomaterials. *Environ. Sci. Technol.* **50:** 6124–6145.

Homaee M B and A A Ehsanpour (2016). Silver Nanoparticles and Silver Ions: Oxidative Stress Responses and Toxicity in Potato (*Solanum tuberosum* L.) Grown *in vitro*. *Hortic. Environ. Biotechnol.* **57**(6): 544-553. DOI: 10.1007/s13580-016-0083-z

Homaee M. B. and A. A. Ehsanpour (2015). Physiological and biochemical responses of potato (*Solanum tuberosum*) to silver nanoparticles and silver nitrate treatments under in vitro conditions. *Ind J Plant Physiol.* (October–December) **20**(4): 353–359. DOI: 10.1007/s40502-015-0188-x

Hou J., X Wang, T Hayat and X Wang (2017). Ecotoxicological effects and mechanism of CuO nanoparticles to individual organisms.

Environmental Pollution, **221:** 209-217.

Hussien, M. M., El-Ashry, S. M., Haggag, W. M., & Mubarak, D. M. (2015) Response of Mineral Status to Nano-Fertilizer and Moisture Stress during Different Growth Stages of Cotton *Plants.***8** (12): 643-650

Javed R., M Usman, B Yücesan, M Zia and E Gürel (2017). Effect of zinc oxide (ZnO) nanoparticles on physiology and steviol glycosides production in micropropagated shoots of *Stevia rebaudiana* Bertoni. *Plant Physiology and Biochemistry,* **110:** 94–99. http://dx.doi.org/10.1016/j.plaphy.2016.05.032

Jayaseelan C, Rahuman AA, Rajakumar G (2011). Synthesis of pediculocidal and larvicidal silver nanoparticles by leaf extract from heartleaf moonseed plant, Tinospora cordifolia Miers. *Parasitol Res* **109:**185–194.

Jha A. K. and K Prasad (2016). Understanding Mechanism of Fungus Mediated Nanosynthesis: A Molecular Approach. In: R. Prasad (ed.), *Advances and Applications Through Fungal Nanobiotechnology, Fungal Biology,* DOI 10.1007/978-3-319-42990-8_1, Springer International Publishing Switzerland

Jo YK, Kim BH, Jung G (2009). Antifungal activity of silver ions and nano-particles on phytopathogenic fungi. *Plant Dis* **93:**1037–1043.

Johnson R. S. (2011). Governing nanobiotechnology: lessons from agricultural biotechnology regulation. *J Nanopart Res* **13:**1467–1476. DOI: 10.1007/s11051-011-0252-z.

Joseph T. and M Morrisson (2006). Nano forum: Nano technology in agriculture and food. *European Nano technology Gateway.*

Joyner, J.R., Kumar, D.V. (2015). Nanosensors and their applications in food analysis: a review, **1** (4): 80-90

Jyoti A and R S Tomar (2016). Detection of pathogenic bacteria using nanobiosensors. *Environ Chem Lett,* DOI: 10.1007/s10311-016-0594-y

Jyoti A and R S Tomar (2017). Detection of pathogenic bacteria using nanobiosensors *Environ Chem Lett* **15:**1–6. DOI: 10.1007/s10311-016-0594-y

Kah M., P Machinski, P Koerner, K Tiede, R Grillo, L. F. Fraceto and T. Hofmann (2014). Analysing the fate of nanopesticides in soil and the applicability of regulatory protocols using a polymer-based nanoformulation of atrazine. *Environ Sci Pollut Res* **21:**11699–11707. DOI: 10.1007/s11356-014-2523-6

Kashyap P. L., S Kumar and A. K. Srivastava (2017). Nanodiagnostics for plant pathogens. *Environ Chem* Lett **15:** 7–13. DOI: 10.1007/s10311-016-0580-4

Kasprowicz MJ, Kozioł M, Gorczyca A (2010). The effect of silver nanoparticles on phytopathogenic spores of *Fusarium culmorum*. *Can J Microbiol* **56:**247–253

Kaushik A. K. and C. K. Dixit (2017). *Nanobiotechnology for Sensing Applications: From Lab to Field.* CRC Press, Taylor & Francis Group, Apple Academic Press, Inc.

Khan M R and T F Rizvi (2017). Application of Nanofertilizer and Nanopesticides for Improvements in Crop Production and Protection. In: M. Ghorbanpour et al. (eds.), *Nanoscience and Plant–Soil Systems, Soil Biology* 48, DOI 10.1007/978-3-319-46835-8_15, Springer International Publishing AG

Khodakovskaya M. V. and M. H. Lahiani (2016). Role of Nanoparticles for Delivery of Genetic Material. In: C. Kole et al. (eds.), *Plant Nanotechnology,* DOI: 10.1007/978-3-319-42154-4_10, Springer International Publishing Switzerland

Kök F. N. (2016). Bionanotechnology: Lessons from Nature for Better Material Properties. In: H. Ünlü et al. (eds.), *Low-Dimensional and Nanostructured Materials and Devices, Nano Science and Technology,* DOI: 10.1007/978-3-319-25340-4_21, Springer International Publishing Switzerland

Kumar V., P Guleria and S K Mehta (2016). Nanoparticles to Sense Food Quality S. Ranjan et al. (eds.), Nanoscience in Food and Agriculture 3, *Sustainable Agriculture Reviews* **23,** DOI 10.1007/978-3-319-48009-1_6, Springer International Publishing Switzerland

Kuppusamy P, M M. Yusoff, G P Maniam, N Govindan (2016). Biosynthesis of metallic nanoparticles using plant derivatives and their new avenues in pharmacological applications: An updated report. *Saudi Pharmaceutical Journal,* **24** (4): 473-484.

Kurbanoglu S., S A. Ozkan, A Merkoçi (2017). Nanomaterials-based enzyme electrochemical biosensors operating through inhibition for biosensing applications. *Biosensors and Bioelectronics,* http://dx.doi.org/10.1016/j.bios.2016.09.102

Lamsal K, Sang-Woo K, Jung JH, Kim YS, Kim KU, Lee YS (2010). Inhibition effects of silver nanoparticles against powdery mildews on cucumber and pumpkin. *Microbiology* **39:**26–32.

Lee J., M Wipf, L Mu, C Adams, J Hannant, M A. Reed (2017). Metal-coated microfluidic channels: An approach to eliminate streaming potential effects in nano biosensors. *Biosensors and Bioelectronics,* **87:** 447-452.

León-Silva S., F Fernández-Luqueño and F López-Valdez (2016). Silver Nanoparticles (AgNP) in the Environment: a Review of Potential Risks on Human and Environmental Health. *Water Air Soil Pollut* **227:** 306. DOI: 10.1007/s11270-016-3022-9

Liscano, J.F.; Wilson, C.E.; Norman, R.J. and Slaton, N.A. (2000). Zinc availability to rice from seven granular fertilizers AAES *Res Bulletin*. **963:** 1–31.

Liu, J., Cai, H., Mei, C., & Wang, M. (2015). Effects of nano-silicon and common silicon on lead uptake and translocation in two rice cultivars. *Frontiers of Environmental Science & Engineering,* **9**(5): 905-911.

López-Valdez F. and F. Fernández-Luqueño (2018). Agricultural Nanobiotechnology: Modern Agriculture for a Sustainable Future. https://doi.org/10.1007/978-3-319-96719-6, Springer Nature Switzerland AG

Lu H., H Dong, W Fan, J Zuo and X Li (2017). Aging and behavior of functional TiO_2 nanoparticles in aqueous environment. *Journal of Hazardous Materials*, **325:** 113-119.

Lu, J. and Bowles, M. (2013) How Will Nanotechnology Affect Agricultural Supply Chains?, *InternationalFood and Agribusiness Management Review,* Vol. **16**, Issue 2.

Luo P., A Roca, K Tiede, K Privett and A Boxall (2018). Application of nanoparticle tracking analysis for characterising the fate of engineered nanoparticles in sediment-water systems. *Journal of Environmental Sciences* **64:** 62-71.

Mahdavi, S., Kafi, M., Fallahi, E., Shokrpour, M., and Tabrizi, L. (2016). Water stress, nano silica, and digoxin effects on minerals, chlorophyll index, and growth in ryegrass. *International Journal of Plant Production,* **10**(2): 251-264

Martínez-Fernández D., Vítková, M., Bernal, M. P., and Komárek, M. (2015). Effects of nano-maghemite on trace element accumulation and drought response of *Helianthus annuus* L. in a contaminated mine soil. *Water, Air, & Soil Pollution,* **226**(4): 1-9.

Mattsson M.-O. and M. Simkó (2017). The changing face of nanomaterials: Risk assessment challenges along the value chain. *Regulatory Toxicology and Pharmacology,* **84:** 105-115. http://dx.doi.org/10.1016/j.yrtph.2016.12.008

McClements D J (2017). The future of food colloids: Next-generation nanoparticle delivery systems. *Current Opinion in Colloid & Interface Science,* **28:** 7-14.

McGillicuddy E., I. Murray, S. Kavanagh, L. Morrison and D. Morris (2017). Silver nanoparticles in the environment: Sources, detection and ecotoxicology. *Science of The Total Environment,* **575:** 231-246.

Mikhak A., A Sohrabi, M Z Kassaee, M Feizian (2017). Synthetic nanozeolite/nanohydroxyapatite as a phosphorus fertilizer for German chamomile (*Matricaria chamomilla* L.). *Industrial Crops and Products*, **95:** 444-452.

Misra P, P K Shukla, K Pramanik, S Gautam and C Kole (2016). Nanotechnology for Crop Improvement. In: C. Kole et al. (eds.), *Plant Nanotechnology,* DOI: 10.1007/978-3-319-42154-4_9, Springer International Publishing Switzerland

Monreal C. M., M. DeRosa, S. C. Mallubhotla, P. S. Bindraban and C. Dimkpa (2016). Nanotechnologies for increasing the crop use efficiency of fertilizer-micronutrients. *Biol Fertil Soils* 52:423–437. DOI: 10.1007/s00374-015-1073-5.

Motesharezadeh B., H Etesami, S Bagheri-Novair and H Amirmokri (2017). Fertilizer consumption trend in developing countries vs. developed countries. *Environ Monit Assess* **189:**103. DOI: 10.1007/s10661-017-5812-y

Musazzi U. M., V. Marini, A. Casiraghi and P. Minghetti (2017). Is the European regulatory framework sufficient to assure the safety of citizens using health products containing nanomaterials? *Drug Discovery Today,* http://dx.doi.org/10.1016/j.drudis.2017.01.016

Nair P. M. G and Ill M. Chung (2014). Physiological and molecular level studies on the toxicity of silver nanoparticles in germinating seedlings of mung bean (*Vigna radiata* L.). *Acta Physiol Plant* **37:**1719. DOI: 10.1007/s11738-014-1719-1

Nair P. M. G, S-H Kim and Ill M Chung (2014). Copper oxide nanoparticle toxicity in mung bean (*Vigna radiata* L.) seedlings: physiological and molecular level responses of *in vitro* grown plants. *Acta Physiol Plant* **36:**2947–2958. DOI: 10.1007/s11738-014-1667-9

Negm AM, MGA Eltarabily (2016). Modeling of Fertilizer Transport Through Soil, Case Study: Nile Delta. In: A.M. Negm (ed.), *The Nile Delta, Hdb Env Chem,* DOI 10.1007/698_2016_88, *Springer International Publishing Switzerland*

Nordmeier A., J Woolford, L Celeste and D Chidambaram (2017). Sustainable batch production of biosynthesized nanoparticles. *Materials Letters,* **191:** 53-56.

Pacheco I and C Buzea (2017). Nanoparticle Interaction with Plants. In: M. Ghorbanpour et al. (eds.), *Nanoscience and Plant–Soil Systems, Soil Biology* 48, DOI 10.1007/978-3-319-46835-8_12, Springer *International Publishing AG*

Park T. J., K G. Lee and S Y Lee (2016). Advances in microbial biosynthesis of metal nanoparticles. *Appl Microbiol Biotechnol* **100**:521–534. DOI: 10.1007/s00253-015-6904-7

Parveen A. and S. Rao (2016). Synthesis of Silver Nanoparticles from Plants and Their Applications. In: M. Anis, N. Ahmad (eds.), *Plant Tissue Culture: Propagation, Conservation and Crop Improvement,* DOI: 10.1007/978-981-10-1917-3_19, Springer Science + Business Media Singapore

Patil S. S., U. U. Shedbalkar, A Truskewycz, Balu A. Chopade, A S. Ball (2016). Nanoparticles for environmental clean-up: A review of potential risks and emerging solutions. *Environmental Technology & Innovation,* **5:** 10-21.

Petosa A R, F Rajput, O Selvam, C Öhl and N Tufenkji (2017). Assessing the transport potential of polymeric nanocapsules developed for crop protection. *Water Research*, **111:** 10-17.

Pourjafar, L., Zahedi, H., & Sharghi, Y. (2016). Effect of foliar application of nano iron and manganese chelated on yield and yield component of canola (Brassica napus L.) under water deficit stress at different plant growth stages. *Agricultural Science Digest,* **36**(3).

Prasad R, Kumar V, Prasad KS (2014). Nanotechnology in sustainable agriculture: present concerns and future aspects. *Afr J Biotechnol* **13:**705–713.

Prasad R, Pandey R, Barman I (2016). Engineering tailored nanoparticles with microbes: quo vadis. *Wires Nanomed Nanobiotechnol* **8:**316–330

Prasad R. and E. Aranda (2018). Approaches in Bioremediation: The New Era of Environmental Microbiology and Nanobiotechnology. *Nanotechnology in the Life Sciences Series,* https://doi.org/10.1007/978-3-030-02369-0, Springer Nature Switzerland AG

Priester J H., S C Moritz, K Espinosa, Y Ge, Y Wang, R M. Nisbet, J P. Schimel, A. S Goggi, J L. Gardea-Torresdey, P A. Holden (2017). Damage assessment for soybean cultivated in soil with either CeO_2 or ZnO manufactured nanomaterials**.** *Science of The Total Environment*, **579:** 1756-1768.

Qados, A. M. A., & Moftah, A. E. (2015). Influence of Silicon and Nano-Silicon on Germination, Growth and Yield of Faba Bean (Vicia faba L.) Under Salt Stress Conditions. *American Journal of Experimental Agriculture*, **5**(6): 509

Rahmani F., A Peymani, E Daneshvand, P Biparva (2016). Impact of zinc oxide and copper oxide nano-particles on physiological and molecular processes in *Brassica napus* L. *Ind J Plant Physiol*. **21**(2): 122–128. DOI: 10.1007/s40502-016-0212-9.

Rai M., S Bansod, M Bawaskar, A Gade, C A dos Santos, A B. Seabra and N Duran (2015). Nanoparticles-Based Delivery Systems in Plant Genetic Transformation. In: M. Rai et al. (eds.), *Nanotechnologies in Food and Agriculture,* DOI: 10.1007/978-3-319-14024-7_10, Springer *International Publishing Switzerland*

Rajan A., A R Rajan, D Philip (2017). *Elettaria cardamomum* seed mediated rapid synthesis of gold nanoparticles and its biological activities. *Open Nano*, **2:** 1-8.

Raman P. P., S Parthiban, B. Srinithya, V. V Kumar, S P Anthony, A Sivasubramanian and M S Muthuraman (2015). Biogenic silver nanoparticles synthesis using the extract of the medicinal plant *Clerodendron serratum* and its *in-vitro* antiproliferative activity. *Materials Letters,* **160:** 400-403.

Rao KJ, Paria S (2013). Use of sulfur nanoparticles as a green pesticide on Fusarium solani and Venturia inaequalis phytopathogens. *RSC Adv* **3:**10471–10478.

Rashid A H A and D D Lateef (2016). Novel Techniques for Gene Delivery into Plants and Its Applications for Disease Resistance in Crops. *American Journal of Plant Sciences,* **7:** 181-193. http://dx.doi.org/10.4236/ajps.2016.71019

Ray M., A Ray, S Dash, A Mishra, K. G Achary, S Nayak, S Singh (2017). Fungal disease detection in plants: Traditional assays, novel diagnostic techniques and biosensors. *Biosensors and Bioelectronics,* 87: 708-723.

Rico, C. (2015). *Nanomaterial Implications for Agricultural Productivity and Food Safety.* http://www.azonano.com/article.aspx?ArticleID=4076, (20/12/2016).

Rizwan M, S Ali, M F Qayyum, Y S Ok, M Adrees, M Ibrahim, M Zia-ur-Rehman, M Farid, F Abbas (2017). Effect of metal and metal oxide nanoparticles on growth and physiology of globally important food crops: A critical review. *Journal of Hazardous Materials,* **322** (Part A): 2-16.

Roy S, T K Das, G P Maiti and U Basu (2016). Microbial biosynthesis of nontoxic gold nanoparticles. *Materials Science and Engineering*: B, **203**: 41-51.

Sabaghnia, N., and Janmohammadi, M. (2015). Effect of nano-silicon particles application on salinity tolerance in early growth of some lentil genotypes/ Wpływ nanocząstek krzemionki na tolerancję zasolenia we wczesnym rozwoju niektórych genotypów soczewicy. *Annales UMCS, Biologia,* **69**(2): 39-55.

Safavi K, Forogh M, Mahtab E, Mohammad (2011). *In vitro* antibacterial activity of nanomaterials for using in tobacco plants tissue culture. *World Acad Sci Eng Technol* **79**:372–373.

Safavi K. (2014). Effect of Titanium Dioxide Nanoparticles in Plant Tissue Culture Media for Enhance Resistance to Bacterial Activity. Bulletin of Environment, Pharmacology and Life Sciences *Bull. Env. Pharmacol. Life Sci*., 3 [Special Issue V] **2014**: 163-166.

Sakao T, A Öhrwallroennbaeck, G Ö Sandsrtoem (2013). Uncovering benefits and risks of integrated product service offerings: Using a case of technology encapsulation. *J Syst Sci Syst Eng* (Dec 2013) **22**(4): 421-439. DOI: 10.1007/s11518-013-5233-6.

Samet J. M. (2014). Engineered Nanomaterials and Human and Environmental Health: Research Strategies to Address Potential Risks. *Curr Envir Health Rpt* **1:**217–226. DOI: 10.1007/s40572-014-0023-y

Santhosh C., V Velmurugan, G Jacob, S K Jeong and A Bhatnagar (2016). Role of nanomaterials in water treatment applications: *A review. Chemical Engineering Journal,* **306:** 1116-1137.

Sarlak N and A Taherifar (2017). Encapsulation of Nanomaterials and Production of Nanofertilizers and Nanopesticides: Insecticides for Agrifood Production and Plant Disease Treatment. In: M. Ghorbanpour et al. (eds.), Nanoscience and Plant–Soil Systems, *Soil Biology* **48,** DOI 10.1007/978-3-319-46835-8_18, Springer International Publishing AG

Sarmast M. K. and H. Salehi (2016). Silver Nanoparticles: An Influential Element in Plant Nanobiotechnology. *Mol Biotechnol* **58:**441–449. DOI: 10.1007/s12033-016-9943-0

Sastry, R.K. (2012). Potential Economic Impacts of Agri- Nanotechnology. *"International Symposium on Assessing the Economic Impact of Nanotechnology*", Washington DC

Schmidt, C. W. (2009). Nanotechnology-related environment, health, and safety research. *Environmental Health Perspectives,* **117**(4), A158-A161.

Schoebitz M. and M D L Belchí (2016). Encapsulation Techniques for Plant Growth-Promoting Rhizobacteria. In: N.K. Arora et al. (eds.), *Bioformulations: for Sustainable Agriculture,* DOI: 10.1007/978-81-322-2779-3_14, Springer India

Seghatoleslami, M., and Forutani, R. (2015). Yield and Water Use Efficiency of Sunflower as Affected by nano ZnO and Water Stress. *Journal of Advanced Agricultural Technologies* **2**(1): 34 – 37.

Seghatoleslami, M., Feizi, H., Mousavi, G., and Berahmand, A. (2015). Effect of magnetic field and silver nanoparticles on yield and water use efficiency of Carum copticum under water stress conditions. *Polish Journal of Chemical Technology,* **17**(1): 110-114.

Servin A D. and J. C. White (2016). Nanotechnology in agriculture: Next steps for understanding engineered nanoparticle exposure and risk. *NanoImpact* **1:** 9–12. http://dx.doi.org/10.1016/j.impact.2015.12.002

Shallan M. A., Hassan H. M., Namich A. A. M., and Ibrahim A. A. (2016). Biochemical and Physiological

Effects of TiO_2 and SiO_2 Nanoparticles on Cotton Plant under Drought Stress. *RJPBCS* **7**(4) P. 1541

Sharma VK, Filip J, Zboril R, Varma RS (2015). Natural inorganic nanoparticles – formation, fate, and toxicity in the environment. *Chem Soc Rev* **44:** 8410–8423.

Shuai H-L, K-J Huang, W-J Zhang, X Cao, M-P Jia (2017). Sandwich-type microRNA biosensor based on magnesium oxide nanoflower and graphene oxide–gold nanoparticles hybrids coupling with enzyme signal amplification. *Sensors and Actuators B: Chemical,* **243:** 403-411

Shukla P K, P Misra and C Kole (2016). Uptake, Translocation, Accumulation, Transformation, and Generational Transmission of Nanoparticles in Plants. In: C. Kole et al. (eds.), *Plant Nanotechnology,* DOI 10.1007/978-3-319-42154-4_8, *Springer International Publishing Switzerland*

Siddiqi K S and A Husen (2017b). Plant Response to Engineered Metal Oxide Nanoparticles. *Nanoscale Research Letters* **12**: 92. DOI: 10.1186/s11671-017-1861-y

Siddiqi K S, A Husen (2017a). Recent advances in plant-mediated engineered gold nanoparticles and their application in biological system. *Journal of Trace Elements in Medicine and Biology,* **40**: 10-23.

Siddiqui, M. H., Al□Whaibi, M. H., Faisal, M. and Al Sahli, A. A. (2014). Nano□silicon dioxide mitigates the adverse effects of salt stress on Cucurbita pepo L. *Environmental Toxicology and Chemistry,* **33**(11): 2429-2437.

Singh J. and B. K. Lee (2016). Influence of nano-TiO_2 particles on the bioaccumulation of Cd in soybean plants (*Glycine max*): A possible mechanism for the removal of Cd from the contaminated soil. *Journal of Environmental Management,* **170:** 88-96.

Soliman, A. S., El-feky, S. A., and Darwish, E. (2015). Alleviation of salt stress on Moringa peregrina using foliar application of nanofertilizers. *Journal of Horticulture and Forestry,* **7**(2): 36-47.

Spinoso-Castillo J. L., R. A. Chavez-Santoscoy, Nina Bogdanchikova, J. A. Pérez-Sato, V. Morales-Ramos, J. J. Bello-Bello (2017). Antimicrobial and hormetic effects of silver nanoparticles on *in vitro* regeneration of vanilla (*Vanilla planifolia* Jacks. ex Andrews) using a temporary immersion system. *Plant Cell Tiss Organ Cult,* DOI: 10.1007/s11240-017-1169-8

Srivastava P. and M. Kowshik (2015). Biosynthesis of Nanoparticles from Halophiles. In: D.K. Maheshwari, M. Saraf (eds.), *Halophiles, Sustainable Development and Biodiversity* **6,** DOI: 10.1007/978-3-319-14595-2_4, Springer International Publishing Switzerland

Subramanian K. S. and M. Thirunavukkarasu (2017). Nano-fertilizers and Nutrient Transformations in Soil. In: M. Ghorbanpour et al. (eds.), *Nanoscience and Plant–Soil Systems, Soil Biology* **48,** DOI 10.1007/978-3-319-46835-8_11, Springer International Publishing AG

Tan W, W Du, A C. Barrios, R Armendariz, J L. Gardea-Torresdey (2017). Surface coating changes the physiological and biochemical impacts of nano-TiO_2 in basil (*Ocimum basilicum*) plants. *Environmental Pollution*, **222:** 64-72.

Tayel A., W. El-Tras, S. Moussa, A. El-Baz, H. Mahrous, M. Salem and L. Brimer (2011). Antibacterial action of zinc oxide nanoparticle agents' foodborne pathogens. *J Food Saf* **31**:211–218

Teow Y., Asharani, P.V., Hand, M.P., Valiyaveettil, S. (2011). Health impact and safety of engineered nanomaterials. *Chem Commun.* **47:** 7025-7038

Tomankova K., J Horakova, M Harvanova, L Malina, J Soukupova, S Hradilova, K Kejlova, J Malohlava, L Licman, M Dvorakova, D Jirova and H Kolarova (2015). Reprint of: Cytotoxicity, cell uptake and microscopic analysis of titanium dioxide and silver nanoparticles *in vitro*. *Food and Chemical Toxicolog*y, **85:** 20-30.

Torney F., B G. Trewyn, V S.-Y. Lin and K Wang (2007). Mesoporous silica nanoparticles deliver DNA and chemicals into plants. *Nature Nanotechnology* **2:** 295 – 300.

Tripathi D K, S Singh, S Singh, R Pandey, V P Singh, N C. Sharma, S M Prasad, N K Dubey, D K Chauhan (2017a). An overview on manufactured nanoparticles in plants: Uptake, translocation, accumulation and phytotoxicity. *Plant Physiology and Biochemistry,* **110:** 2-12.

Tripathi D K, S Singh, V P Singh, S M Prasad, N K Dubey and D K Chauhan (2017b). Silicon nanoparticles more effectively alleviated UV-B stress than silicon in wheat (*Triticum aestivum*) seedlings. *Plant Physiology and Biochemistry* **110:** 70-81

Tripathi D K, P Ahmad, S Sharma, D K Chauhan and N K Dubey (2019). *Nanomaterials in Plants, Algae* *and Microorganisms: Concepts and Controversies,* Volume 2. Academic Press, Elsevier Inc.

Vena M. P, Matías Jobbágy and Sara A. Bilmes (2016). Microorganism mediated biosynthesis of metal chalcogenides; a powerful tool to transform toxic effluents into functional nanomaterials. *Science of The Total Environment,* **565:** 804-810.

Vestergaard M. C. and E. Tamiya (2015). Nanobiosensors and Nanobioanalyses: A Review. In: M.C. Vestergaard et al. (eds.), *Nanobiosensors and Nanobioanalyses*, DOI: 10.1007/978-4-431-55190-4_1, Springer Japan

Vestergaard M. C., K Kerman, I-M Hsing and E Tamiya (2015). *Nanobiosensors and Nanobioanalyses.* DOI: 10.1007/978-4-431-55190-4, Springer Japan

Walz, T., B. L. Smith, et al. (1994) Biologically active two-dimensional crystals of aquaporin CHIP." *J. Biol. Chem*. **269:** 1583-1586.

Wang, S., F. Wang and S. Gao (2015). Foliar application with nano-silicon alleviates Cd toxicity in rice seedlings. *Environmental Science and Pollution Research,* **22**(4), 2837-2845.

Wigger H. (2017). *Environmental Release of and Exposure to Iron Oxide and Silver Nanoparticles: Prospective Estimations Based on Product Application Scenarios.* Springer Fachmedien Wiesbaden GmbH, DOI: 10.1007/978-3-658-16791-2

Xu M, X Bai, L Pei and H Pan (2016). A research on application of water treatment technology for reclaimed water irrigation. *International Journal of Hydrogen Energy*, **41** (35): 15930-15937.

Yang Y-F, Y-H Cheng and C-M Liao (2017). Nematode-based biomarkers as critical risk indicators on assessing the impact of silver nanoparticles on soil ecosystems. *Ecological Indicators,* 75: 340-351.

Yuan C-G, C Huo, S Yu and B Gui (2017). Biosynthesis of gold nanoparticles using Capsicum annuum var. grossum pulp extract and its catalytic activity. *Physica E: Low-dimensional Systems and Nanostructures,* **85:** 19-26.

Zafar H., A. Ali and M Zia (2017). CuO Nanoparticles Inhibited Root Growth from Brassica nigra Seedlings but Induced Root from Stem and Leaf Explants. *Appl Biochem Biotechnol* **181**:365–378. DOI: 10.1007/s12010-016-2217-2

Zuverza-Mena N., D Martínez-Fernández, W Du, J A. Hernandez-Viezcas, N Bonilla-Bird, M L. López-Moreno, M Komárek, J R. Peralta-Videa, J L. Gardea-Torresdey (2017). Exposure of engineered nanomaterials to plants: Insights into the physiological and biochemical responses-A review. *Plant Physiology and Biochemistry*, **110:** 236-264.

(*Received* 16/12/2018;
accepted 10/1/2019)