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Nanoparticles: A Novel Approach for Sustainable Agro-productivity

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THE GLOBAL agricultural production suffers from many problems and challenges including climate change, natural resources depletion, environmental pollution, soil degradation, etc. Hence, the global security of this vital sector definitely will be threaten including water security, soil security, energy security, food security, etc. Day by day, several attempts already have been conducted in seeking of the humanity for suitable and sustainable solutions to overcome these previous problems. Nanotechnology was and still one of the most important solutions, which will help us to overcome these problems. So, several nanomaterials have been successfully used in many agro-production fields including nanofertilizers, nanopesticides, nanoremediation, nanobiosensors as well as using of nanoparticles in agri-food production. These nanomaterials can help the agro-production to exploit the natural resources in more sustainable manner and to minimize the agro-wastes. Therefore, regulations for more safety in nanomaterials utilization for agro-production should be starting from the handling for seed germination till the handling for postharvest of agricultural products. Several investigations have been proved the importance of nanomaterials in global securities, the agro-production through the nano-agro-chemicals, management of the agro-wastes, etc. Therefore, this review will highlight new insights and novel approaches for using nanomaterials for sustainable agro-productivity. It will also include the impact of nanomaterials on the agro-environement and the enhanced productivity in frame of sustainability.

Keywords: Nanomaterials; Sustainable; Water security; Soil security; Nanofertilizers; Agro-production; Nanoremediator.

Introduction

Due to the limitation of water and arable land resources, an urgent need is requested to increase effective use of these resources as well as minimize the agro-ecology damage by using the effective modern technologies like nanotechnology (Manjunatha et al. 2016). Several applications of nanotechnologies can be addressed in the developing countries including production, conversion and storage energy (like CNT storage of H; Zhang et al. 2014(a or b); Li and Sun 2016; Liu et al. 2017), enhancement of the agricultural productivity (like herbicide delivery; Pandey et al. 2016; Chhipa and Joshi 2016), water treatment and remediation (like nano-membranes; Toli et al. 2016; Polloni-Silva et al. 2017), diagnosis and screening of diseases (Wang et al. 2016; Mignani et al. 2017), delivery systems of drugs (like nano-capsules; Nawaz and Wong 2017; Wang et al. 2017), processing, coating, packaging and storage of foods (Carbone et al. 2016; Sarkar et al. 2016; Chalco-Sandoval et al. 2017), remediation of air pollution (like nano-catalysts; Kuppusamy et al. 2016), durability of construction (Balapour et al. 2017; Fallah and Nematzadeh 2017), monitoring

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of health (like sensors; Nag-Chowdhury et al. 2016), detection, control of vector and pests (like sensors and pesticides; Chhipa et al. 2016; Dubey and Mailapalli 2016; Manjunatha et al. 2016).

Serious and terrible threats face the world including the global security resulting from the continuous global changes. This global security includes different security types such as water security (Gohar and Cashman 2016; Kang et al. 2017; Malekian et al. 2017; Zhang and Vesselinov 2017), soil security (Koch et al. 2012 2013; Koch 2017), food security (Gohar and Cashman 2016; Kang et al. 2017; Zhang and Vesselinov 2017), energy security (Markovska et al. 2016; Zhang and Vesselinov 2017), environment security (Markovska et al. 2016; Kang et al. 2017), communication security (Alexiou et al. 2016; Gandotra et al. 2017), information security (Spanos and Angelis 2016; Han et al. 2017), etc. The sustainable agro-production mainly depends on many mentioned securities including soil, water, energy and food security. Furthermore, there is closed links among these securities such as food, water, soil and energy security, where the agro-food production and its security need the integration among all these securities. It is worth mentioning that, nanotechnology applications can be used to achieve these previous securities (Siddiqui et al. 2015; Belal and El-Ramady 2016; Dasgupta et al. 2016; Dubey et al. 2016; Kole et al. 2016; Shalaby et al. 2016; Rai and da Silva 2017).

Concerning the applications of nanotechnology in agriculture sector, it thought that nanotechnology will totally revolutionize it (Singh and Prasad 2016). This nanotechnology has the ability to penetrate different agricultural fields including treatment and detection of plant diseases (Park et al. 2006; Al-Samarrai 2012; Servin et al. 2015; Álvarez et al. 2016; Wang et al. 2016; Mignani et al. 2017; Ray et al. 2017), using as sensors (Fryxell and Cao 2007; Otles and Yalcin 2010; Rai et al. 2012; Farrell et al. 2013; Ansari et al. 2016; Chhipa and Joshi 2016; Dubey and Mailapalli 2016; Jyoti and Tomar 2016; Purkayastha and Manhar 2016; Bäcker et al. 2017; Bazin et al. 2017; Lee et al. 2017; Ray et al. 2017; Saylan et al. 2017),(Only recent references are sufficient) nanofertilizers (Naderi and Danesh-Shahraki 2013; Tarafdar et al. 2014; Dubey and Mailapalli 2016; Chhipa 2016; Chhipa and Joshi 2016), nanopesticides (Kah et al. 2013, 2014; Kah and Hofmann 2014; Dubey and Mailapalli 2016; Chhipa 2016; Chhipa and Joshi 2016; Pandey et al. 2016; Zhao et al. 2016; Balaure et al. 2017; Jacques et al. 2017), and using in gene transfer as smart delivery systems (Peters et al. 2016; Singh and Prasad 2016). The over application of nanomaterials in agriculture leads to the negative effects representing in the toxic action of these nanomaterials for the agroecosystems (Holden et al. 2013; Hong et al. 2013; García-Gómez et al. 2015; Belal and El-Ramady 2016; Dwivedi et al. 2016; El-Temsah et 2016; Hegde et al. 2016; Hu et al. 2016; Singh and Prasad 2016; Guo et al. 2017).

Nearly all agricultural practices and production may be touched or penetrated by the nanotechnological sciences. So, several agro-products could not be only fabricated using nanomaterials but also a huge amount of agro-wastes can be managed using these nanomaterials (Dwivedi et al. 2016; Panpatte et al. 2016; Peters et al. 2016; Adebisi et al. 2017; Patil et al. 2017). Hence, great challenges have been created seeking for the sustainability of agro-production including soil security, water, security, energy security, food security, reduction of poverty and improvement of human public health (Ditta et al. 2015; Gupta and Verma 2015; Bello et al. 2016; De La Cueva Bueno et al. 2017; Nuhoff-Isakhanyan et al. 2017). Therefore, many risks have been resulted from this using nanomaterials in agro-production and hence safety approaches should be regulated (Hegde et al. 2016; Mattsson and Simkó 2016; Pandey et al. 2016; Servin and White 2016; Syberg and Hansen 2016; Yang et al. 2016; de Lourdes Oshiro et al. 2017). Although these nanoparticles may have the ability in conservation of both water and lands through certain applied concentrations, they substantially should also sustain or conserve the environment (Chen and Yada 2011; Prasad et al. 2012; Ditta et al. 2015; Bello et al. 2016; Cecchin et al. 2016; Antunes et al. 2017; De La Cueva Bueno et al. 2017). Therefore, this chapter will focus on different applications of nanoparticles in a sustainable agro-production including nano-agrochemicals, nanobiosensors and nano-agro-food production. The application of nanoparticles in the management of agro-wastes and the risks as well as safety of these nanoparticles will be also highlighted.

Nanoparticles for sustainable agro-production

Agriculture sector directly or indirectly is the backbone of most developing countries and it has been one of the primary drivers of economy.

Therefore, it is important to recognize the global agro-production problems such as changing climate, sustainable use of natural resources and environmental issues like runoff and accumulation of pesticides and fertilizers as well as urbanization (Lal et al. 2016; Arodudu et al. 2017; Chen et al. 2017). In addition, the world's population will grow to a reach about to 6-9 billion people by 2050 and it must improve to feed a rapidly growing world population (Chen and Yada 2011; Ditta et al. 2015). Hence, it is necessary to use the modern agricultural technologies such as nanotechnology and nanobiotechnology for sustainable agro-production, which it can be use of nano-sized particles with some unique properties such as thermal, optical, chemical, physical, magnetic and electrical compared to properties of their bulk material (Duràn et al. 2007). On the other hand, complete characterization of nanoparticles (NPs), including shape, surface area, surface chemistry, surface charge, size distribution, crystallinity, porosity, and solubility are poorly understood (Dhawan and Sharma 2010; Anandharamakrishnan 2014; Maskos and Stauber 2017).

Therefore, the topic of nanoparticles could be considered as one of the most important tools in sustainable agro-production by improving the productivity of crops including crops for human consumption and animal feeding as well as reducing pesticide use (Dwivedi et al. 2016; Shalaby et al. 2016; Thakur and Maiti 2016). Furthermore, the application of nanoparticles can help the environment through agro-waste reduction as well as high-value products and pollution control (Hong et al. 2013; Belal and El-Ramady 2016; Bäuerlein et al. 2017). To sum up, the most important parameter that should be considered for characterization of nanoparticles is the size (Madhumitha et al. 2016). Also, it is critical for assessment of the interactions of nanoparticles with living systems (Berhanu et al. 2009; Sayesand Warheit 2009; Warheit 2008; Siddiqui et al. 2015; Kole et al. 2016). To determine the size and other physico-chemical properties of nanoparticles there are many methods and technology such as atomic force microscopy (AFM), scanning electron microscopy (SEM), transmission electron microscopy (TEM), dynamic light scattering (DLS), Brunauer–Emmett–Teller (BET), X-ray diffractometer (XRD) and UV–vis spectrophotometer (e.g., Kumar et al. 2011a, b, c; Park et al. 2014; Pu et al. 2015; Madhumitha et al. 2016).

Therefore, it could be sustained the agricultural production using different nanomaterials and nanoparticles. This point of view has been explained in details in many studies such as Ditta et al. (2015), Belal and El-Ramady (2016), Chhipa and Joshi (2016), Chhipa (2016), Dubey and Mailapalli (2016), Dwivedi et al. (2016), Panpatte et al. (2016), Shalaby et al. (2016), etc. Hence, the sustainable agricultural production using different nanomaterials can be performed in different natural resources including plants (Siddiqui et al. 2015; Kole et al. 2016; Dubey et al. 2016), water (Dasgupta et al. 2016), soil (Belal and El-Ramady 2016; Shalaby et al. 2016), energy (Rai and da Silva 2017), etc. Furthermore, the depletion or over-consumption of these previous resources can be considered a great threat to the sustainability of the agricultural activities. Therefore, it should be focused on the security of these previous resources (water security, soil security, energy security, food security, environment security, etc.) in frame of the sustainability of nanomaterials.

Nanoparticles and water security

Due to several challenges facing the humanity, there is a crucial need for the green nanotechnology to overcome these problems. The nanomaterials can provide us with the sustainable natural resources including energy, water, lands, etc (Belal and El-Ramady et al. 2016; Shalaby et al. 2016) and several nanoparticles can be used in sustaining different agricultural fields. Therefore, a new mission for the nanotechnology will be created in our seeking towards the security of the entire environment and its components. There is a growing attention for the agricultural water security due to some threats and hazards related to water including floods, drought, pollution, etc. (Dressler and Kargl 2012; Malekian et al. 2017). It is worth to mention that, the agricultural water security is of utmost importance because the agriculture uses represent about 70 % from the renewable water resources worldwide (Taylor 2015; Malekian et al. 2017). A great pressure will be increased on irrigation systems as well as the agricultural production and its quality due to water security. Therefore, without the consideration of the water availability, any discussion about any agricultural activity will be incomplete (Malekian et al. 2017).

Nanomaterials have been used in treatment of agricultural waste water and remediation of pollution (An and Dong 2015). It was reported that, nano-materials (like nano-iron and nano-TiO_2)

have been used in remediation of groundwater and removing of nitrate, perchlorate, trichlorethylene and other pollutants (An and Dong 2015; Georgi et al. 2015; El-Temsah et al. 2016; Hamza et al. 2016; Khalil et al. 2017). Concerning nanoremediation, it is well known that, the nanoremediation process refers to the using of nanomaterials in remediating different environmental compartments including contaminated soils, groundwater, waste water, sediments, etc. (Abhilash et al. 2016; Belal and El-Ramady 2016; Gomes et al. 2016; Gil-Díaz et al. 2016; Kuppusamy et al. 2016; Pulimi and Subramanian 2016; Gil-Díaz et al. 2017). This process includes some techniques in case of wastewater treatment such as metal-based nano-adsorbents (nano-TiO_2, nanoiron oxide and nano-Al_2O_3 and polymeric nano-adsorbents), nanomembrane filtration techniques (nano-composite, nano-fiber membranes and thin-film nano-composite membranes) and photocatalysis (Qu et al. 2013; Hamza et al. 2016). Therefore, a further research concerning nanomaterials and the water security is needed including different water issues (proper quantity and quality as well as clean and safe water for all populations). Several factors should be also considered concerning water security ranging from the infrastructural, political, economical, social, financial, and biophysical to the global climate changes. Water security also should include both the top level (the global challenge) to the bottom level (societal value).

Nanoparticles and soil security

Great environmental challenges face humanity including the security of food, water, energy, climate changes and protection the global biodiversity (Bouma and McBratney 2013). So, several global securities containing environment security, water security, food security and energy security and these securities involves how to provide all population worldwide with safe food, water, energy. Therefore, it could be defined the soil security as reported in the great book: „*Global Soil Security*" edited by Field et al. (2017). This definition is based on the the rationale (McBratney et al. 2017), the soil dimensions (Field 2017) including the soil capability (Bouma et al. 2017), the soil condition (Lewis et al. 2017), the soil capital (McCarl 2017), the connectivity (Carré et al. 2017), and finally the codification (Koch 2017) as well as the securitisation (McBratney and Jarrett 2017). Therefore, this section will address the questions raised by the use of nanotechnology and its effects on soil security.

At the same time, there is an urgent need to enhance and sustain the agricultural productivity, mitigation of global climate changes, restoration the soil and water resources quality and improvement of the global biodiversity (Lal 2009; Koch 2017). Also, there are several functions of soil such as (1) biomass production, (2) filteration and transformation of substances and nutrients, (3) acting as a carbon and a biodiversity pools, (4) acting as a physical, cultural environments and source of raw materials, and (5) archiving of the geological and cultural heritage (McBratney et al. 2014). From these previous soil functions, a direct or indirect link between nanomaterials and soil security can be found such as nanomaterials and biodiversity (Macer 2014; Schlich et al. 2016), nanomaterials and biomass production (De and Luque 2016; Ma et al. 2017), nanomaterials and soil holding of water and nutrients (Thul and Sarangi 2015; Belal and El-Ramady 2016; Dwivedi et al. 2016; Pulimi and Subramanian 2016; Servin and White 2016), etc.

Nanoparticles and energy security

It is well known that, energy is the backbone and the crucial element for different kinds of development for all countries including the social, economical and sustainable fields. Several factors control the energy demand including the growth rate of population, the demographic changes and the income per capita, etc (Shaikh et al. 2016). Therefore, an urgent need for the security of energy should be considered or kept into account and the energy should be addressed with water and the environmental systems in frame of the sustainable development. Several challenges will face the universe concerning the energy security during the 21st century such as advancing the energy technologies (like using nanomaterials), enhancing the energy efficiency and energy savings in buildings and moving towards energy systems based on renewable energy sources (Markovska et al. 2016). Regarding the nanomaterials use for bioenergy and biofuel production, Springer already has published a book entitled „nanotechnology for bioenergy and biofuel production" edited by Rai and da Silva (2017). This book emphasized that it could be used nanotechnology in production both of the sustainable biofuel and bioenergy. Several nanomaterials can be used as nanocatalysts including nanofiber, nanotubes, metal nanoparticles, nanosheets and others in the production of biofuels (e.g., bioethanol and biodiesel) as reported by Antunes et al. (2017).

Many applications of nanomaterials in bioenergy and biofuels production have been confirmed including lignocellulosic biomass (de Oliveira et al. 2017), carbon-based nanomaterials in the biofuel cell (Ma et al. 2017), nanomaterials for microalgae-based biofuels (Seo et al. 2017), deoxygenation of nonedible biomass (Lee and Juan 2017), and magnetic nanoparticles for biogas production (Antunes et al. 2017). Therefore, many beneficials for nanomaterials in the biofuel production such as improving of the raw materials and assisting in processes and products developed in the industry of sugarcane. On the other hand, several problems will be generated by using of nanomaterials for the biofuel production. Seeking for a sustainable future of the use of nanomaterials in the biofuel production, a concern nanotoxicity research, governance, regulation and the social perspectives should be developed (de Lourdes Oshiro et al. 2017).

Therefore, it could be concluded that, nanotechnology is a promising field in dealing with the sustainability of different agricultural activities. This sustainable agriculture can be achieved through different applications of nanotechnology including the management and security of the natural resources from water, food, energy, soil, to the entire environment. There is not only a sustainable agro-production without considering the security of all natural resources, but also we can not use the applications of nanotechnology without considering the rules of the sustainability. Hence, great challenges face the agricultural production using the nanomaterials and more attention should be done at all levels from the top to bottom and *vis versa.* The recent agricultural practices can be improved with help of the nanotechnology by enhancing the conservation and management of cultivated crops.

Nanoparticles in agro- production

Nanoparticles application to the agro-production sector is multidisciplinary in nature. Therefore, the use of nanoparticles in agriculture has been touched several topics including nanoagrochemicals, nanofertilizers, nanopesticides and nanosensors as mentioned before (Dwivedi et al. 2016; Panpatte et al. 2016; Servin and White 2016). Also, it must improve the global food production, enhancing its quality and reducing the agro-wastes (**Fig. 1**). The most

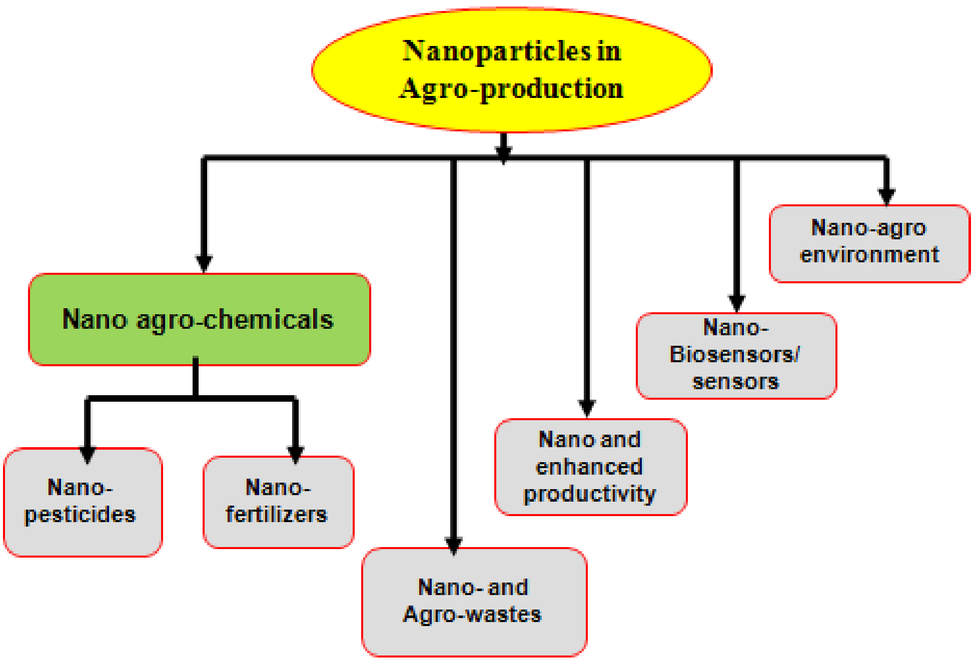

Fig. 1. Multidisciplinary nature of nanoparticles in agro-production including the agrochemicals like fertilizers and pesticides, nanomaterials and agro-wastes, nanosensors, using nanoparticles in enhancing the plant productivity.

important applications of nanotechnology in agriculture include the monitoring of different environmental stresses (Calanca 2017), delivering different and proper nutrients for plants (Chhipa and Joshi 2016), enhancing the plant protection against pests and diseases (Dubey and Mailapalli 2016), delivering the appropriate pesticides (Chhipa 2016), enhancing the nutritional and quality of yields (Patra et al. 2016) and remediating the contaminated soil and groundwater (Dasgupta et al. 2016; Pulimi and Subramanian 2016; Singh and Prasad 2016). This section includes the application of nano-agrochemicals (nanofertilizers, nanopesticides, soil nano-conditioners, etc.) in increasing the efficiency of agricultural practices.

Nano-agrochemicals

Food security and nutrition are essential dimensions of sustainable agro-production development. In addition, climatic changes at global level have led to drastic reduction in agro-production sector as well as sustainable use of natural resources, urbanization and environmental factors (Aouada and de Moura 2015; Panpatte et al. 2016; Pramanik and Pramanik 2016). Over use fertilizers and accumulation of pesticides are the most important problems of modern agriculture. This poses a serious threat to food security of human on this planet. Because of this, modern agricultural require the use of nanoagrochemicals (Sekhon 2014; Campos et al. 2015; Pulimi and Subramanian 2016). The use of nanoagrochemicals applications in the form of nanofertilizers and nanopesticides for plant nutrition and protection is crucial for sustainable agro-production (Mastronardi et al. 2015; Chhipa 2016). It is worth to mention that, the nano-agrochemicals may include nanofertilizers, nanopesticides, soil nano-conditioners, etc.

Nano-fertilizers

Most of the applied fertilizers are rendered unavailable to plants due to many factors, such as leaching, degradation by hydrolysis, photolysis and decomposition (Belal and El-Ramady 2016; Chhipa 2016). Hence, it is necessary to minimize nutrient losses during fertilization processes and to increase the crop yield through the exploitation of new applications with the help of nanoparticles (Siddiqui et al. 2015; Pulimi and Subramanian 2016; El-Ramady et al. 2017b). Fertilizers play a pivotal role in increasing the agricultural production by up to 35-40%. Therefore, it is very important for plant growth and development. Application of nanofertilizers for traditional fertilizer is beneficial because these nanofertilizers have the ability to release nutrients into soils steadily and in a controlled way preventing water pollution (Naderi and Danesh-Shahraki 2013; Singh et al. 2015b; Pandey et al. 2016). Because of development and application of nanofertilizers are still at initial stages, further research should be carried out including all crops and edible plants.

Nanofertilizers can be classified into two categories including macro- and micro-nutrient nanofertilizers. Concerning macronutrient nanofertilizers such as N, P, K, Mg and Ca, they are comprised of one or more elements that are able to provide essential macronutrients to plants (Liu and Lal 2015). The use of macro-nutrient nanofertilizers leads to an increased efficiency of the elements and reduces the toxicity of the soil, to at least reach the negative effects (Naderi and Danesh-Shahraki, 2013). On the other hand, micronutrient nanofertilizers include Fe, Mn, Zn, Cu, and Mo among others, whereas these micronutrients are essential elements that are used by plants in small quantities. In nanofertilizers, the nutrients can be used as coated with thin protective polymer film or capsulated inside nanomaterials (Rai et al. 2012). There are a few systemic studies on the effects of applying nutrient nanofertilizers under field conditions (Liu and Lal 2015). Fertilizers formulations of chitosan NPs for controlled release of NPK (Corradini et al. 2010; Hasaneen et al. 2014), hydroxyapatite NPs for the provider of P nutrients to crops (Sarkar et al. 2015; Das et al. 2016).

Foliar application of nano-Ca and nano-K chelated fertilizers on *Ocimum basilicum* had beneficial effect on production characteristics of plants (Ghahremani et al. 2014). Calcium phosphate nano gel fertilizer composites were found to increase the germination in *Oryza sativa*, *Arachis hypogea* and *Amaranthus spinosus* plants (Umarani and Mala 2013). Pot studies with foliar spray approach with zinc oxide nanoparticle solution at 20 mg mL^{-1} on alfalfa, tomato and cucumber plants at the germination stage showed improved growth and biomass production as compared to control plants (Panwar et al. 2012 and de la Rosa et al. 2013; Sekhon 2014; Adhikari et al. 2015, 2016). Therefore, the application of nanofertilizer has several benefits such as it increases the efficiency of the elements, decreases the soil toxicity and reduces the frequency of fertilizer's application. Fertilizer particles can be coated with nano-membranes that facilitate the slow and steady release of nutrients (Table 1; Singh and Prasad 2016). Furthermore, nutrients derived from nanoencapsulation or nanofertilzers have some properties like the controlled release of chemical fertilizers regulating plant growth, enhancing target activity and making them effective to crops demand (De Rosa et al. 2010; Nair et al. 2010; Mani and Mondal 2016; El-Ramady et al. 2017b).

Therefore, it could be concluded that, nanofertilizers have many distinguished properties such as (1) the main dimension of nutrient carrier ranges from 30 – 40 nm, (2) the nutrient use efficiency of nanofertilizers is high comparing with traditional fertilizers, as well as release of nutrients is slowly and steadily for

TABLE 1. Different effects of nanofertilizers on some agricultural crops.

Crop (Plant species)	**Nanofertilizer (used dose or rate)**	**Biological impact of nano-fertilizer on agricultural crop**	**Reference**
Maize (Zea mays L.)	Nano-CuO (10 ppm)	Promoting of plant growth by 51% over control	Adhikari et al. (2016)
	Nano-ZnO (10 ppm)	Improving both of the plant height and dry weight	Adhikari et al. (2015)
	Nano- SiO2 (0–25 ppm)	Improving in the mean germination time	Najafi Disfani et al. (2016)
Pomegranate (*Punica granatum* L.)	Nano-B (34 mg B tree^{-1}) and nano-Zn (636 mg Zn tree^{-1})	Increasing pomegranate fruit yield, fruit quality and the number of fruits per tree	Davarpanah et al. (2016)
Pearl millet (*Pennisetum americanum* L.)	Zn nanofertilizer (39.2 ppm)	Improving grain yield (by 38 %), enhancing soil alkaline phosphatase (77 %), acid phosphatase (62 %) phytase (322 %) over the control	Tarafdar et al. (2014)
Lettuce (Lactuca sativa L.)	Nano-Cu, -Mn, -Fe, -Zn (5–20 ppm)	Stimulating the growth of lettuce seedlings by 12–54 %	Liu et al. (2016)
	Nano-Cu (130–600 ppm)	Increasing in both of shoot and root length	Shah and Belozerova (2009)
Mung bean (Vigna radiata L.)	Nano-ZnO (500 – 4000 ppm)	Stimulating seed germination, photo-synthetic pigments and nutritive values of seeds	Patra et al. (2013)
	Nano-ZnO (01–2000 ppm)	Increasing the plant growth at 20 ppm	Mahajan et al. (2011)
	Nano-Mn (0.05–1 ppm)	Increasing in chlorophyll content, photosynthesis rate and shoot length	Pradhan et al. (2013)
Wheat (*Triticum aestivum* L.)	Nano- SiO2 (50 – 800 ppm)	Decreasing in leaf chlorophyll, carotenoids content, increasing in leaf proline, lipid peroxidation and CAT activity > 200 ppm but enhanced growth at 50-100 ppm	Karimi and Mohsenzadeh (2016)
	Nano-ZnO (125 – 500 ppm)	Improving of Zn levels in plants at low concentration but inhibition root elongation at higher ones	Watson et al. (2015)
	Nano-ZnO (1000 ppm)	Inhibition soil microbial activity and plant growth parameters	García-Gómez et al. (2015)
Rice (Oryza sativa L.)	Nano-CuO (2.5 – 1000 ppm)	Increasing level of oxidative and osmotic stress, higher expression of APX and SOD enzymes	Da Costa and Sharma (2016)
Bean (Phaseolus vul-garis L.)	Nano-CuO (100 – 500 ppm)	Nano-CuO decreased uptake levels of Fe, Zn and Ca by shoots	Dimkpa et al. (2015)
Brassica juncea	Nano-CuO2 (200 – 1500 ppm)	Phytotoxic at higher concentration causing cell death and accumulated reactive species	Rao and Shekhawat (2016)

Abbreviations: APX: ascorbate peroxidase; SOD: superoxide dismutase; CAT: catalase more than 30 days, (3) the nanofertilizers are easy to synthesize through fortifying nutrients in single or in combinations so, deliver slowly over a long time reducing the loss of nutrients to the environment (Subramanian et al. 2015; Belal and El-Ramady 2016).

Nano-pesticides

It is well known that, the pesticides are substances used in plant defence against pest organisms. The applied pesticides include fungicides, insecticides, herbicides, nematicides etc. Unsustainable management of our soil resources has been resulted from the use of synthetic pesticides, although several pesticides eliminate the problem of pests (Bhattacharyya et al. 2016). In the modern agricultural, pesticides are commonly used to increase crop yield and efficiency. Therefore, nanopesticides are one of new strategies used to solve the problems of non-nanopesticides (Sasson et al. 2007; Pandey et al. 2016; Petosa et al. 2017). Nanoparticles can be used in the preparation of novel formulations like pesticides, insecticides and insect repellants (Gajbhiye et al. 2009; Fulekar 2010; Vinutha et al. 2013; Chhipa 2016). In the recent research, nano-sized agrochemicals are mostly nano-reformulations of existing fungicides and pesticides (Green and Beestman 2007). Nanopesticides including polymeric nanoparticles, gold nanoparticles, silver ions and iron oxide nanoparticles have been exploited as pesticides. Nanopesticides can offer a way to control delivery of pesticide and achieve higher effects with lower chemical dose (Chhipa and Joshi (2016). Therefore, nanopesticides are generally expected to improve the apparent solubility of poorly soluble active ingredients, and release the active ingredient in a slow manner and protect against premature degradation (Kah et al. 2013, 2014; Kah and Hofmann 2014; Dubey and Mailapalli 2016). Also, it is important to note that some nanopesticides may offer a number of benefits, including increased efficacy, exposure to non-target organisms or the development of resistances and reductions in application rates (Khot et al. 2012; Bhattacharyya et al. 2016; Zhao et al. 2016).

Aspects of nanoparticle, some researchers have various reported about characterization, effect of their characteristics, formulation and their applications in management of plant diseases (Al-Samarrai 2012; Álvarez et al. 2016; Dubey and Mailapalli 2016; Pandey et al. 2016). Some formulations contain nanopesticides within the 100–250 nm size range that are able to dissolve in water which are more effective than existing ones (Pérez-de-Luque and Rubiales 2009; De et al. 2014; Servin et al. 2015; Servin and White 2016). Other formulations contain uniform suspensions of pesticidal or herbicidal nanoparticles in the range of 200–400 nm such as nanocapsules herbicides can enable effective penetration through cuticles and tissues, allowing to slow and constant release of the active substances. The potential of nanopesticides in pest management as modern approaches of nanotechnology has been reported (Khandelwal et al. 2016; Zhao et al. 2016). It is reported that, silver nanoparticles have received significant attention as a pesticide for agricultural applications (Lamsal et al. 2011; Bhattacharyya et al. 2016). Silver nanoparticles can be inhibited mycelia growth and conidial germination on pumpkins and cucurbits against powdery mildew at 100 mg kg^{-1}. Also, in soda lime glass powder, copper nanoparticles showed efficient antimicrobial activity against fungi and gram-positive and gram-negative bacteria (Esteban-Tejeda et al. 2009). Silica–silver nanoparticles against *Botrytis cinerea*, *Rhizoctonia solani*, *Calllectotrichum gloeosporioides*, *Bipolaris sorokiniana* and *Magnaporthe grisea* have been reported by Park et al. (2006) and Jo et al. (2009) as well as against *Escherichia coli* and *Staphylococcus aureus* as reported by Priebe et al. (2017).

Using of nano-insecticides and their applications in agriculture have been opened a new field regarding plant protection management. Therefore, nanoencapsulation is currently the most promising technology for protection of host plants against insect pests (Lai et al. 2006; Hussain et al. 2017). With nanoencapsulation techniques, it is possible to step down the chemical release under controlled situations, reducing the current application dosage and improving efficiency (Sastry et al. 2007; Balaji et al. 2017). A novel degradable insecticide involving nanoparticles has been reported (e.g., Loganathan and John 2017; Kailasa and Rohit 2017). Nano-silica has been successfully employed to control a range of agricultural insects/pests as well as ecto-parasites in animals. Such nanoparticles get absorbed into cuticular lipids (which used by insects to prevent death from desiccation) by physical sorption and cause insect death by physical when applied on leaves and stem surfaces (Ulrichs et al. 2005; Bapat et al. 2016). Nano-encapsulated pesticides will have the ability to kill targeted insects only, thereby reducing the effective dose when compared to traditional pesticides. Also, significant mortality of two insect pests (*Sarocladium oryzae* and *Rhyzopertha dominica*) after 3 days exposure to nano-structured alumina-treated wheat (Stadler et al. 2010). Therefore, it could be concluded that, the nanopesticides can be defined as any formulation includes elements in the nm size range and/or claims novel properties associated with these small size range. These nanopesticides include two main ingredients organic (such as polymers) and inorganic like metal oxides in various forms (Ragaei and Sabry 2014).

Nano-remediators and nano-reclaimants

The removing of pollutants from soils and waters can be considered one of the most important challenges facing the universe. The remediation of contaminated areas is not only the main target but also the sustainable remediation is an urgent need (El-Ramady et al. 2017a). Therefore, nanoremediation may be considered as a promising strategy in controlling pollution and management using nanomaterials with mediated animal, plants, and microbes (El-Ramady et al. 2017a). Furthermore, nano-remediators of soils such as zero-valent iron nanoparticles (nZVI), iron sulfide (FeS) nanoparticles, iron phosphate nanoparticles, ZnO, TiO_2, carbon nanotubes, fullerenes and bimetallic nano-metals can be used (Rabbani et al. 2016). These nanoparticles have four missions in soil nanoremediation including (1) reducing the soil heavy metal concentration in leachates to acceptable level (Alvarez et al. 2017), (2) immobilization of soil heavy metals (e.g. Cr VI, Pb II, As III and Cd) in polluted soils (Michálková et al. 2016; Rani et al. 2017), (3) remediation the redox potential enhancing the convert of some soil heavy metals (like Cr VI) to less toxic forms (Boruah et al. 2017) and (4) degradation of organic contaminants (e.g. DDT, chlorinated organic solvents, carbamates, etc) (Abhilash et al. 2016; Saylan et al. 2017).

It is well documented that, nanotechnology can play a great role in managing many stressed regions like salt-affected and marginal lands (Patra et al. 2016). Several approaches may be used in managing these lands including chemical reclamation (a very expensive source) or nanomaterials. These soil nano-reclaimants can effectively create improved soil materials and systems as well as managing these lands using nanoproperties (Patra et al. 2016; Floris et al. 2017). Therefore, it could be used many nanomaterials (nanoreclaimants) in developing and reclamation salt-affected soils including nano gypsum, nano-calcium (Nano-Ca^{2+}) and nano-magnesium (nano-Mg^{2+}) compounds, etc. These nanoreclaimants are more efficient and readily manufacturable as well as enhancement hydraulic characteristics and soil stability (Mukhopadhyay and Kaur 2016; Patra et al. 2016). These nano-reclaimants have several advantages in reclamation the salt-affected soils such as:

1. Improving soil drainage through removing Na^+ from soil solution and improving soil structure in subsurface and sub soils using nano-Ca^{2+}, nanoferrites as well as biofriendly nanopolymers
2. Replacing Na^+ by Ca^{2+} by removing Na^+ from soil and replacing by nano-Ca^{2+}, nano-Mg^{2+} and nano-K^+
3. Reducing salt concentration in soil solution through enhancement Na removal, soil stability and hydraulic characteristics using polymeric carriers in nano-reclaimants *via* clay binding processes
4. Prevention of Na_2CO_3 formation through nanomaterials (nanocalcium carbonates, nano-Ca^{2+}, nano-Mg^{2+}, nano-K^+ and nano-iron oxides may be used in preventing Na_2CO_3 formation in soils)
5. Addition of K^+ or nano-K^+ in clay minerals like illite can accelerate ion exchange reactions (Ca^{2+}, Mg^{2+} and Na^+) to reduce exchangeable sodium saturation (Patra et al. 2016).

Nanobiosensors/ nanosensors

It is reported that, the sustainable agriculture may support for enhancing crop productivity using nanobiosensors. These nanobiosensors can be effectively used for sensing a wide variety of fertilizers, herbicide, pesticide, insecticide, pathogens, moisture, soil pH, and their controlled use (Rai et al. 2012; Sekhon 2014). The future application of these nano-biosensors recently developed by several authors such as Zhang et al. (2014a, b), Bazin et al. (2017), Bhat et al. (2017), Kurbanoglu et al. (2017), Lee et al. (2017) and Ray et al. (2017). Nanobiosensors are getting applications in different industries other than food and agriculture, but recently many sensors have been developed after considering its importance (Sekhon 2014; Jyoti and Tomar 2016). This technology can provide farmers in agro-production sector with better fertilization management, reduction of inputs and better management of time and the environment, thereby increasing productivity in agriculture as well as could help in the efficient use of agricultural natural resources like water, nutrients, chemicals (Farrell et al. 2013; Dasgupta et al. 2015; Ansari et al. 2016). Also, in the field nanobiosensors can detect the presence of plant viruses and other crop pathogens and the level of soil nutrients (Jones 2006; Brock et al. 2011).

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 nanotube (SWCNTs) 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 (Wanekaya et al. 2006; Ramnani et al. 2016). Significant contributions in the field of nanobiosensors research, which bionanotechnology has 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 confirmation of the enzyme molecule and binding always takes place outside the enzyme active centers (Yotova et al. 2013; Bäcker et al. 2017). Therefore, the development of sensors/biosensors depends on specific interactions makes atomic forcespectroscopy (Shuai et al. 2017).

Nanomaterials in agri-food production

No doubt that the agriculture is the main source for our food. So, a very important book series published by Springer entitled "*Nanoscience in Food and Agriculture*". This book series already published till now 3 volumes and edited by Eric Lichtfuse and his co-editors. This reflects the potential of three items at the same time including the nanotechnology, food and agriculture. Furthermore, several book chapters have been published within this series regarding the applications of nanotechnology in food and agriculture sectors. These chapters include nano-food processing and packaging (e.g., Brandelli et al. 2016; Kumar et al. 2016; Kuswandi 2016; Purkayastha et al. 2016; Rao and Naidu 2016; Sarkar et al. 2016; Singh et al. 2016), nano-agriculture (Chowdhury et al. 2016; Dasgupta et al. 2016; Kasana et al. 2016; Madhumitha et al. 2016; Pramanik and Pramanik 2016; Shalaby et al. 2016), nanoparticles remediation in soils and water (Belal and El-Ramady 2016; Khan et al. 2016; Prashantha Kumar et al. 2016; Pulimi and Subramanian 2016; Shalaby et al. 2016; Xue et al. 2016), nanobiotechnology (Brandelli et al. 2016; Kasana et al. 2016), etc.

The sustainable technology is considered as one of the greatest challenges facing the European Commission, so a strategy for key enabling technologies (KETs) for Europe has been established by European Commission in (2012). These technologies include (1) nanotechnology, (2) micro- and nano-electronics, (3) industrial biotechnology, (4) advanced materials, (5) photonics and (6) advanced manufacturing technologies (EC 2017). This nanotechnology may offer further innovations in many industrial sectors such as the animal feed, different food processings, different food additives, food contact materials and the primary agricultural production or agri/feed/food (Kah and Hofmann 2014; Sekhon 2014; Peters et al. 2016). As mentioned before, due to the unique propoerties of the nanomaterials (natural and engineered), the nanotechnology is working in characterizing, manufacturing and manipulation of materials at a size range of the nanometer scale. Concerning the engineered nanomaterials used in agri/feed/food, they may be divided into 3 groups including inorganic (nano-silicon dioxide for food processing as anti-caking agent metals, nanoselenium for food or health supplements, etc.), organic (e.g., proteins, carbohydrates and fats to build food-grade like polymers or nano-encapsulates and nano-emulsions), and combined materials (e.g., surface modified clays) as reported by Peters et al. (2016).

Nanoparticles for more sustainable agro-production

The using of nanomaterials in agro-production has several dimensions including the sustainable agro-production, the agro-environmental sustainability of nano-materials, the enhancement of agro-productivity using nanomaterials, the management of agro-wastes using nanomaterials, etc. Without these previous dimensions, it is very difficult to reach to the global security in all sectors including food security, soil security, water security, environment security, etc. Here, we will focus on these previous dimensions in more details.

Nanoparticles and agro-environment

Fate and transport of nanoparticles in the environment can consider one of the most important environmental issues (**Fig. 2**). This fate and transport include the behavior of nanoparticles in different environmental compartments (air, water, soil, sediment, plants, humans, animals, etc.). Concerning the agricultural environment, it is the place in which we can produce our food, feed, fibre and fuel. So, the movement of nanoparticles and their translocation in the terrestrial environments is a crucial issue and should be addressed. Moreover, this behavior of nanoparticles in agroecosystems includes both the positive side (enhancement plant growth, nano-remediation, nanofertilizers, nanopesticides, nano soil conditioners, nanoreclaimants, etc) and the negative side (phytotoxicity, oxidative stress, carcinogenicity, etc). Therefore, several studies have been published concerning the release, transport and toxicity of engineered nanoparticles in the environment (e.g., Terekhovaa and Gladkova 2013; Miseljic and Olsen 2014; Aouada and de Moura 2015; Soni et al. 2015; Schultz et al. 2015; Hedayati et al. 2016; Hegde et al. 2016; Mottier et al. 2017; Tolaymat et al. 2017). Hence, the distribution and transport of nanoparticles in different environments remains an open question.

World food production system depends on the use of traditional pesticides and fertilizers to increase this food production, which leads to several negative effects on the environment (Baker et al. 2013; Wan et al. 2013; Alvarez et al. 2017). Naturally, nanoparticles are contributing immensely to the biogeochemical cycling of carbon, nitrogen, sulfur and phosphorus in the environment. Therefore, nanotechnology represents some new approaches to increase agricultural production and ameliorate of contaminated agro-ecosystem (Powell and Kanarek 2006; Jin et al. 2016; Yang et al. 2016; Formentini et al. 2017; Samarajeewa et al. 2017; Wang et al. 2017). Most nanoparticles are made up of carbon, silicon, metal or metal oxides, which have directly or indirectly adversely effects on the environment and then human health. Furthermore, nanoparticles can be released during their use into the soils and waters as well as increased in different environmental matrixes reflected by an increasing concern over the potential impact (DEFRA 2007; Navarro et al. 2008; Handy et al. 2008; Baun et al. 2008; Soni et al. 2015; Belal and El-Ramady 2016; Yang et al. 2016; Oleszczuk and Kołtowski 2017; Samarajeewa et al. 2017; Vítková et al. 2017).

By active or passive uptake, nanoparticles may enter or transport into the food chain by plants and/or other microorganisms from some different environments. Many factors impact on this translocation of nanoparticles such as

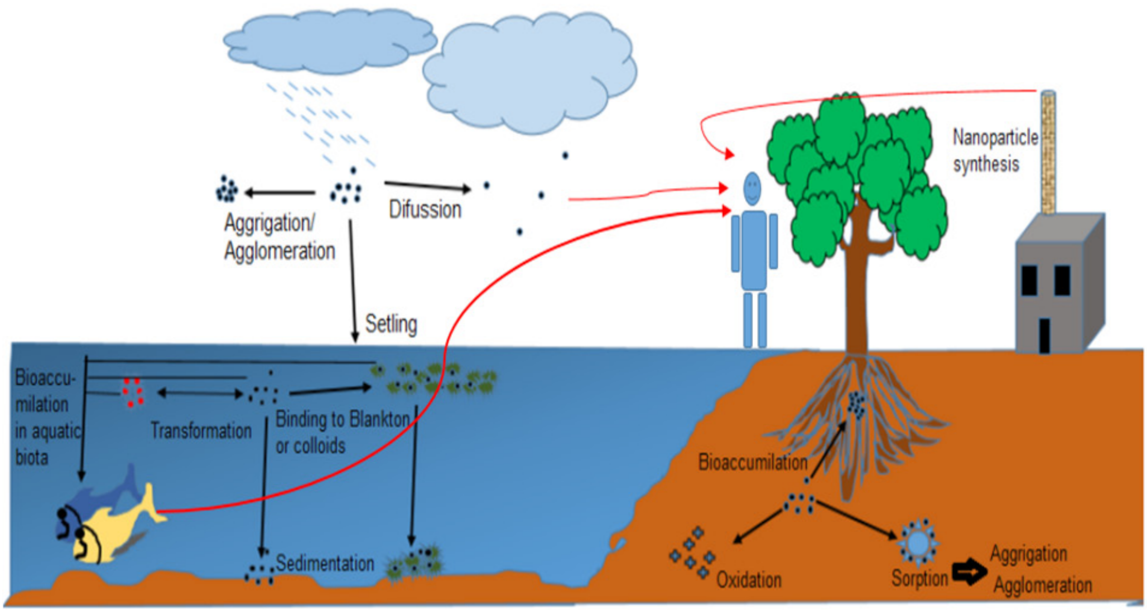

Fig. 2. The fate and behavior of nanoparticles in the environment. This behavior of nanoparticles in agroecosystems includes the positive and the negative effects as well as the release, transport and toxicity of engineered nanoparticles in the terrestrial environments.

air, soil, water and sediment as well as causing serious alterations in humans and animals (Holbrook et al. 2008; Bouldin et al. 2008; Lin et al. 2009; Soni et al. 2015; Kwak and An 2016). Also, nanoparticles have a potential to carry toxic materials (e.g., lipophilic pollutants and heavy metals) due to large surface areas and a highly reactive nature (Baun et al. 2008; Gil-Díaz et al. 2016, 2017). Other types of nanoparticles may enter into the plants *via* the root cell walls which have pores with a size ranging from 5 to 20 nm that allow the passage of small particles (Hischemöller et al. 2009; Cifuentes et al. 2010; Doolette et al. 2015; Tripathi et al. 2017; Zhang et al. 2017). Thereby nanoparticles with sizes smaller than the pore diameter may pass and reach the plasma membrane. Also, some evidences that nanoparticles may enter cells *via* ion channels and embedded transport carrier proteins and that they may interfere with normal metabolic processes, possibly by the production of reactive oxygen species (Navarro et al. 2008; Tolaymat et al. 2017; Tripathi et al. 2017).

Several researchers reported about the recent applications of nanotechnologies in agro-environmental studies including the transport and fate of these nanomaterials as well as the beneficial of these applications. The interaction between nanoparticles under soil-plant system can consider one the most important agro-environmental studies. Therefore, several studies have been focused on these agro-environmental studies including the interactions between nanoparticles under soil-plant systems (Manceau et al. 2008; Anjum et al. 2013; Soni et al. 2015; Belal and El-Ramady 2016; Majumdar et al. 2016; Wu et al. 2016; Tripathi et al. 2017; Zhang et al. 2017), the impacts of applied nanoparticles on the microbial community in soils (Pawlett et al. 2013; Chunjaturas et al. 2014; Sri Sindhura et al. 2014; Simonin and Richaume 2015; Antisari et al. 2016; Pallavi et al. 2016; Read et al. 2016; Samarajeewa et al. 2017), the using of nanoparticles in remediation both of soils and waters (An and Dong 2015; Cecchin et al. 2016; Ghosh et al. 2016; Gonçalves 2016; Zhao et al. 2016; De La Cueva Bueno et al. 2017; El-Ramady et al. 2017a; Fernandes et al. 2017; Kuppusamy et al. 2017), the enhancement of nanofertilizers and nano-pesticides for the plant growth and its protection (Davarpanah et al. 2016; Zhao et al. 2016; El-Ramady et al. 2017b; Balaji et al. 2017; Petosa et al. 2017), the using of soil nano-reclaimants and nano-conditioners under sustainable agro-production (Patra et al. 2016; Fernandes et al. 2017;), nano-enhancement for crop productivity under stress (Abdel-Haliem et al. 2017; Rizwan et al. 2017; Tassi et al. 2017), etc.

Nanoparticles and enhanced productivity

Nanotechnology has a great potential, as mentioned before, to increase the global food production, food quality, plant protection, detection of plant and animal diseases, monitoring of plant growth and reduce wastes for sustainable crop productivity (Gruère et al. 2011; Frewer et al. 2011; Biswal et al. 2012; Sonkaria et al. 2012; Prasad et al. 2014; Handford et al. 2015; Ditta et al. 2015; Belal and El-Ramady 2016; Panpatte et al. 2016; Pramanik and Pramanik 2016; Shalaby et al. 2016; Ashoka et al. 2017; Servin et al. 2017). The aim of the use of nanoparticles in the field of agriculture is to enhance the efficiency and sustainability of agricultural productivity by using less inputs and generating less wastes. In world-wide, heavy use of nitrogen and phosphorus fertilizers has become the major anthropogenic factor due to eutrophication problems in freshwater and coastal ecosystems (Conley et al. 2009; Zak et al. 2015; Ge et al. 2016; Wang et al. 2017). Thus, the application of novel nanotechnology in agriculture sector is considered as one of the important approaches in improving crop production and feeding the world by developing and minimize nutrient losses during fertilization processes (Lal 2008; Ditta et al. 2015; Panpatte et al. 2016; Rizwan et al. 2017).

To study the impact of nanoparticles and its roles in enhancing the crop productivity, the interaction of nanoparticles with plants from different sides starting from the seed germination reaching to the harvested crop should be studied (Khan et al. 2017). The applied nanoparticles to cultivated crops may cause various physiological and biochemical changes depending on the properties of these nanoparticles, their concentration and it varies from plant to plant as well as different soil properties (Wang et al. 2016; Tripathi et al. 2017). Nowadays, several reports have been published concerning different impacts of nanoparticles on seed germination, photosynthesis and plant growth with the main target to promote their use of agricultural applications. Recently, Springer also succeeded in publishing some distinguished books such as „*Plant Nanotechnology: Principles and Practices*" edited by Kole et al. (2016) and "*Nanotechnology and Plant Sciences: Nanoparticles and Their Impact on Plants*" edited by Siddiqui et al. (2015) and the outcoming book this year "*Nanomaterials and Plant Potential*" edited by Azamal Husen and Muhammad Iqbal beside book about „ *Nano Phytotoxicity and Plant Biotech*nology".

Concerning nanoparticles and enhanced crop productivity, the crop production can be enhanced through the proper management of growth factors including fertilizers, irrigation, plant protection, cultural practices, etc. The previous practices may be enhanced by using nanomaterials such as nanofertilizers (Mastronardi et al. 2015; Mani and Mondal 2016; Bradfield et al. 2017), nanopesticides (Bhau et al. 2016), nanosensors (Dubey and Mailapalli 2016; Chhipa and Joshi 2016), irrigation management (Singh and Kumar 2016) and nano-farming (Dwivedi et al. 2016). It is worth to mention that, several factors effect on crop productivity including the physiological functions (uptake of nutrients and water, respiration, photosynthesis, transpiration, water relations, etc.) and the environmental conditions (e.g., humidity, precipitation, temperature, biotic/abiotic stresses) (Maiti and Kumari 2016). Therefore, the agricultural productivity may be controlled by application of nanoparticles for each growth period and all cultural practices. Several publications have been involved in different impacts of applied nanoparticles during the entire plant growth and development periods as follows:

Some studies suggest that metal silver nanoparticles (AgNPs) increased the root length in maize and cabbage plants in comparison with $AgNO_3$ (Pokhrel and Dubey 2013). Also, gold nanoparticles (Au-NPs) increased the number of leaves, plant height, leaf area, chlorophyll content and sugar that result in better crop yield (Arora et al.2012; Gopinath et al. 2014). Almeelbi and bezbaruah (2014) reported the effect of iron- NPs on Fe content in spinach roots, stem and leaves increased 11-21 times in hydroponic solution. Also, Zn NPs significantly enhanced shoot (10.8%), chlorophyll content (18.4%) and grain yield (29.5%) in pearl millet (Tarafdar et al. 2014). Mixture nanoparticles of TiO_2 and SiO_2 increased the nitrate reductase activity and stimulated the antioxidant system in soybean (Lu et al. 2002). Therefore, root elongation in soybean was promoted at a particular concentration of ZnO NPs (Lopez-Moreno et al. 2010). Plant growth and development enhanced by nanoSiO_2 by increasing photosynthetic rate, transpiration rate, electron transport rate (Xie et al. 2011; Al-Whaibi 2014). According to Gupta and Tripathi (2011), TiO_2 NPs may be used for production of H_2 as a fuel by decomposition of organic compounds. Foliar application of ZnO NP at 1.5 mg L^{-1} concentration improved biomass as compared to foliar application of $ZnSO_4$ in chickpea (Burman et al. 2013). The mode of action of these nanoparticles by which they take part in the growth and development of plants needed to study. Also, plant species and environmental factors will affect the uptake and accumulation of NPs is still to be investigated.

Nanoparticles application in agro-wastes management

Enormous amounts of wastes generated from different agricultural sectors, where some of these agri-wastes may be offensive odor as well as their decayed matters could alter the pH of soil and the disposal of agricultural wastes have become a major problem (Bello et al. 2016). The agricultural wastes or agro-wastes can be defined as the crop fraction, which does not constitute the harvested crop itself (Kallel et al. 2016; García et al. 2016). These agro-wastes depend mainly in their composition on the crop source, conditions of growing and harvesting crop (García et al. 2014). Every year are generated about 140 billion tons of industrial and agricultural wastes driving by processing of animal and plant's raw materials (FAO 2011). Industrial and agricultural wastes include solid wastes, air pollutants and wastewaters. They can be reduced and/or treated by process control, emission control and waste treatment. Therefore, the application of nanoparticles could help in improving the environment and controlling the pollution (Ghasemi et al. 2017).

Among the solutions is the nanotechnology approach to help in the smooth transition to alternative and renewable energy sources (Bello et al. 2016; Mekki et al. 2016; García et al. 2016; Adebisi et al. 2017) through using the nanotechnology in transesterification, pyrolysis, gasification, hydrogenation and the reforming of biomass (Fryxell and Cao 2007; Galadima and Muraza 2015). Furthermore, the application of microorganisms or enzymes (biocatalysts) has gained increasing attention as a possible means to decrease the environmental industrial wastes as well as to convert these wastes to potentially valuable products such as bioplastics and biopolymers (Amulya et al. 2016; Emadian et al. 2017). Also, in the second-generation conversion, liquid biofuels depends on biomass cellulosics, which convert to ethanol and biodiesel (Trindade 2011; Valenstein 2012; Zhang et al. 2016). Solid wastes (spent tea) could be used for the production of biodiesel, bioethanol and also hydrocarbon fuel gases through (i) gasification (yielded 60% liquid extract, 28% fuel gases and 12% charcoal as well as gaseous products contain 53.03% ethene, 37.18% methanol, and 4.59% methane). (ii) transesterification gave 40.79% ethyl ester (biodiesel), and (iii) production of bioethanol 57.49% by *Aspergillus niger* (Mahmood and Hussain 2010).

The management of agro-wastes using nanoparticles is a crucial issue worldwide. This issue has at least two dimensions; the first includes the conversion of the agro-wastes into energy (Nanda et al. 2016; Adebisi et al. 2017) and the second represents using these agro-wastes in removing different types of pollutants from water (Bello et al. 2014; Bello et al. 2016). Moreover, the agro-wastes could be handled as materials for biomass production or a renewable source as well as recyclable or biodegradable products. Hence, it is proposed that the agri-waste materials are economic and eco-friendly (Kumar and Kumar 2014). On the other hand, several agro-wastes have been used in removing of different pollutants from aqueous solutions such as cassava peel (Horsfall et al. 2006), orange peel (Ningchuan et al. 2009), rice bran (Suzuki et al. 2007), periwinkle shell (Bello et al. 2008), coconut shell (Bello and Ahmad 2012), coconut husk (Tan et al. 2008), cocoa pod husk (Bello and Ahmad 2011), mango leaf (Khan et al. 2011), loquat leaves (Akl and Salem 2012), alumina-coated carbon nanotubes (Gupta et al. 2011), multi-walled carbon nanotubes–ionic liquid–carbon paste electrode (Khani et al. 2010) as reported by Bello et al. (2016).

Risk and safety of nanomaterials in agro-production

Due to the rapid propagation in nanotechnology, huge amounts of nanomaterials have been applied in all our life sectors (Rico et al. 2011) including food additives and packing (Peters et al. 2016), soil and water remediation (Gil-Díaz et al. 2017), cosmetics (Nazarenko et al. 2012), textiles (Geranio et al. 2009), electronics (Shulaker et al. 2013), medicine (Murday et al. 2009), etc (Hu et al. 2016; Priester et al. 2017). So, these nanomaterials could be released into the soils, waters, air, and interact with the biological tissues because of their small size as well as the high surface activity (Holden et al. 2013). Therefore, there is an urgent need to follow different biological responses related to both human health and the ecological safety (Oomen et al. 2014; Syberg and Hansen 2016; Boonrungsiman et al. 2017). Different investigations regarding the adverse effects of nanomaterials have been carried out including the biological, medical and terrestrial environments (Hu et al. 2016; Kwak and An 2016; Mattsson and Simkó 2016).

There are risks of adverse and unintended consequences with nanotechnology and it is important to pay attention to public views regarding new technologies in agro-production during the product development stages (Zuverza-Mena et al. 2017). This risk is due to the small size and large surface area of nanoparticles, which allow easy dispersion, might cross anatomical barriers and showing potential toxicity (Rico et al. 2011). In the agro-production sector, millions of small farmers can be a leading health risk by using of nanofertilizers and nanopesticides which allow easy dispersal into the soil, water and atmosphere (Tripathi et al. 2017). Nanoparticles could enter the food chain via nutrient/pesticide systems or through processed foods raising concerns of toxicity in the ecosystem (Mattsson and Simkó 2016). Therefore, life cycle analysis, particle uptake by plants, bio-distribution and entry into the food chain, etc need a thorough investigation before these tools are used as products in agro-production sector (Rico et al. 2011; Holden et al. 2014, 2016).

It could be concluded that, for the regulatory purposes as well as the risk management activities, it should be assessed the risk assessment of manufactured nanomaterials (Mattsson and Simkó 2016). This assessment of nanomaterial risks requires knowing some information about the exposure time, the potential hazard and the dose as well as the kind of nanomaterials. Moreover, the life cycle of nanomaterials, the possible changing in nanomaterials and its properties over time (Bicho et al. 2016; Priester et al. 2017). There are still open questions concerning the fate and behavior of nanomaterials in different environments, despite of an accepted progress in developing the risk assessment of nanomaterials (Schulte et al. 2016; Mattsson and Simkó 2016). According to the European Parliament, there are some regulations regarding agro-production as follows (Lee and Stokes 2016):

1. Legislation on food additives (Regulation: EC no. 1333 /2008, Art 12),
2. Legislation on food information for consumers (Regulation: EU no. 1169 /2011, e.g. Art 18),
3. Legislation on cosmetic products (Regulation: EC no. 1223 /2009, e.g. Art 13 (1),
4. Legislation on waste electrical and electronic equipment (Directive 2012/19/EU, Art 8 (4),
5. Legislation on restrictions on hazardous substances in electrical and electronic equipment (Directive 2011 /65/EU, Recital 16),
6. Legislation on biocidal products (Regulation: EU no. 528/2012, e.g. Art 19 (1),
7. Legislation on food for infants (Regulation: EU no. 609/2013, Art 9 (2)

Therefore in the near future, it will be possible to perform a complete and scientifically sound risk assessment of application of engineered nanoparticles in all industrial and public sectors, including agriculture, healthcare, transport, energy, materials, information and communication technologies.

Conclusion

There is no doubt that, the global natural resources including water and lands are very limited. So, an urgent need is essential to increase use efficiency of these resources as well as minimize the agro-ecology damage through using the effective modern technologies like nanotechnology. Concerning nanotechnology, many nanomaterials have been penetrated several fields including (1) enhancement of the agricultural productivity, (2) production, conversion and storage energy, (3) water treatment and its remediation, (4) remediation of air pollution, (5) diagnosis and screening of diseases, (6) delivery systems of fertilizers and drugs, (7) processing, coating, packaging and storage of foods, (8) durability of construction, (9) monitoring of health and (10) detection, control of vector and pests. On the other hand, serious and terrible threats face the world including the global security resulting from the continuous global changes. This global security includes security of water, soil, food, energy, environment, communication, information, etc. Therefore, sustainable agro-production mainly depends on many previous securities including soil, water, energy and food security. Furthermore, there is closed links among these securities such as food, water, soil and energy security, where the agro-food production and its security based on the integration among all these securities. It is worth mentioning that, nanotechnology applications can be used to achieve through these previous securities. Concerning the applications of nanotechnology in agriculture sector, it could be noticed that nanotechnology may be totally revolutionized this sector through its ability to penetrate different agro-fields including (1) treatment and detection of plant diseases, (2) nanobiosensors, (3) nanofertilizers, (4) nanopesticides and (5) gene transfer as smart delivery systems. Whereas, the over-application of nanomaterials in agriculture leads to the negative effects representing the toxic action of these nanomaterials in the agroecosystems.

It is worth to mention that, nearly all agricultural practices may be touched or penetrated through the nanotechnology. So, several agro-products could not be only fabricated using nanomaterials but also a huge amount of agro-wastes could be managed using these nanomaterials. Hence, great challenges have been created seeking for the sustainability of agro-production including (1) global soil security, (2) water security, (3) energy security, (4) food security, (5) reduction of poverty and (6) improvement of human public health. Therefore, many risks have been resulted from this using in agro-production and hence safety approaches should be regulated. Although these nanoparticles may have the ability in conservation of both water and lands through certain applied concentrations, they substantially should also sustain or conserve the environment. Therefore, further investigations are needed in our handling nanoparticle applications for the sustainable agro-production, the management of agro-wastes, the risks and safety of these nanoparticles in different agroecosystem compartments.

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