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A general overview of the benefits and possible negative effects of the nanotechnology in horticulture

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ABSTRACT

Since nanotechnology was defined by Richard Feynman, multiple approaches has been developed in the field of communication, defense, food, biotechnology, electrical, chemical, sports and agricultural industry. The use of nanotechnology in horticulture are around of hybrid varieties, synthetic chemicals and biotechnology related with the fields of food processing, packaging, safety, nutrition, pesticides, and nutraceuticals. However, these applications still generating doubts about the possible environmental and human risks. The aim of this review is to discuss some advantages and impacts provided for the use of nanotechnology applied to the horticultural sector. Those advantages are focus on the main nanotechnology applications as Nanofertilizers or nano-encapsulated nutrients, germination and growth of plants as a negative effect of the nanomaterials, the effects of the natural processes (Photosynthesis) and Phytotoxic and some proposals of mechanism in the metabolic processes.

1. Introduction

Since the conference of "*there are plenty of room at the bottom*" by Richard Feynman (Feynman, 1960), the word Nanotechnology was defined. Nanotechnology is the study of the techniques and manipulation of the materials in the range of 1–100 nm (Curtis et al., 2006; Di Sia, 2017; Satalkar et al., 2016; Servin and White, 2016). Nanoparticles exhibit different properties than the bulk materials, this is due to the high surface and volume ratio (Bhattacharyya et al., 2009; Satalkar et al., 2016; Singh, 2017), and the quantum phenomena that occurs in nanoscale increasing the catalytic activity (Purohit et al., 2017; Satalkar et al., 2016; Singh, 2017). The nanomaterials have been used in communication, defense, food, biotechnology, electrical, chemical, sports and horticultural industry. In agricultural sector, the innovation and changes are around of hybrid varieties of crops, synthetic chemicals and biotechnology related with the fields of food processing, packaging, safety, nutrition, pesticides, and nutraceuticals (Handford et al., 2015; Zibareva, 2015).

The use of Nanotechnology into the horticultural field continue rising doubts about the possible human and environmental implications, the dimensions of the nanomaterials could affect the biochemical mechanisms of the human and vegetal process and the possible bioaccumulation(Chen et al., 2015; Kaphle et al, 2017; Purohit et al., 2017), that's why the resulting field of Nanotoxicology has been created in order to answer the implications and answer the mechanisms to minimize the main problem and also in the develop of policy guidelines (Foladori, 2013; Gruère, 2012; Iavicoli et al, 2017; Kaphle et al., 2017), for this reason the scientific community must to focus the efforts in the toxicological and environmental effects, physico – chemical and hazardous properties, biological mechanisms, and conditions of the nanoparticles used in the horticultural field (Iavicoli et al., 2017; Kostoff et al, 2008).

The main objective of this review is to provide a better understanding about the interaction of the nanomaterials (such as metallic, oxide, bio compounds and composites) in the horticultural field, the interaction with the biological process of plants (germination, growth), the affectation, photosynthesis and physiologic modifications and toxicity of the use of nanoparticles.

2. Nanotechnology in horticultural activities

As a new technology, which takes an impulse in the 2000 year (Salaheldeen et al., 2015), the Nanotechnology has been used in many applications in diverse fields of the science like physics, chemistry, medicine, aeronautical, materials, pharmaceutical, food and in recent years in horticulture (Duhan et al., 2017).

Use of the nanomaterials (NM) has led to a new era, the Nano-revolution is present in the intense research at both, academic and

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industrial level. The unique properties of these materials make them a viable choice for the design and development of suitable tools in support specifically in sustainable horticulture.

2.1. Definition

The nanotechnology is the matter manipulation at atomic, molecular and supra-molecular levels. According to the Nanotechnology National Initiative (NNI) this matter manipulation it has to be between 1 and 100 nm. The interest on this size is because the mechanic-quantum phenomena unlike the material at bigger scale or bulk where the phenomena are related the classic mechanics (Vance et al., 2015).

According to the NNI, the nanotechnology has been developed in four generations. The first generation (years 2000–2005) represents the era of the "passive nanostructures", where the materials just fulfill a single function by taking advantage of the passive properties of the material. The second generation (years 2005-2010) is the era of the "active multitask nanostructures", which will change as it is used. The third generation (years 2010-2015) is known as the "nanosystems", where several nano-tools works together to achieve a common target. The final generation, the fourth one (years 2015-2020) is the era of the "molecular nanosystems" which includes the smart design of molecular and atomic devices, where a simple product may include a wide variety of diverse capacities (Salaheldeen et al., 2015).

2.2. Nanomaterials classification and manufacture

The NM can be classified according to the number of dimensions, which at least one of them must be in nanometers. The zero-dimension nanomaterials are the nanoparticles, where the three dimensions are in the nanometric scale. The NM classified as one-dimension has two nanometric dimension and the third one is variable like the nanofibers. The two-dimension NMs only has one dimension in the nanometric size such as the thin films. Finally, the three-dimension classification is that the NM is formed by nanometric units but the complete material is out of the nanometers size like a nanoparticles supra-network (Nersisyan et al., 2017; Yang et al., 2017). These NMs have unique physiochemical properties such as high reactivity, high surface area, tunable pore size and also they can contain active compounds inside of its structure.

Another NMs classification could be according of the chemical nature of the material, as is shown in Fig. 1. In this classification it can be found the Carbon based NMs, Dendrimers and composites, Biomaterials, Metals based NMs and Metal oxides.

Some examples include single-walled and multi-walled carbon nanotubes (SWCNT/MWCNT), magnetized iron nanoparticles (Fe_3O_4), aluminum (Al), copper (Cu), gold (Au), silver (Ag), silica (SiO_2), zinc (Zn) and zinc oxide (ZnO), titanium dioxide (TiO_2), and cerium oxide (Ce_2O_3). Also, it is worth to mention that in nature it is possible to found some NMs which are group into the biomaterials such as, enzyme/ceramics and enzyme/polymers composites.

These materials are also used in horticulture production and crop protection (Emamifar et al., 2010; Nair et al., 2010). However, in the field of horticulture, the use of nanomaterials is relatively new and needs further exploration.

The NMs can be manufactured by diverse synthesis methods, and those are classified in two big groups: Top-down processes, in which a bulk material is reduced its dimensions until a nanometric scale. And the Bottom-up processes are those methods where atoms and ions are assembled until they reach a nanometric size, such as chemical vapor deposition and sol-gel method (DeHon, 2008). By the selection of the synthesis method, the resultant material, it could be applied to a diverse use, such as in horticulture.

2.3. Horticultural applications of the nanomaterials

Nanotechnological advances can led us to a new world of applications in the horticultural area. Some of these uses are focused on renovation of food and agricultural wastes to energy, cleaning of water, chemical sensors, prevention of diseases and treatment in plants with nanocides (Farooqui et al., 2016).

Nanofertilizers or nano-encapsulated nutrients are also recently used to release the right amount of nutrients and in that way standardize the plant growth and development. Also increases the crop yield and minimize the environmental hazard (Iavicoli et al., 2017).

The nanotools such as the nanofertilizer has been modifying conventional farming practices into precision farming. Different types of nanoparticles such as carbon nanotubes, Cu (5 nm), Ag (5–10 nm), Mn (10-20 nm), Mo (10-20 nm), Zn (20-30 nm), Fe (20 nm), Si (20-30 nm), Ti (25-40 nm), their oxides nanoparticles and nanoformulations of conventional horticultural inputs like phosphorus, urea, sulphur, validamycin, tebuconazole and azadiractina have been converted into theses valuable tools (Chhipa, 2017). By the size of these materials, it is possible to detected it in leaves and root but not in the final products such as fruits. Further effects are described in section 3.

The use of nanoformulation, nanoencapsulation or functionalized nanomaterial provides site-specific and controlled delivery of active ingredients. Specifically, a nanofertilizer is responsible for providing one or more micro or macronutrients to the plant and improves the growth and even the production of the crops (Liu and Lal, 2015).

High-volume-to-surface ratio of nanomaterial reduces the amount and increases the efficiency of macronutrient nanofertilizer in comparison with conventional fertilizers. Some of the macronutrients like nitrogen (N), phosphorous (P), potassium (K), magnesium (Mg), sulphur (S) and calcium (Ca) has been coupled with the nanotechnology as nanoencapsulated materials in order to deliver the proper amount of the nutrient and avoid the unnecessary requirements of the extra expenses in the acquirement of regular fertilizers (Wang et al., 2016a). Some of the chemical compounds used to this purpose is urea, chlorides and oxides.

As a phosphorous source, a nanostructured water-phosphorite suspension was obtained for the first time from the natural raw phosphorite of Tatarstan's Syundyukovskoe deposits by Sharonova N.L. research group. It was established that the morphometric indices of plants increases from 8.3% to 3.5-fold, the fresh yield increases from 2.4% to 2.2-fold, and the fruit yield increases from 14.5 to 24.1%. The improvement in crop production quality by a set of indices from 0.3% to 2.6-fold was noted (Sharonova et al., 2015).

Urea modified zeolites, mesoporous silica and hydroxyapatite NPs, has been used as nitrogen macronutrient sources (Liu and Lal, 2015; Monreal et al., 2016), shown their capabilities as slow and controlled release of N for long time periods.

The micronutrients are trace elements that are required by the plants in quantities less than 100 ppm and are essential for diverse metabolic processes. The presence of this micronutrients improves the plant growth and nutrition quality (Chhipa, 2017).

In this regard, Yttrium doping-stabilized γ-Fe_2O_3 nanoparticles were studied for its potential to serve as a plant fertilizer and were delivered by irrigation in a nutrient solution to *Brassica napus* plants grown in soil. Growth rate of leaves was enhanced from 33 to 50% growth compared to fully fertilized plants and SPAD-measurements of chlorophyll increased from 47 to 52 suggesting improved agronomic properties compared to chelated iron (Palmqvist et al., 2017).

Hu et al. (2017) also found that γ-Fe_2O_3 NPs could enter plant roots but no translocation from roots to shoots. 20 mg/L γ-Fe_2O_3 NPs had no impact on plant growth. 50 mg/L γ-Fe_2O_3 NPs significantly enhanced chlorophyll content by 23.2% and root activity by 23.8% as compared with control in *Citrus máxima* plants. And 100 mg/L γ-Fe_2O_3 NPs notably increased MDA formation, decreased chlorophyll content and root activity (Hu et al., 2017).

Another study was conducted by Liu et al. at 2015 to assess the effects of laboratory-prepared Cu, Zn, Mn, and Fe oxide NPs in low concentrations ($<$ 50 ppm), as micronutrients, on the germination of