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A REVIEW OF THE PERSPECTIVES OF NANOTECHNOLOGY IN AGRICULTURE AND ENVIRONMENT[1]

REVISÃO DAS PERSPECTIVAS DA NANOTECNOLOGIA NA AGRICULTURA E NO AMBIENTE

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ABSTRACT

Since the elaboration of the concept of nanotechnology in 1959 on Richard Feynman, researchers of different areas of acknowledgment had an increased interest due to broad applicability. Nanotechnology could introduce benefits in various areas, like medicine and health, drugs, cosmetics, pigments, adhesives nanoelectronic and technology of computers, aeronautical and environment, biotechnology and agriculture, and others. Nanotechnology representing a new frontier in modern agriculture is anticipated to become a major thrust shortly by offering potential applications. This integrating approach, agri-nanotechnology, has great potential to cope with global challenges of food production insecurity, sustainability. However, despite the potential benefits of nanotechnology in agriculture so far, their relevance has not reached up to the field conditions. Nowadays, the applications of nanotechnology in agriculture have contributed to the development of technologies that range from seed improvement, plant growth, and protection, to herbicide/pesticide residue monitoring and pathogen detection. However, the present article aimed at a literature review emphasizing the positive and negative aspects of the use of nanotechnology in agriculture as well as its impact on the environment. For this purpose, different sources of research such as PubMed and Scielo were consulted with the following keywords: nanotechnology, nanoparticles, environment, and pesticides. The survey was conducted from 2000 to 2017. We conclude, however, that despite the wide range of benefits, further studies and specific legislation are needed that cautiously assess the risks and benefits of applying nanotechnology to agriculture and the environment.

Keywords: herbicides, nanomaterials, nanoparticles, nanotoxicology.

RESUMO

Os nanomateriais são classificados como materiais que possuem um tamanho estrutural na dimensão de partícula menor que 10^{-9} nanômeros, cujas propriedades diferem dos materiais com maior escala, sendo assim

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objeto de estudo da nanociência e da nanotecnologia. Desde a elaboração do conceito de nanotecnologia em 1959 por Richard Feynman, pesquisadores de diferentes áreas de conhecimento tiveram um interesse crescente devido à vasta aplicabilidade. A nanotecnologia poderia introduzir benefícios em várias áreas, tais como: medicina e saúde, drogas, encapsulamento de células vivas, vacina em dose única, cosméticos, pigmentos, adesivos, materiais e fabricação, nanoeletrônica e tecnologia de computadores, exploração aeronáutica e exploração espacial, energia e meio ambiente, biotecnologia e agricultura (pesticidas), alimentos, embalagens entre outros. Com o aumento da população, a área da agricultura tem crescido rapidamente, exigindo maior atenção ao meio ambiente. Atualmente às aplicações da nanotecnologia na agricultura tem contribuído no desenvolvimento de tecnologias que se estendem desde a melhoria das sementes, crescimento e proteção de plantas, até o monitoramento de resíduos de herbicidas/pesticidas e detecção de patógenos. Dessa forma, o presente artigo teve como objetivo uma revisão da literatura enfatizando os pontos positivos e negativos da utilização da nanotecnologia na agricultura bem como o seu impacto no meio ambiente. Para isto, diferentes fontes de pesquisa como o Pubmed e Scielo foram consultadas com as seguintes palavras-chave: nanotecnologia, nanopartículas, meio ambiente, pesticidas. O levantamento foi de 2000 a 2017. Concluímos, no entanto, que apesar da vasta gama de benefícios, são necessários mais estudos e uma legislação específica que avalie cautelosamente os riscos e benefícios da aplicação da nanotecnologia na agricultura e no meio ambiente.

Palavras-chave: *herbicidas, nanomateriais, nanopartículas, nanotoxicidade.*

INTRODUCTION

The nanotechnology currently is defined as a scientific field, multidisciplinary staff, based on development, characterization, production, and application of structures, devices, and systems with the shape and size on the nanometer scale (SANTOS; FIALHO, 2014). The size of the particle is quite important because that is capable of modifying the impacts of processes and products in the environment and health of the population (MARTINS, 2009; MCGILLICUDDY et al., 2017). The development of nanotechnology in conjunction with biotechnology has significantly expanded the application domain of nanomaterials in various fields (KOTH et al., 2012). However, the technology is characterized by the change of release the active principles with drugs and pesticides and is very diversified, being matrix polymer system the increasingly used in microparticle shape (microspheres) or vesicular structure (microcapsules) (SUAVE et al., 2006).

The microcapsule consists of an encapsulated agent (normally is a polymeric material) that promotes protection isolating active substance, which could be in the form of droplets, solid particles or gaseous material (SILVA et al., 2014). That polymer membrane dissolves with specific stimulus in a desired location, releasing the inner substance (RÉ, 2000). These microcapsules have a vast number of applications in various areas. Among whom they have inserted agrochemicals (herbicides, repellents, pesticides), pharmacists (oral or injectable), cosmetics, food ingredients, labels, curing agents and encapsulating living cells (including enzymes and microorganisms) (SANTOS; FERREIRA; GROSSO, 2000).

New devices and tools for the molecular and the rapid detection and treatment of diseases, the enhancement of the ability of plants to absorb nutrients, the delivery of specific substances to specific sites and water treatment processes are some examples of developments (RAFIEI; HADDADI, 2017; PÉREZ-DE-LUQUE; RUBIALES, 2009).

Nanotechnology representing a new frontier in modern agriculture is anticipated to become a major thrust shortly by offering potential applications (MISHRA et al., 2017). This key enabling technology has evidenced broad and remarkable applications in diverse fields such as electronics, medicines, cosmetics, textiles, food, and agriculture (CARUTHERS et al., 2007; SASTRY et al., 2011; SHARON et al., 2010). The expansion of nanotechnology industry was anticipated because its market value will reach about US$ 75.8 Billion by 2020 because of its significant expansion at a global level (RESEARCH AND MARKETS, 2015). The nanotechnology-based researches have contributed to the global growth by delivering strong applications in many industrial sectors. On the other hand, it is a well-known fact that nanotechnology has enormous potential to benefit society by revolutionizing the agricultural sector. This new technology has left to the agricultural based business sector an annual growth rate of 25% (US$ 1.08 billion). It is estimated that the advanced nanotechnology in agriculture would thrust the global economic growth to about US$ 3.4 trillion by 2020 (SABOURIN; AKANDE, 2015; SODANO; VERNEAU, 2014). This accentuates the relevance of agri-nanotechnological researches equipped with comprehensive knowledge on its environmental impact, biosafety concerns and regulatory issues (MISHRA et al., 2017). The nanotechnology risk management strategies and environmental regulations continue to rely on hazard, and exposure assessment protocols developed for nanomaterials, including larger size particles, while commercial application of nanomaterials increases (LAUX et al., 2017). However, the aim this review is emphasizing the positive and negative aspects of the use of nanotechnology in agriculture as well as its impact on the environment.

MATERIAL AND METHODS

In this bibliographic review, in addition to the consultation in books, relevant scientific articles were used in the area of nanotechnology and environment, published between 2000 and 2017. For this purpose, different sources of research such as Pubmed and Scielo were consulted with the following keywords: nanotechnology, nanoparticles, environment, pesticides.

THEORETICAL FOUNDATION

NANOMATERIALS IN AGRICULTURE

Agriculture is an important area that meets the growing needs of global sustainability. Due to the increase in population, scarcity of land and water, changes in temperature and consequent drop in the productivity of some crops and the need to use clean energy, agriculture is an important area to be studied (CHEN; YADA, 2011). The use of new technologies has the objective of minimizing inputs and maximizing the results of agricultural production, reducing damages to the environment (SEKHON, 2014). In this way, the use of nanotechnology devices and tools has shown promise in the agrifood system (CHEN; YADA, 2011; RESCH; FARINA, 2015).

Among the many possibilities of nanotechnology in the rural environment, we highlight the nanosensors and nanocatalysts that can monitor the diagnosis of plant diseases, improve the capacity of nutrient absorption and the application of pesticides, herbicides, and fertilizers. In this way, nanomaterials allow the increase of income in the agricultural sector, by reducing costs, increasing productivity, reducing production losses and reducing environmental impacts (PRASAD; BHATTACHARYYA; NGUYEN, 2017; RAMOS et al., 2009). A great advantage is the control of the supply of active ingredients and chemicals, distributed in specific places of the plantations, that promote a reduction of damages in non-target plants, minimizing the number of substances released to the environment (PARISI; VIGANI; CEREZO, 2014). The nanoparticles have great potential as “magical bullets,” loaded with herbicides, chemicals or nucleic acids, targeting specific plant tissues to release their charge (PÉREZ-DE-LUQUE; RUBIALES, 2009).

There are several studies correlating nanomaterials with positive effects on germination and growth of some species with the aim of promoting its use to crops (KHAN; RIZVI, 2017; PÉREZ-DE-LUQUE; RUBIALES, 2009).

Currently, agrochemicals commonly used in agriculture can reduce the absorption and degradation of active ingredient in the soil, thereby increasing the environmental contamination. For example, the Atrazine is an herbicide of the class of triazines used in plantations for weed control. Their bioaccumulation and soil contamination makes this compound affects not only the target plants, attacking non-target plants reducing productivity. In a recent study using atrazine encapsulated, no yielding plantings were lost compared to the herbicide in free form. Also, less genotoxic effects were observed compared to current methods, thus concluding that the use of herbicides associated with nanoparticles offers a good alternative for weed control, as well as reducing damages to the environment and human health (PEREIRA et al., 2014).

The triazines are widely used to control weeds in maize crops and sugar cane, where its properties show a high degree of flow, prolonged persistence in the soil, slow hydrolysis, low vapor pressure, low solubility in water and moderate adsorption clays and organic matter. These characteristics facilitate bioaccumulation and contamination of water and soil air. Also are very harmful to humans and the environment (PEREIRA et al., 2014). Grillo et al. (2012) conducted a study which evaluated nanocapsules PLC (Polymeric polycaprolactone) containing three herbicides from the class of triazines (ametryn, atrazine, and simazine) for 270 days and concluded that the controlled release system was less toxic than traditional herbicides. Corroborating these data, Pereira et al. (2014), in a more recent study, reported that Atrazine encapsulated generates no loss in crops compared with the herbicide in free form, with less genotoxic effects. Thus they were concluding that the use of herbicide associated with the nanoparticles have a good alternative for weed control and reduce damage to the environment and human health.

Some nanotechnologies can improve existing crop management techniques in short to medium term. Nanocapsules would avoid phytotoxicity on the crop by using systemic herbicides against parasitic weeds (MATTIELLO; MARCHIOL, 2017; PÉREZ-DE-LUQUE; RUBIALES, 2009). One of the advantages of nanoscale delivery vehicles in agronomic applications is its improved stability of the payloads against degradation in the environment, thereby increasing its effectiveness while reducing the amount applied (CHEN; YADA, 2011). Some scientists have shown that the compounds with different concentrations of titanium (TiO2) in nanoscale agriculture have a positive effect (FEIZI et al., 2012). A combination of nanometers in SiO2 and TiO2 realized the increase in nitrate reductase enzyme from soybean (glycine max), thus increasing the absorption capacity and the use of water and fertilizers, favoring the antioxidant system and accelerating germination and growth of crops. In another study on the growth of spinach about the age of their seeds, they concluded that the plants originated from seeds with nanoparticles of titanium (TiO2) increased by three times the rate of photosynthesis and 45% the formation of chlorophyll compared to the control group over a period of 30 days. The authors reported the results to the fact that the smaller the nanoparticles, the greater the absorption of inorganic nutrients and decompose organic particles, eliminating the formation of free radicals, thereby increasing the photosynthetic rate (ZHENG et al., 2005). Feizi et al. (2012) compared the interaction of wheat crops with concentration and size of TiO2 and concluded that its use in appropriate concentration accelerates the germination and rates of vigor. On the other hand, when associated with high concentrations of TiO2 the authors concluded that these effects are neutral on the criteria described above corroborate such findings, conducted a study to assess the effects of metal nanoparticles. (Si, Pd, Au, and Cu) on the germination of lettuce seeds and concluded that the use of these has positive influences on the germination and that its use does not affect soil microorganisms (SHAH; BELOZEROVA, 2009).

According Khodakovskaya et al. (2009) in a study of tomato seeds concluded that nanoparticles increased up to 90% of plant biomass compared to the control group in only 20 days. Navarro et al. (2008) work with the hypothesis nanoparticles kidnapping nutrients in the lettuce from the surface, helping as a supply of nutrients for organisms, due to the antimicrobial properties of the nanoparticles, increasing the strength and stress resistance of plants.

CYTOTOXICITY

Nanotoxicology is the study of the toxicity of nanoscale materials, has advanced in line with nanotechnology regarding the amount of literature being published. Indeed, unlike what has been the case for harmful substances in the past, nanotoxicology is running more in parallel with developments in nanotechnology. This review examines findings from environmental and nanotoxicology health effects research. Then, It means that not all nanomaterials are created equal regarding their toxic potential, and likewise, not all ambient particulate matter or ultrafineparticles (UFP, <100 nm in diameter) have the same potential to induce health effects (STONE et al., 2017).

Nanoparticles (NPs) have opened doors to a plethora of improvements in the agriculture sector. However, the sizes and physical-chemical characteristics raise concerns about the long-term damage that these particles can cause to living things and the environment (SINGH, 2009; SIQUEIRA-BATISTA et al., 2010). The NPs may undergo a transition between their molecules or atoms, which can modify the physical properties (conductivity, reactivity, and sensitivity) and may produce adverse biological effects on the cells (GRILLO et al., 2012).

The NPs are absorbed by the human body through inhalation, ingestion and dermal deposition and can be transported through the bloodstream to various organs (KRUG; WICK, 2011). After reaching the human body, NPs can enter the cell through a series of mechanisms, which can damage cellular organelles and cause interactions damaging the DNA (CHEN et al., 2005; GEISER et al., 2005; SUMERS et al., 2011). Also, the interaction of NPs with organelles and DNA can promote the generation of reactive oxygen species (ROS). These reactive species may result in chromosomal breaks, DNA adducts formation, histone modification, methylation, altered protein expression, among others (KARLSSON et al., 2008; NAVARRO et al., 2008; SINGH et al., 2009).

Corroborating these findings, some researchers have demonstrated the toxicity of nanoparticles (e.g., carbon nanotubes and metal oxides) in human cells, bacteria and rodents (GRILLO et al., 2012). Some studies included in the literature relating the use of nanoparticles with the possibility of chromosomal aberrations in plant cells, interaction with photosynthesis plants and the use of high concentrations of various nanoparticles (200 mg/L) affect the development of some roots (GRILLO et al., 2012). Some results have been published concerning plant cells and magnetic nanoparticles, suggesting possible development of chromosomal aberrations and interactions with photosynthetic system II. Ultrahigh concentrations (2000 mg L^{-1}) of different nanoparticles can affect root growth of some plants (RICO et al., 2011).

Lee et al. (2008) studied the phytotoxicity and bioavailability of copper nanoparticles to two species of plants (Phaseolus radiates and Triticum aestivum) and concluded that growth and plant length was negatively related to the concentration of nanoparticles. Some studies show that when inhaled nanoparticles with diameters less than 50 nm size can be highly toxic as demonstrated by Oberdörster (2004) demonstrated that oxidative stress was causing a significant lipid peroxidation in brain tissue of fish. The formation of reactive species and the consequent oxidative stress has been proposed to explain such toxicity, but the mechanisms by which nanomaterials affect living organisms remains to be elucidated. Kumari et al. (2009) show that silver nanoparticles showed cytotoxicity in roots of Allium cepa by decreasing the mitotic index dependent on their cell dose, and chromosomal abnormalities and disintegration of the cell wall.

Liposomes already being incorporated in the development and formulation of agrochemicals, but their use is still limited, and only large companies with great research resources or academic institutions are working on them. (PÉREZ-DE-LUQUE; RUBIALES, 2009). Regarding the control of the parasitic plantations, Nanoencapsulation can be used to solve the phytotoxicity compared to other currently used pesticides. Controlling parasitic plants, nanoencapsulation could be used to solve problems regarding phytotoxicity on the crop of the herbicides used against the parasite (GOLDWASSER et al., 2003).

Biological materials such as plant extracts, sugars, polyphenols, vitamins, and microorganisms may be used as reducing and capping agents in the synthesis process. This lead to more stabilized and biocompatible nanoparticles with higher longevity (KHARISSOVA et al., 2013). Bio fabricated nanoparticles exhibit relatively lower toxicity compared to chemically produced nanoparticles (ÓRDENES-AENISHANSLINS et al., 2014). Consequently, with the growing interest in the nanotoxicity and its environmental impact, considerable attention is required for employing biosynthesized nanoparticles for agricultural purposes. However, there are no studies aimed at toxicity, associated risk factors and environmental impact of biosynthesized nanoparticles. There is growing research in this underexplored, emerging and challenging area. Hence, considerable efforts must be devoted to in-depth study on the environmental impact of biosynthesized nanoparticles. Therefore, we believe that meticulous application of biosynthesized nanoformulations in the agricultural system would eventually remove its negative perception.

CHEMICAL DISPERSION

Although nanoscience and nanotechnology are in full development and their use and applications are promising, the physicochemical characteristics of the nanoparticles facilitate their dispersion in the atmosphere, soil, water and living systems (IAVICOLI et al., 2017; SIQUEIRA-BATISTA et al., 2010).

Nanomaterials may be grouped into four types: carbon-based materials, the base metal (nano zinc, nano aluminum) and nanoscale metal oxides (TiO2, ZnO, Al203), dendrimers (from branched units capable of adapted to perform specific chemical functions), and combinations of nanoparticles, the most common and studied (LIN; XING, 2007; KARLSSON et al., 2008).

Possible fate and environmental impacts of nano-pesticides were discussed to analyze the suitability of current regulatory exposure assessment (KAH; HOFMANN, 2014). The widespread use of fungicides, herbicides, and pesticides has contributed not only to the contamination of soil but also of ground and surface waters and even oceans (WIJAYA et al., 2010). One such herbicide, 2,4-dichlorophenoxyacetic acid (2,4-D), is widely used for the control of broadleaf weeds in agriculture, and forestry; and has been shown to be very harmful to aquatic life (ORUC; SEVGILER; UNER, 2004; WIJAYA et al., 2010).

Grows daily concern regarding contamination of water resources, groundwater sources for drinking water production, which are often bombarded with pesticide residues (BENITÉZ et al., 2009). The variety of information in the literature regarding the use of nanofiltration and ultrafiltration for the removal of micropollutants is conventional wide, have the advantage of the high quality of the final permeate questions low temperature and energy, the absence of chemical substances. The big disadvantage is constituted of clogging of the membrane, Which results in a reduction of flow, and has been associated with the content of organic matter found in the water to be treated (BENITÉZ et al., 2009). The use of nanofiltration is promising since each component is partially or entirely removed.The study was conducted to analyze if the nanofiltration of contaminated groundwater with pesticides is efficient to treat the groundwater for drinking water production using 4 types of membranes and concluded the treatment could produce that in a quality drink water with low investment costs (VAN DER BRUGGEN et al., 2001).

LEGISLATION

The safety of NPs has drawn attention because of its increased use and benefits, although studies evaluating their toxicological effects and impacts are still limited (ASSIS et al., 2012; BLASCO; PICÓ, 2011). The potential applications of nanotechnology are broad, although food and agricultural sectors are relatively scarce. However, products and applications in these sectors are advancing, and the forecast is for it to grow rapidly in the future (FAO/WHO, 2009).

Recently, there was an international conference about the NMs applications in the areas of food and agriculture in Brazil with great interest in identifying important areas of developing countries. These areas of particular interest include water safety, packaging and contaminant detection (FAO/WHO, 2009).

International agencies have identified several factors relevant to that research be conducted to obtain scientific basis to support a future regulation. Such factors include: development of reliable measurement methods for evaluation of health, safety and environment, interactions with the environment, the characterization of materials, collection of information as the life cycle of the NMs, understanding the interactions of these NMs the cellular and molecular levels, identification of potential exposure, possible toxicity, assessment of risks not only for the population but also for the protection of workers (THOMAS; SAYRE, 2005; BLASCO; PICÓ, 2011).

Researchers from all over the world are aware, showing several studies with good prospects and calling attention to some care. Recent studies described in the literature show that the NPs inorganic engineering and carbon nanostructures can incidentally or intentionally get in touch with living organisms, disrupting normal activity and consequently lead to diseases and malfunction (BLASCO; PICÓ, 2011).

According to the literature, the determination of toxicity is due mainly to their size, but the chemical composition, morphology, surface structure, surface charge, solubility, presence or absence of certain chemical functional groups also contribute to this factor (BLASCO; PICÓ, 2011; SAVOLAINEN et al., 2010).

The handling of chemicals and biological materials follows specific rules. However, for NT studies necessary to the use of the system for identification and manipulation of nanostructures (SAVOLAINEN et al., 2010).

The specific regulations in the area of NT are non-existent in the world. There is a lack of legal instruments, scientific, information and resources to supervise and monitor this area in accelerated growth. The cost-benefit assessment is not so easy because each new NP should be assessed individually taking into account its properties and characteristics (BLASCO; PICÓ, 2011).

It is necessary to the implementation of regulation for the NT to evaluate in depth the effects of these can be fixed or reverted to an acceptable level, and those that would lead to unacceptable risks. However, at the moment there is no research to conclude the real consequences of the NMs (SAVOLAINEN et al., 2010). Due to the uncertainty of regulatory frameworks and difference in opinion across the world, the nanoparticle-based products for agricultural benefits are not increasing and facing difficulties in reaching to the market. Risk assessment and management are the topmost priorities to be considered in framing regulatory policies for addressing biosafety issues. Sharing views and opinion on the public platform across the globe would be helpful in dealing with efficient regulatory measures (LAUX et al., 2017; MISHRA et al., 2017).

PROSPECTS FOR THE USE OF NANOTECHNOLOGY IN AGRICULTURE AND ITS RELATIONSHIP WITH ENVIRONMENT

Nanotechnology provides the possibility of precision farming (augmenting agricultural production with minimum input) in the era where increasing demand of sustainability compels to reduce the cost and excessive use of agricultural and natural resources (CHEN; YADA, 2011). However, despite the results obtained by the involvement of ground-breaking nanotechnology in agriculture so far, their relevance has not yet reached up to the market. This fact is mainly attributed to small-scale bench-top researchers, ambiguous technical benefits, insufficient economic interest, biosafety concerns and regulatory issues (PARISI et al., 2014). Additionally, the apprehensions about fate, transport, bioavailability, and toxicity of nanoparticles, limit the complete acceptance and willingness to adopt nanotechnology in the agricultural sector. Nevertheless, nanotechnology renders precise capability to revolutionize the agricultural sector. At the same time, it is important to note that its concrete contribution to agriculture is still uncertain and at its nascent stage. We need to include a system level approach providing more accurate information on nanoparticles exposure and their risk in agricultural systems. According to Mishra et al. (2017), we highlight the future directions for improved agri-nanotechnology researches with special emphasis on; (A) optimization of the safe use of nanoparticles at permissible level for agricultural benefits by modulating the behavior, fate, bioavailability and toxicity determining factors (B) advancement in experimental design and, (C) incorporation of biosynthesized nanoparticles and assessing their relative advantages over nanoparticles from non-biological sources.

The production of engineered nanomaterials is a scientific breakthrough in material design and the development of new consumer products. While the successful implementation of nanotechnology is important for the growth of the global economy, we also need to consider the possible environmental health and safety impact as a result of the novel physicochemical properties that could generate hazardous biological outcomes (STONE et al., 2017).

FINAL CONSIDERATIONS

The development of nanotechnology has provided a novel and exciting frontier to various fields of industrial applications with profound impact on human's life. Information on possible influences on the use of NPs in agriculture and their elimination on the environment, including nanopesticide residues, remains scarce and insufficient for a reliable assessment of their benefits and harms, as well as their use and regulation. More studies are needed regarding the development of experimental protocols and appropriate destinations; information on bioavailability and durability, detection and monitoring of pollution; evaluation of approaches to environmental risks and its improvement and whereas the effects of nanoparticles in plants may be positive or negative, depending on the type of nanomaterial and its potential application.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

REFERENCES

ASSIS, L. M. et al. Características de nanopartículas e potenciais aplicações em alimentos. **Brazilian Journal of Food Technology**, v. 15, n. 2, p. 99-109, 2012.

BENITÉZ, F. J. et al. Nanofiltration processes applied to the removal of phenyl-ureas in natural Waters. **Journal of Hazardous Materials**, v. 165, n. 1, p. 714-723, 2009.

BLASCO, C.; PICÓ, Y. Determining nanomaterials in food. **Trends in Analytical Chemistry**, v. 30, n. 1, p. 84-99, 2011.

CARUTHERS, S. D.; WICKLINE, S. A.; LANZA, G. M. Nanotechnological applications in medicine. **Current opinion in Biotechnology**, v. 18, n. 1, p. 26-30, 2007.

CHEN, H.; YADA, R. Nanotechnologies in agriculture: New tools for sustainable development. **Food Sciences and Technology**, v. 22, n. 11, p. 585-594, 2011.

CHEN, J. et al. Gold nanocages: bioconjugation and their potential use as optical imaging contrast agents. **Nano Letters**, v. 5, n. 3, p. 473-477, 2005.

FAO/WHO - FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS/ WORLD HEALTH ORGANIZATION. **Expert Meeting on the Application of Nanotechnologies in the Food and Agriculture Sectors**: Potential Food Safety Implications: Meeting Report. Rome, 2009. 104p.

FEIZI, H. et al. Impact of bulk and nanosized titanium dioxide (TiO2) on wheat seed germination and seedling growth. **Biological trace element research**, v. 146, n. 1, p. 101-106, 2012.

GEISER, M. et al. Ultrafine particles cross cellular membranes by nonphagocytic mechanisms in lungs and cultured cells. **Environment Health Perspective**, v. 113, n. 11, p. 1555-1560, 2005.

GRILLO, R. Poly (e-caprolactone) nanocapsules as carrier systems for herbicides: physico-chemical characterization and genotoxicity evaluation. **Journal of Hazardous Materials**, v. 231, p. 1-9, 2012.

GOLDWASSER, Y. Control of Orobanche crenata and Orobanche aegyptiaca in parsley. **Crop Protection**, v. 22, n. 2, p. 295-305, 2003.

IAVICOLI, I. et al. Nanotechnology in agriculture: opportunities, toxicological implications, and occupational risks. **Toxicology and Applied Pharmacology**, v. 15, n. 329, p. 96-111, 2017.

KAH, M.; HOFMANN, T. Nanopesticide research: Currend trends and future priorities. **Environment International**, v. 63, p. 224-235, 2014.

KARLSSON, H. L. et al. Copper oxide nanoparticles are highly toxic: a comparison between metal oxide nanoparticles and carbon nanotubes. **Chemical Research in Toxicology**, v. 21, n. 9, p. 1726-1732, 2008.

KHAN, M. R.; RIZVI, T. F. Application of Nanofertilizer and Nanopesticides for Improvements in Crop Production and Protection. In: **Nanoscience and Plant-Soil Systems**. Springer International Publishing, p. 405-427, 2017.

KHARISSOVA, O. V. et al. The greener synthesis of nanoparticles. **Trends in Biotechnology**, v. 31, n. 4, p. 240-248, 2013.

KHODAKOVSKAYA, M. et al. Carbon nanotubes are able to penetrate plant seed coat and dramatically affect seed germination and plant growth. **ACS Nano**, v. 3, n. 10, p. 3221-3227, 2009.

KOTH, L. R. et al. Apliccations of nanomateriais in agricultural production and cop protection: A review. **Copy Protection**, v. 35, p. 64-70, 2012.

KRUG, H. F.; WICK, P. Nanotoxicology: an interdisciplinary Challenge. **Angewandte Chemie International Edition**, v. 50, n. 6, p. 1260-1278, 2011.

KUMARI, M.; MUKHERJEE, A.; CHANDRASEKARAN, N. Genotoxicity of silver nanoparticles in Allium cepa. **Science of the Total Environment**, v. 407, n. 19, p. 5243-5246, 2009.

LAUX, P. et al. Biokinetics of Nanomaterials: the Role of Biopersistence. **NanoImpact,** v. 6, p. 69-80, 2017.

LEE, W. M. et al. Toxicity and bioavailability of copper nanoparticles to the terrestrial plants mung bean (*Phaseolus radiatus*) and wheat (*Triticum aestivum*): plant agar test for water-insoluble nanoparticles. **Environmental toxicology and chemistry**, v. 27, n. 9, p. 1915-1921, 2008.

LIN, D.; XING, B. Phytotoxicity of nanoparticles: Inhibition of seed germination and root growth. **Environmental Pollution**, n. 150, p. 243-250, 2007.

MARTINS, P. Nanotecnologia e meio ambiente para uma sociedade sustentável. **Estudios Sociales,** v. 17, n. 34, p. 293-309, 2009.

MATTIELLO, A.; MARCHIOL, L. Application of Nanotechnology in Agriculture: Assessment of TiO2 Nanoparticle Effects on Barley. In: **Application of Titanium Dioxide**. InTech, Web of Science, 2017.

MCGILLICUDDY, E. et al. Silver nanoparticles in the environment: Sources, detection and ecotoxicology. **Science of The Total Environment**, v. 575, p. 231-246, 2017.

MISHRA, S. et al. Integrated Approach of Agri-nanotechnology: Challenges and Future Trends. **Frontiers in Plant Science**, v. 8, 2017.

NAVARRO, E. et al. Environmental behavior and ecotoxicity of engineered nanoparticles to algae, plants, and fungi. **Ecotoxicology,** v. 17, n. 5, p. 372-386, 2008.

OBERDÖRSTER, E. Manufactured nanomaterials (fullerenes, C60) induce oxidative stress in the brain of juvenile Largemouth Bass. **Environmental Health Perspectives**, v. 112, n. 10, p. 1058-1062, 2004.

ÓRDENES-AENISHANSLINS, N. A. et al. Use of titanium dioxide nanoparticles biosynthesized by Bacillus mycoides in quantum dot sensitized solar cells. **Microbial cell factories**, v. 13, n. 1, p. 90, 2014.

ORUC, E. O.; SEVGILER, Y.; UNER, N. Tissue-specific oxidative stress responses in fish exposed to 2,4-D and azinphosmethyl. **Comparative Biochemistry and Physiolgy Part C: Toxicology & Pharmacology,** v. 137, n. 1, p. 43-51, 2004.

PARISI, C.; VIGANI, M.; CEREZO, E. R. Proceedings of a Workshop on" Nanotechnology for the agricultural sector: from research to the field". **Joint Research Centre** (Seville site), 2014.

PEREIRA, A. E. S. et al. Application of poly (épsilon-caprolactone) nanoparticles containing atrazine herbicide as na alternative technique to control weeds and reduce damage to the environment. **Journal of Hazardous Materials**, v. 268, p. 207-215, 2014.

PÉREZ-DE-LUQUE, A.; RUBIALES, D. Nanotechnology for parasitic plant control. **Pest management science**, v. 65, n. 5, p. 540-545, 2009.

PRASAD, R.; BHATTACHARYYA, A.; NGUYEN, Q. D. Nanotechnology in sustainable agriculture: recent developments, challenges, and perspectives. **Frontiers in microbiology**, v. 8, p. 1-13, 2017.

RAFIEI, P.; HADDADI, A. Pharmacokinetic Consequences of PLGA Nanoparticles in Docetaxel Drug Delivery. **Pharmaceutical Nanotechnology**, v. 5, n. 1, p. 3-23, 2017.

RAMOS, S. de F. et al. Reflexões acerca das nanotecnologias e as novas densidades técnicas-científicas--informacionais na agricultura. **Estudios sociales (Hermosillo, Son.)**, v. 17, n. 34, p. 313-326, 2009.

RÉ, M. I. Microencapsulação: Em busca de produtos inteligentes. **Ciência Hoje**, v. 27, n. 162, p. 24-29, 2000.

RESCH, S.; FARINA, M. C. Mapa do conhecimento em nanotecnologia no setor agroalimentar. **Revista de Administração Mackenzie**, v. 16, n. 3, p. 51-75, 2015.

RESEARCH AND MARKETS. **Global Nanotechnology Market Outlook 2015-2020**. 2015. Available at: <https://goo.gl/c9QfTX>.

RICO, C. M. et al. Interaction of nanoparticles with edible plants and their possible implications in the food chain. **Jounal of Agricultural and Food Chemistry**, v. 59, n. 8, p. 3485-3498, 2011.

SABOURIN, V.; AYANDE, A. Commercial opportunities and market demand for nanotechnologies in agribusiness sector. **Journal of technology management & innovation**, v. 10, n. 1, p. 40-51, 2015.

SANTOS, R. M. M. dos; FIALHO, S. L. Nanopartículas: Uma alternativa para a administração de biofármacos. **Biotecnologia Ciência e Desenvolvimento**, n. 37, p. 52-59, 2014.

SANTOS, A. B.; FERREIRA, V. P.; GROSSO, C. R. F. Microcápsulas: uma tecnologia viável. **Biotecnologia, ciência e desenvolvimento**, v. 3, n. 16, p. 26-30, 2000.

SASTRY, R. K.; RASHMI, H. B.; RAO, N. H. Nanotechnology for enhancing food security in India. **Food Policy**, v. 36, n. 3, p. 391-400, 2011.

SAVOLAINEN, K. et al. Risk assessment of engineered nanomaterials and nanotechnologies-a review. **Toxicology**, v. 269, n. 2-3, p. 92-104, 2010.

SEKHON, B. S. Nanotechnology in agri-food production: an overview. **Nanotechnology, Science and Applications**, v. 7, p. 31-53, 2014.

SHAH, V.; BELOZEROVA, I. Influence of metal nanoparticles on the soil microbial community and germination of lettuce seeds. **Water, Air and Soil Pollution**, v. 197, n. 1-4, p. 143-148, 2009.

SHARON, M.; CHOUDHARY, A. Kr; KUMAR, R. Nanotechnology in agricultural diseases and food safety. **Journal of Phytology**, v. 2, n. 4, 2010.

SILVA, P. T. da et al. Microencapsulation: concepts, mechanisms, methods and some applications in food technology. **Ciência Rural**, v. 44, n. 7, p. 1304-1311, 2014.

SINGH, N. NanoGenotoxicology: the DNA damaging potential of engineered nanomaterials. **Biomaterials**, v. 30, n. 23, p. 3891-3914, 2009.

SIQUEIRA-BATISTA, R. et al. Nanociência e Nanotecnologia como temática para discussão de ciência, tecnologia, sociedade e ambiente. **Ciência e Educação**, v. 16, n. 2, p. 479-490, 2010.

SODANO, V.; VERNEAU, F. Competition policy and food sector in the european union. **Journal of International Food & Agribusiness Marketing**, v. 26, n. 3, p. 155-172, 2014.

STONE, V. et al. Nanomaterials Versus Ambient Ultrafine Particles: An Opportunity to Exchange Toxicology Knowledge. **Environental Health Perspectives.** v. 125, n. 10, p. 106002-1-106002-17, 2017.

SUAVE, J. et al. Microencapsulação: Inovação em diferentes áreas. **Revista Saúde e Ambiente/ Health and Environment Journal**, v. 7, n. 2, p. 12-20, 2006.

SUMMERS, H. D. et al. Statistical analysis of nanoparticle dosing in a dynamic cellular system. **Nature nanotechnology**, v. 6, n. 3, p. 170-174, 2011.

THOMAS, K.; SAYRE, P. Research strategies for safety evaluation of nanomaterials, Part I: Evaluating the human health implications of exposure to nanoscale materials. **Toxicological Scienes**, v. 87, n. 2, p. 316-321, 2005.

VAN DER BRUGGEN, B. et al. Application of nanofiltration for removal of pesticides, nitrate and hardess from ground water: rejection properties and economic evaluation. **Journal of Membrane Sciense**, v. 193, n. 2, p. 239-248, 2001.

ZHENG, L. et al. Effect of nano-TiO2 on strength of naturally aged seeds and growth of spinach. **Biological trace element research**, v. 104, n. 1, p. 83-91, 2005.

WIJAYA, I. P. M. et al. Femtomolar detection of 2,4-dichlorophenoxyacetic acid herbicides via competitive immunoassays using microfluidic based carbon nanotube liquid gated transistor. **Lab on a Chip**, v. 10, n. 5, p. 634-638, 2010.