9 Alternative Food Production: Nanotechnology in Agri-food Applications

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Introduction

As indicated in the previous chapter, technological solutions have tended to be promoted as ways in which the issue of food security may be addressed. Another technological advance that affects the complete supply chain is that of nanotechnology. Nanotechnology can be explained as the science and technology used to design and build apparatuses in which almost every atom and chemical interaction is precisely known (Mukhopadhyay, 2014). Nanotechnology is not necessarily a specific set of techniques, devices or products, but rather the set of capabilities that can be utilized to achieve improvement in yields and exploitation beyond what can be achieved by traditional means. Nanoscience and nanotechnology have found applications in a wide range of fields, which include energy production (e.g. solar panels), medicine, electronics, communications, and agriculture and food (Sozer and Kokinin, 2009; Handford *et al*., 2015; Azzawi, *et al*., 2016; Hanaei *et al*., 2016). Some nano-applications are based on nanodevices that mimic naturally occurring molecules such as proteins, DNA, and membranes; while other nano-applications work specifically on the premise that tiny particles are produced that have a markedly increased surface area per unit mass. In almost all instances, equivalents to nano particles can be found in nature. For instance, proteins from the planet's most abundant bacterium (*Pseudomonas syringae*) are present on all decaying plant material in autumn, and get carried into the atmosphere where the proteins act as nucleation sites for snowflakes (Davies, 2014). The equivalent nano-biotechnological application is the use of *P. syringae* derived biological ice nuclei for the production of artificial snow (Hara *et al*., 2016). While the applications of nanotechnology are quite wide and diverse, this text will focus on some of the applications of nanotechnology as they apply to the agricultural and food supply chain in its broadest form.

Agricultural applications of nanotechnology

The search for sustainable agriculture through the development of new technologies or the improvement of existing farming practices has been one of the main goals to enhance food availability and to reduce the environmental impacts caused by traditional intensive agricultural practices such as agrochemicals (Anderson *et al*., 2016). The use of nanotechnology in conjunction with biotechnology has proved to be a promising tool to combat such problems, promising higher yields in the field and lower production costs (Das *et al*., 2015). In this way, several engineered nanomaterials (ENMs) with different compositions and morphologies are being synthesized with the aim of increasing the quality and production yields of crops, improving the physical-chemical stability of pesticides and fertilizers, minimizing nutrient losses during the application of fertilizers, reducing applications of plant protection products, and increasing yields through optimized nutrient management (Khot *et al*., 2012; Campos *et al*., 2014; Parisi *et al*., 2014). Engineered nanomaterials present different properties compared to their more traditional counterparts, since ENMs have a greater surface area to volume ratio, and therefore they are more biologically available. Such ENMs are often employed in the form of lipids, polymers or emulsions, titanium dioxide nanoparticles (TiO2-NPs), silver nanoparticles (Ag-NPs) or silica nanoparticles (Si-NPs) (Gogos *et al*., 2012; Martirosyan and Schneider, 2014). The United States and China are the pioneers in the development of ENMs, however many other countries, including Japan, Russia, South Korea, Brazil, Canada, Singapore, India, Germany and some other European countries, are increasing their studies and investments in the agricultural sector (Gogos *et al*., 2012; Donga *et al*., 2016).

Recently, a wide range of review articles have been described addressing the potential use of nanotechnology in agriculture (Nair *et al*., 2010; Gogos *et al*., 2012; Khot *et al*., 2012; Kah and Hofmann, 2014; Cicek and Nadaroglu, 2015; Das *et al*., 2015; Dasgupta *et al*., 2015; Parisi *et al*., 2015; Fraceto *et al*., 2016; Grillo *et al*., 2016; Rizwan *et al*., 2017). Among these we can highlight: nanocarriers, the fabrication of nano and biosensors, synthesis of nanostructures, and the exploitation/development of catalytic properties of nanoparticles.

The development of nanocarriers can be associated with pesticides (de Oliveira *et al*., 2014; Kashyap *et al*., 2015; Grillo *et al*., 2016), genes (Torney *et al*., 2007) and fertilizers (Corradini *et al*., 2010), whose main purpose is promoting a controlled release of these active ingredients in order to reduce their toxicity and improve the physical-chemical stability and specificity for target sites (Kah and Hofmann, 2014; Grillo *et al*., 2016). The fabrication of nano- and biosensors can be used for enhancing the sensitivity and speed of detection of various active ingredients used in agriculture (Valdes *et al*., 2009; Rai *et al*., 2012; Duran and Marcato, 2013). Alternatively, nano- and biosensors can be employed to predict environmental changes that could compromise a crop, as well as assist in the diagnosis of pathogens (Valdes *et al*., 2009; Gibson *et al*., 2016). The synthesis of nanostructures can aid in facilitating enhanced seed germination and plant growth, for example, by treating it with carbon nanotubes (Haghighi and da Silva, 2014), or through soil management, using nanoclays or nanozeolites (Fraceto *et al*., 2016). Finally, nanotechnology can be used in agriculture, through the synthesis or enhancement of catalytic properties of nanoparticles (e.g. TiO_2, silver, gold, platinum, SnO_2, ZnO), nanofilters, nanoadsorbents, and nanomembranes, for remediation of pesticides, dyes or metals in soils and water (Zheng *et al*., 2008; Shan *et al*., 2009; Patil *et al*., 2016). In addition to these examples, the development of advanced hybrid systems, consisting of organic and inorganic materials with capacity to combine multiple applications on a single system, is rapidly becoming a hot research topic in nanoagriculture, as it is already established in nanomedicine (Nguyen and Zhao, 2015). Moreover, agriculture can be enhanced by applying nanotechnology in other economic sectors, such as energy efficiency, through the creation of new solar cells, fuel cells and batteries (Baxter *et al*., 2009; Das *et al*., 2015). Thus, it is possible to reduce irrigation costs (Alnaimi *et al*., 2014) and to promote the development of more efficient electric drives and machines for agriculture (Karner *et al*., 2014). Furthermore, it is also possible to produce nanotech-based tools and equipment with greater functionality and lifespan to be used by rural workers.

Food applications of nanotechnology

The food industry is directing new product development towards the area of functional foods, due to consumers' demand for healthier foods, containing lower concentrations of synthetic additives and a greater presence of compounds that facilitate biological functions that are perceived to be of benefit to maintaining a healthy lifestyle. Among the explorational nanotechnological studies that have been carried out in recent decades, there have been many functional components that have been rapidly and efficiently applied to the development of functional and improved foods. Many functional components, especially active ingredients in plants such as flavonoids, isoflavones, and anthocyanins, have preventive and therapeutic potential in the treatment and prevention of diseases. However, many of these components have low levels of solubility, stability and bioavailability in the human body, which makes their inclusion in (functional) foods at their effective levels in the target tissues somewhat unrealistic (Wang *et al*., 2014). Formulation improvement into highly stable, water-soluble and orally bioavailable forms is regarded as a prerequisite for the nutritional or clinical application of those functional components (Shakeri and Sahebkar, 2016). Various nanotechnologies can be applied to compensate for their insolubility and consequent slow dissolution rate, which commonly includes nanoemulsions, solid lipid nanoparticles, micelles, nanoliposomes, and poly lactic-co-glycolic acid (PLGA) nanoparticles.

Nanoemulsions

Nanoemulsions are kinetically stable liquid-in-liquid dispersions with droplet sizes in the order of 100 nm. A typical (nano)emulsion contains oil, water, surfactant and possibly a co-surfactant (Figure 9.1) (Gupta *et al*., 2016).

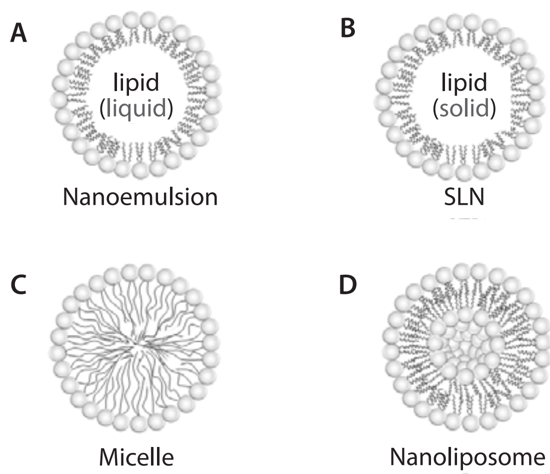

Figure 9.1: Schematic structure of nanoemulsion (A), solid lipid nanoparticle (B), micelle (C) and nanoliposome (D).

Emulsions may be of the oil-in-water (O/W) type, or water-in-oil (W/O) type; depending on whether the oil is dispersed as droplets in water (O/W), or as water droplets dispersed in oil as the continuous phase (W/O) (McClements, 2012). With regards to nanoemulsions, their nano size leads to advantageous properties such as: lasting stability, high surface area per unit volume, optically crystal clear appearance, and tunable rheology (Gupta *et al*., 2016). Over the past decade or more, much research has focused on preparing nanoemulsions through various methods, broadly classified into two primary categories: high-energy and low-energy methods (Fryd and Mason, 2012; Solans *et al*., 2005; Tadros *et al*., 2004).