Nanotechnology in agriculture: from nanomaterials to nanobiosensors

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Nanotechnology is since years one of the most important areas of research and development worldwide being agriculture one of the application fields. NANOALB, the Albanian Nanoscience and Nanotechnology Unit next to the Academy of Sciences of Albania also considers agriculture a priority area for future applications and is trying to push the research in this direction that will be quite beneficial for the country, the quality of the agriculture products and their impact to the citizen's life.

Nowadays, in order to make work in the agricultural sector more attractive and easier, specialists have turned to new and modern technologies such as nanotechnologies. Also, taking into account the demands that agriculture has for increasing yields by optimizing plant nutrition as well as protecting crops from pests with the aim of maintaining food safety and protecting the environment, researchers and farmers need nanotechnology, devices such as nanobiosensors and nanomaterials for various applications. To diagnose and manipulate processes such as the spread of pests and especially plant pathogens, researchers have found fast and accurate solutions in nanotechnology. Among the most recent applications of nanotechnology are nanoparticle-mediated gene or DNA transfer in plants for the development of resistant varieties. Parasitic effects are one of the main causes for a decrease in production. Moreover, nanotechnology can increase the development of production not only for food but also for biomass to be used as fuel.

Summarizing according to Dziergowska et al. 2022, the application of nanotechnology in agriculture is mainly considered in five aspects, such as (1) plant growth stimulation, (2) crop productivity increase, (3) plant protection, (4) soil quality improvement, and (5) smart monitoring (pathogen and pesticide residue detection), but still it remains an insufficiently explored/investigated area in the research community [1].

Nanomaterials for encapsulation and controlled delivery of pesticides.

An interesting application area of nanotechnology is related to nanomaterials. Nanomaterials in agriculture are used for the encapsulation of pesticides (forming nanopesticides) or to develop active nanomaterials [2] that are especially useful for hazardous chemicals. Pesticides are one of most hazardous compounds for the environment and human health that are still in use in agriculture. The control of their levels remains the focus of maintaining safe products for health, regardless of global initiatives for limiting their usage and finding replacement alternatives which is quite important.

When compared to conventional pesticides, nanomaterials with the capacity to encapsulate and transport pesticide active components in a responsive (for instance, regulated, targeted, and synchronized) manner present new options to boost pesticide efficacy and efficiency. Numerous studies demonstrate that compared to their traditional analogues, nanoinsecticides may be more effective, robust, and environmentally friendly. If properly utilized, these advantages can promote greater agricultural yields, which will support sustainable agriculture and help ensure global food security [3].

Eco-friendly agricultural practices ensure nanotechnology-based synthesis for slow or controlled release fertilizers, pesticides and herbicides, minimizing the losses and dramatically increasing their efficiency [4]. Nano formulations or encapsulation of pesticides have revolutionized the plant protection sector, facilitating the persistence or controlled release of active ingredients in root zones or inside plants without compromising the effectiveness [5]. Based on their actions, nano fertilizers can be used beside others for the control or slow release of fertilizers to supply wide range of macro- and micro-nutrients in desirable properties [4, 6]. The use of nanomaterials for this purpose can increase crop productivity without disturbing the environmental health [7].

Herbagreen nano-particles, for example, are reported to directly penetrate plants after being applied, thus becoming immediately part of the plants' lifecycle and metabolism. This is due to the new nano- and micro-dimensions of the grinded particles after being treated through TMAC (Tribo-Mechanical Activation of Calcite). This technology does not interfere with the mineral initial composition [8].

Nanomaterials are found to be effective also in detoxification or remediation of harmful pollutants like heavy metals in soils. Nano-Si at low concentrations has revealed plant stress tolerance toward heavy metals such as Pb, Cu, Zn and Cd [9, 10]. Nano-Si fertilizers show a distinctive advantage over traditional fertilizers in reducing heavy metal accumulation [10].

Nanobiosensors in agriculture

The application of nanotechnologies for plant pathogen identification, which is the primary driver of the usage of pesticides, particularly chemical ones, is another highly intriguing feature. In this context nanobiosensors can be potentially used in the plant protection, pathogen detection and pesticide residual analysis with more precision and efficiency.

The development of nanobiosensors to measure and monitor crop growth and soil conditions, nutrient deficiency, toxicity, diseases, and the entry of agrochemicals into the environment assures soil and plant health, product quality, and overall safety for sustainable agriculture and environmental systems [11]. The combination of biology with nanomaterials in sensors has aroused a wider prospect to increase specificity, sensitivity and rapid responses to sense the impairments [12]. Nanosensor-based global positioning system (GPS) is used for real-time monitoring of cultivated fields. This assures a real-time and comprehensive monitoring of the crop growth and effective high-quality data that provide opportunities for most excellent management practices by avoiding an overdose of agricultural inputs [4,13]. In the scenario of water limitation, nanosensors estimate soil water tension in real-time coupled with autonomous irrigation control [14]. Recent reports have shown that coupling micro- and nanotechnology-based diagnostics devices with machine learning would bring advantages in the food and agriculture sectors that in turn are going to have positive impact to our planet [15].

Foods quality control regarding their freshness or storage in safe conditions is very important to be monitored using simple and fast analytical methods. Thus the screen printed electrodes (SPE), are developed and used for determination of histamine in real samples of fish and sauce [16].

A wireless nanosensor has been developed for the detection of insect attacks [17]. This sensor distinguishes the emitted volatile organics in many host plant species in relation to the insect types. Moreover, nano-gold based immunosensor are shown to be effective in the detection of karnal bunt disease in wheat plants [18]. Great potentials in precision farming have shown the development of bionic plants by inserting nanoparticles into the cells and chloroplasts of living plants for sensing or imaging objects in their environment and to communicate as infrared devices or even self-powering of plants as light sources [19,20].

Nanopore sequencing technology (MinION, Oxford, UK), and its applications in basic and applied research have undergone significant growth since Oxford Nanopore Technologies (ONT) provided the first nanopore sequencer, MinION, in 2014 [21,22]. This technology relies on a nanoscale protein pore, or ‘nanopore’, that serves as a biosensor and is embedded in an electrically resistant polymer membrane [21]. Being a low-cost, accurate, fast, and easy in-situ handling technology, its’ application for detecting and characterizing known and undescribed plant pathogens in different plant species and crops have gained a lot of space in agricultural research. The big advantage of such innovative technology resides in the supremacy of multiple detection and characterization of many pathogens and in a reduction of expenses of posting the DNA in foreign laboratories to perform the analysis, as well as the time of obtaining the sequences.

Early diagnosis and detection of viral and virological illnesses aid in routine screening as well as ongoing disease control and prevention. Tests can be used to find infections before they become serious issues and in this context nanotechnology is playing a crucial role. Aptamer-based sensors to identify plant diseases are reported [23]. Another reported method ise related to the In-Situ plant virus nucleic acid isothermal amplification detection on gold nanoparticle-modified electrodes. Gold nanoparticle (AuNP)-modified sensing substrates and electrochemical impedance spectroscopic (EIS) detection were applied for Citrus Tristeza Virus (CTV)) diagnostics. [24].

The mentioned nanomaterials and nanobiosensors are only a small part of a variety of interesting applications of nanotechnologies. More efforts are still on the way including special attention on a better understanding of any harmful effect that nanomaterials as any other chemical reagent may have before any application and transfer of the technologies/materials to the agriculture related end-users.

The research in nanotechnology by NANOALB research groups will pay a special attention to these issues trying to introduce modern methods and materials with interest for agriculture. The possibilities are enormous and the support to be given to such important research field is very necessary.

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