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Nanotechnology and The Use Of Nanoparticles and Its Effect On Wheat Growing

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A B S T R A C T

It is expected that the rapid increase in the human population will cause the increasing demand for agricultural land to be unmet in the near future. Therefore, soil fertility is gaining importance day by day and soil texture is becoming a strategic element. With the development of nanotechnology, the usability of nanoparticles in many fields has started to be investigated and discussed. In recent years, the application of nanotechnology-based applications in agriculture has been one of the topics of interest to researchers. Studies in agricultural nanotechnology have generally focused on using less pesticides, increasing yields or developing stress-resistant crops. Some studies in this field have started to yield positive results. However, more studies are needed for nanotechnology to be used in agriculture. Because deciding on the use of nanoparticles is an issue that can be reached in the long term. In line with these needs, it has become inevitable to use nanotechnology to increase plant resistance in wheat, one of our main food sources, and to control the effectiveness and safety of pesticides and fertilizers. In this study, the strengths, weaknesses, opportunities and targets of the use of nanotechnology and nanoparticles in wheat agriculture are presented.

1. INTRODUCTION

Wheat is one of the most widely grown and consumed cool climate cereals in the world. People do not consume wheat directly. It is known that almost half of people's daily energy needs are met from wheat-origin products such as flour, bulgur and bread. The sentence needs to be revised in this regard. Intense population growth and malnourished societies require a significant increase in wheat production. However, in developed countries, which produce most of the world's wheat, there has been little or no increase in wheat yields in the last 20 years. In this situation, most of the deficit has been met by developing countries with yields far below their wheat production potential. The most important obstacles to production growth and sustainability are limited land and water resources and global climate change. Conflicts over the use and sharing of these resources will be inevitable in the coming years. One of the possible scenarios is that food will be the only thing that money cannot buy in times of severe famine.

Regardless of the level of development of a country, it is important that its productivity is absolutely self-sufficient. It has been shown how indispensable the product is for countries where wars and famines in the past were essential foods. No matter how strong a country is economically, if it cannot produce the wheat for which its product is sold, it would otherwise always work to survive (Akay, 2005).

Wheat constitutes the main food source of the majority of people in the world, especially in Europe, North America and the Near East. Cereals are one of the most studied plants due to their high economic importance. As a result, varieties and genotypes that can adapt to many different environmental conditions have been developed. Cereals are the most widespread plant group in the world due to their richness of varieties and forms (Sepetoğlu, 2006).

Wheat ranks first among the cultivated plants used in human nutrition in terms of cultivation and production in the world. This is because the wheat plant has a wide range of adaptability. Wheat provides about % 20 of the total calories provided to the world population from plant-based foods. In Turkey, this rate is % 53. Wheat, the main raw material of the grain-based industry, is of critical importance for our country's agriculture. Wheat is used in many food and industrial sectors, especially bakery products (Anonymous, 2022). It is also seen that the sector operates in many different areas (such as biscuits, bread, chocolate).

Wheat production has economic and strategic importance in the world. Wheat; It has been the basis of nutrition for thousands of years and constitutes the basis of self-confidence and stability in society. It is the product with the largest share and importance among the herbal products produced in Turkey. Wheat is a food product that meets the needs of humans and animals. Although the consumption of wheat varies depending on the population of the countries, it is of great importance in terms of constituting the raw material of bread, which is the basic nutrient in developing and underdeveloped countries (Oğuz and Arisoy, 2005).

According to the United Nations (UN) report titled "World Population Prospects", the world population, which is currently around 7.7 billion, is projected to increase by two billion to 9.7 billion by 2050 (U.N., 2019). In addition, preferences for meat-based diets and growing demands for bioenergy crops are triggering an ever-increasing demand for agricultural production globally. In this context, FAO has projected that global cereal production will need to increase by %70 by 2050 to meet these demands. Given the limited arable land and scarcity of water resources in the world, a significant increase in the application of agricultural fertilizers is seen as an approach to reach the production potential required for global food production. However, high rates and long-term applications of various conventional fertilizers in the agricultural sector to maintain current levels of grain production have caused serious environmental problems globally. For example, the intensive use of nitrogen (N) and phosphorus (P) fertilizers have become major anthropogenic factors exacerbating and even influencing worldwide eutrophication problems in surface freshwater bodies and coastal ecosystems (Conley et al, 2009).

There is a need to develop innovative, effective fertilizers using new technologies for sustainable agriculture and the environment. Nanotechnology is used in food and agriculture as in many other fields. Today, nanotechnology is recognized as a solution to improve nutrient utilization efficiency (Gunaratne et al., 2016). Nanofertilizers, which increase plant growth and development by providing one or more nutrients to the plant, have an important potential in increasing agricultural production (Daghan, 2017).

There is an imperative research need to develop innovative fertilizers to increase wheat yields, improve the efficiency of plant-nutrient uses and minimize environmental degradation for global sustainable development. In the context of sustainable agriculture, the application of innovative nanotechnology in agriculture (including fertilizer development applications) is considered as one of the promising approaches to significantly increase crop production and feed the world's rapidly growing population (Lal, 2008). For this purpose, studies are being carried out for fertilizer R&D studies of nanotechnology in order to increase the effect of fertilizers used in conventional agriculture on yield factors (Uzal and Yaşar, 2023).

Although many researchers are interested in the development and application of nanomaterial-related fertilizers, research directly related to the effect of nanotechnology on wheat yield is not sufficient. However, some recent research in nanotechnology has shown a promising perspective in terms of nanofertilizer development and application. For example, observations that C nanotubes (CNTs) and zinc oxide nanoparticles (NPs) can penetrate tomato (Lycopersicon esculentum) plant roots or seed tissues suggest that a new nutrient delivery system can be developed through the use of nanoscale porous areas on plant surfaces (De Rosa et al., 2010). Therefore, the main objective of this research is to analyze the strengths and weaknesses of nanotechnology and nanoparticles that can improve wheat plant growth, yield and reduce environmental risks.

2. DEFINITION AND APPROACH OF NANOTECHNOLOGY IN AGRICULTURE

Cereals are an important food source in the basic and healthy nutrition of people. In this context, it is of great importance that they are grown in a healthy manner and delivered to consumers with the same care. FAO estimates that global production needs to be increased by 70% by 2050 to cope with a rapidly growing global population and meet demand by 2050. But with arable land and water resources limited, other strategies are needed to increase global food production. In recent years, the application of nanotechnology-based applications in agricultural fields is one of the strategies that have attracted the attention of researchers (Ergül and Çakır, 2023).

Nanotechnology has the potential to revolutionise the agriculture and food industry with new approaches such as molecular treatment of diseases, rapid disease diagnosis, enhancing the ability of plants to absorb nutrients. Smart biosensors and controlled release systems will help the agricultural industry fight viruses and other pathogens. In the near future, nanostructured catalysts will make pesticides and herbicides more effective with lower doses. Nanotechnology will also reduce pollution through the use of alternative (renewable) energy compounds and filter/catalysts and indirectly protect the environment by cleaning existing pollutants (Scott and Chen, 2002).

Nanotechnology is the science that investigates the development of nanoscale materials, systems and devices. It has a wide range of applications in medicine, cosmetics, textiles, pharmaceuticals, electronics and food industries. In recent years, nanotechnology has enabled the development of healthy and innovative foods in the food industry. In line with the demands of consumers, studies are carried out especially in areas such as food processing, storage, packaging, development of nanoadditives (additives) and nanosensors for high quality, fresh, long-lasting and high quality foods (Saka & Gülel, 2015; Ameta, 2020). Nanotechnology explores a wide range of areas and creates a wide spectrum for various applications in the fields of biotechnology and agriculture. Nanotechnology has become a new technology that can be used in various industries; industry, pharmaceuticals, food science and safety, smart packaging and agriculture.

Especially in recent years, the use of nanotechnology in many stages of agriculture has increased, and it is widely applied in agricultural product production, development, processing, packaging, storage and transportation, making major changes in food and agricultural systems. It has also been used to increase plant resistance and to control the efficacy and safety of pesticides and fertilizers (Torney et al., 2007; Perez and Rubials, 2009; Sekhon, 2014; Salama D.M. et al., 2018; El Mohamedy et al., 2019). Thus, it is predicted that the application of nanostructured materials designed for sustainable crop production reduces nutrient losses and plant diseases and increases yields (Dura and Tang, 2022).

Agriculture is the backbone of developed countries and the livelihood of more than 60% of the population depends on it. Nanotechnology is being used to develop systems for monitoring the release of pesticides/herbicides. In this way, the biology of different crops can be understood, potentially improving crop productivity and nutritional quality (Kumari and Yadav, 2014).

Attempts to apply nanotechnology in agriculture began with the growing realization that conventional agricultural technologies can neither further increase productivity nor restore ecosystems damaged by existing technologies to their pristine state. Together with the need to phase out irrigation, fertilizers and pesticides, the long-term effects of farming with "miracle seeds" are being questioned at both scientific and political levels.

Nanotechnology in agriculture has gained momentum in the last decade with ample public funding, but the pace of development has not been as fast as desired, even though many disciplines fall under the agricultural umbrella. Because of the unique nature of farm production, functioning as an open system in which energy and matter are freely exchanged; because the scale of demand for input materials, unlike industrial nanoproducts, is always gigantic; because, unlike industrial nanoproducts (e.g. cell phones), there is no control over input nanomaterials and their fate must be considered on the geosphere (pedosphere)-biosphere-hydrosphere-atmosphere continuum; the delay in emerging technologies reaching the farmers' field, especially given the unwillingness of many developing economies to spend on innovation; and the lack of foresight resulting from the fact that agricultural education has not attracted sufficient numbers of bright minds worldwide have affected the pace of development of nanotechnology in agriculture.

Agricultural production and yields are affected by a number of factors, including climatic conditions, crop and land management practices, pathogens, diseases and pests, and increases in weather events. According to studies, for each degree of global temperature increase, the yield of cereals such as wheat and maize, which have an important place in the nutrition of the world and our country's population, is expected to decrease by 4-6%, increases in temperature are expected to affect plant productivity similarly, and it is predicted that by the end of the century, there will be a decrease in the yield of producing areas worldwide (Leimu et al., 2010; Greaver et al., 2016; Pugh et al., 2016). Plant pathogens and pests have shown latitudinal distribution shifts as a product of climate change, and changes in regional climatic conditions are expected to exacerbate yield losses by altering plant pathogen virulence and infection rates (Velasquez et al., 2018). Adaptation to changes in climatic conditions, such as the number of extremely hot or cold days, changes in the optimal locations for planting different crops, crop management and production of cultivated plants are likely to adapt to these changes (Fini et al., 2017). That is, this includes crop changes such as the expansion of cultivation areas for drought-resistant crops in drought-prone areas and the cultivation of new crop varieties that are better adapted to the changing environment. For this purpose, it has become inevitable to expand the use of nanotechnology.

3. DEFINITION AND APPROACH OF NANOPARTICLES IN AGRICULTURE

Improving the long-term sustainability of food production is key to ensuring future food and nutrition security. Increasing world food production is possible by reducing production costs through better crop management, increasing yields and developing new technologies. In this context, innovations in fertilizer technology and use play an important role in increasing productivity.

At the nanoscale, matter shows extraordinary properties that bulk materials do not. For example, the surface area, cation exchange capacity, ion adsorption, complex formation and many other functions of clays are multiplied when brought to the nanoscale. One of the main ways in which a nanoparticle differs from a bulk material is that a high proportion of atoms in a nanoparticle are located on the surface (Maurice and Hochella 2008). Compared to macro-sized particles, nanoparticles can have different surface compositions, different type and site densities, and different reactivity according to processes such as adsorption and redox reactions, which can be profitably used in synthesizing nanomaterials for use in agriculture (Hochella et al., 2008; Waychunas et al., 2005).

Nutrients encapsulated in nanoparticles are released according to environmental conditions and plant demand, leading to increased yields. In addition, slow and controlled release fertilizers also improve the soil and reduce the negative effects of excessive fertilizer application (Gunaratne et al., 2016). Encapsulation is defined as coating the target object with a homogeneous or heterogeneous matrix. Encapsulation method has many benefits such as protection of the coated object from adverse conditions, controlled release and precise targeting (Ezhilarasi et al., 2012; Gunaratne et al., 2016; Özdemir and Kemerli, 2016). Different encapsulation technologies are mentioned depending on the size and shape of the capsules. Macro encapsulation/coating creates macro-scale capsules, while micro and nano encapsulation creates micro and nano-scale particles (Özdemir and Kemerli, 2016).

In a study in the USA, nanoparticles made of iron were used to clean contaminated land and groundwater. Iron nanoparticles, trichloroethene, carbon tetrachloride, dioxin and many toxic It catalyzed the degradation and oxidation of organic contaminants such as non-simple carbon compounds (Anonymous, 2024). In another study, iron oxide nanoparticles, underground It was extremely effective in removing arsenic from water by binding (Wong et al., 2002).

Some laboratory studies have shown that a number of NPs (silica, Fe oxides, C-coated Fe and polymers) can enter plant tissues/cells and transport DNA and chemicals within tissues/cells (Ambrogio et al., 2013, Ghafari et al., 2013, Gonzalez-Melendi et al., 2008, Torney et al., 2007). Such studies have supported the hypothesis that zinc oxide nanoparticles (NPs) can provide nutrients to plants as a new fertilization or feeding technique. However, there is as yet no concrete evidence demonstrating the advantages of this approach over conventional methods in increasing fertilizer use efficiency or reducing risks of environmental degradation. For example, since crops are naturally able to absorb soluble nutrients (e.g. N, P and K) from soil solutions through their root systems, stronger and more specific justifications are needed to support the research and implementation of such novel approach of delivering nutrients to plants through these inert zinc oxide nanoparticles (NPs), as to the necessity of injecting nutrient-laden zinc oxide nanoparticles (NPs) into plant tissues to enhance their growth.

In wheat cultivation, nanofabricated materials containing plant nutrients can be used in aqueous suspension and hydrogel forms to provide non-hazardous application, easy storage and a convenient delivery system. Similarly, the application of zero-valent iron nanoparticles or even nanoparticles derived from iron rust can be used to remediate soils contaminated with pesticides, heavy metals, and radionuclides, given the high adsorption affinity that these nanomaterials have for organic compounds and heavy metals (Liu and Lal, 2012).

4. THE IMPACT OF NANOTECHNOLOGY AND NANOPARTICLES ON WHEAT AGRONOMICS

Recent studies have shown that wheat is directly sensitive to environmental factors. Wheat is extremely adversely affected by pests and diseases due to direct effects of climate change, such as changes in temperature, precipitation and carbon dioxide concentrations, and indirect effects such as changes in the distribution and frequency of soil moisture (Abeysingha et al., 2016; Ludwig et al., 2009). In a study conducted in India, wheat yields are estimated to decrease by about 6-23% and 15-25% in the 2050s and 2080s, respectively (Kumar et al., 2014). This decrease, which corresponds to a significant potential in wheat agriculture due to climate change, has increased the importance of nanotechnology. Many researchers have shown that nanotechnology plays a vital role in mitigating stress-induced changes in plants. The use of nanotechnology in wheat agriculture will enable the deployment of pesticides, encapsulated nanocides, controlled and targeted release of nanomaterials as well as pesticides containing stabilization nanomaterials (Kashyap et al, 2015).

4.1. Nanoparticle-Wheat Interaction

Of the nanoparticle (NPs) formulations, those containing essential metals are being considered. Fertilization to enhance plant nutrition in soils has the property of low metal bioavailability, low uptake efficiency of water and essential Ca and Fe nutrients for seed germination and plant growth and development that can enhance seed germination and plant growth (Villagarcia et al., 2012). In a study conducted under laboratory conditions, germination and root elongation of wheat improved with industrial grade MWCNTs (2,560 mg kg^{-1}) without significant uptake or translocation were found to be significant, as CNTs adsorbed to the root surfaces of wheat (Miralles et al. 2012). In another study, soluble CNTs in water wheat plants affected root and shoot growth under light and dark conditions (Tripathi and Sarkar 2015).

4.2. Uptake, Transport and Accumulation of Some Nanoparticles by Wheat

Noteworthy studies have examined the uptake, transport and accumulation of some nanoparticles by wheat. In these studies, it was determined that the wet and dry weights of some wheat cultivars and a significant part of the root were affected by nTiO2 and wheat plants with increased NPs regulated the activity of enzymes related to growth and product components under water deficit stress (Ceberzade et al. 2013). NPs (TiO2) also help nitrogen metabolism such as nitrate reductase, glutamate dehydrogenase, glutamine synthase and glutamic-pyruvic plants to absorb nitrate. It also promoted the conversion of inorganic nitrogen to organic nitrogen. Nitrogen in the form of protein and chlorophyll increased the fresh weight and dry weight of the plant (Mishra et al., 2014).

In another study conducted in wheat plants, it was reported that foliar application of NP decreased nAl2 O3 (<50nm) of wheat seedlings, increased root length and increased superoxide dismutase and catalase enzymes as a result of oxidative stress (Riahi-Madvar et al. 2012).

4.3. Reactions Of Wheat To Nanoparticles

In a published biocompatible report, hydrated graphene ribbon (HGR) was observed to enhance germination and resistance of aged wheat seed to oxidative stress, and analysis of HGR's metabolism of carbohydrate, amino acid, and secondary determinant fatty acids, nitrogen sequestration, cell membrane integrity, permeability, and oxidation resistance metabonomics showed (Hu and Zhou 2014).

4.4.Effects Of Nanoparticles On Oxidative Stress And Antioxidant Defense System

Titanium dioxide nanoparticles (nTiO2), an efficient and beneficial nutrient source for plants, have improved biomass production due to enhanced assimilation, photoreduction activities of photosystem and electron transport chain, scavenging of reactive oxygen species and nitrogen (Raliya et al., 2015; Morteza et al., 2013). It has been reported that nanoparticles (TiO2) do not have different effects on plants, but on seed germination in wheat, NPs can translocate through the roots to the leaves (Larue et al., 2012). During the accumulation of titanium dioxide nanoparticles (nTiO2), it was reported that NPs could only form in wheat roots when the diameter of the NPs was <140 nm, with higher accumulation occurring when the NPs were much smaller (14-22 nm) (Larue et al., 2012). It was also reported that titanium dioxide at the optimum concentration of nano (1200 ppm) has a stimulating effect on root and shoot growth Mahmoodzadeh and Aghili, 2014).

4.5. Effects of Nanoparticles on Wheat Abiotic Stress Response

Drought and heat stress often occur together in many crops, such as maize and wheat, and the combination of these stress types causes more significant yield reductions than each stress alone (Muller and Martre, 2019). Drought and heat stress reduce nutrient uptake and photosynthetic efficiency in plants, and stress responses include a wide range of physiological and biochemical responses. The difficulty in producing stress-tolerant plants is the large number of genes involved in stress responses. Transcription factors, which control genes activated by stress in plants, are an important component in plant signaling and studies in various plants have reported that overexpression of transcription factors increases drought, cold and salt tolerance (Chowdhury et al., 2017; Zampieri et al., 2017; Reside et al., 2018). Modulation of transcription factors could be an effective way to increase the environmental stress tolerance of many agricultural crops, and targeting them within traditional and novel cultivation technologies could be an effective strategy to produce better crops.

5. CONCLUSIONS AND RECOMMENDATIONS

Tackling global food challenges is possible by integrating nanotechnology into wheat agriculture. Considering agricultural sustainability and climate change, so far the level of interest of nanotechnology in wheat breeding has not reached field conditions. Therefore, extensive studies are needed.

The development and application of new types of fertilizers using innovative nanotechnology is one of the effective options to significantly increase agricultural production on a global scale, which is necessary to meet the future demands of a growing population. A review of the existing literature shows that some engineered nanomaterials can enhance plant growth at certain concentration ranges and can be used as nanofertilizers in agriculture to increase agricultural yields of crops and minimize environmental pollution.

Macronutrient nanosolvents, Micronutrient nanosolvents, nutrient-laden nanosolvents and plant growth enhancing nanomaterials should be studied with reference to the chemical composition, particle size, applied concentrations, plant species utilized, plant nutrition methods and plant growth enhancement aspects and rates of nanomaterials according to cereal and legume categories. The importance, research directions and research needs of each nanosubstance category should also be specifically studied to achieve sustainable agriculture.

Nanotechnology can have both positive and negative impacts on the agroecosystem. Therefore, it is necessary to carefully study the relationship between NPs and wheat. Nanotechnology can be used as an important tool to develop new methods to improve plant traits, yield and tolerances to biotic and abiotic stresses in wheat agriculture. Therefore, genetic and molecular modification mechanisms for the interaction of different nanomaterials with wheat crops need to be explored.

Experimental verification of the permissible limit of use requires that the nanoparticle dosage is within safety limits. The interaction of nanomaterials with plants varies according to the concentration applied, type and number of NPs, treatment duration, plant genotype and developmental stage. When conducting nanotoxicity studies, the study should be kept in mind and the selection of the permissible level along with the study, intergenerational and food (trophic) chain transfer effects should be considered.

Nanosensor research is of high value for rapid technology in diagnostics and effective pest management. Therefore, it is extremely important to explore the application of nanosensors, i.e. the detection of wheat pests in fields and grain storage structures.

Despite these potential benefits, nanotechnology in applied wheat breeding may be negatively affected if nanomaterials are misused in plants that do not pose risks to the environment, as well as soil microbes and other life forms that may be beneficial. Therefore, the achievement of better agro-ecological results in nanotechnology is particularly related to the dose response, the release of ions and nutrients with effects specific to the nanoparticles of the mineral, it is important to exploit the expected benefits in terms of nano-formulation applications.

The effect of nanotechnology on the germination of wheat seeds, its use as a fertilizer, the use of nanoparticles in seed development, the use of nanotechnology as plant protection products in wheat, the use of nanotechnology against abiotic stress in wheat agriculture are among the researches that should be focused on first.

Recent research shows that nanotechnology is underutilized in wheat agriculture, although it meets expectations. So far, no knowledge base on the transformations and bioavailability of nanoparticles is available. There is a need to create an up-to-date and accessible database. Bioavailability is the basis for the increase in wheat yield and plant quality. With this understanding, it is necessary to utilize the advantages of nanotechnology. Within nanotechnology, it is of great importance today to develop precision toolkits such as nanosorbents, nanopesticides, nanoherbicides, nanosensors and smart delivery systems.

Compliance with Ethical Standards

Author Contributions

Authors contributed equally to this paper.

Conflict of Interest

The authors do not have any conflicts of interest to declare.

Ethical Approval

For this type of study, formal consent is not required.

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