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Nanofertilizers: A Smart Delivery Approach

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Introduction

Eco-friendly technology is becoming progressively important in modern agricultural applications as alternatives to traditional fertilizers and pesticides. Nanotechnology offers an alternative solution to overcome the disadvantages of conventional agriculture. Nano-fertilizers are essential to reduce the use of inorganic fertilizers and reduce their antagonistic effects on the environment. They are more reactive, can penetrate the epidermis allowing for gradual release, and targeted distribution, and thus reducing nutrients surplus, enhancing nutrient use efficiency (El-Saadony*et al.*, 2021).

Nano-fertilizers

Nano-fertilizers provide some nutrients in a nano form, enhancing plant growth and production (Dimkpa and Bindraban, 2016). Based on the nutrient needs of plants, nano fertilizers are classified into three categories: macro nano-fertilizers, micro nano-fertilizers, and nano-particulate fertilizers (Chhipa and Joshi, 2016). They provide nutrients to plants in an available form, thus increasing nutrient uptake by plants, and boosting plant production (Table 1). The relevant features of nano-fertilizers briefed in (Guru *et al.*, 2015):

- delivering the appropriate nutrients for enhancing plant growth through foliar and soil applications.
- they are low-cost and sustainable sources of plant nutrients.
- they have a high fertilization efficiency.
- they play a key role in preventing pollution.

A large portion of inorganic fertilizers added to the soil are lostand become unavailable to plants. For example, 40–70%, 80–90%,and 50–90% of nitrogen (N), phosphorus (P), and potassium (K) fertilizers are lost and/or fixed in soils, resulting in economic losses(Ombódi and Saigusa, 2000). Slowlyreleased nano-fertilizers may be a great alternative to dissolvableinorganic fertilizers. Thus, plants would be able to absorb themajority of their nutrient requirements without losses (Huiyuan*et al.*, 2018). Besides, nano-fertilizers aid in the removal of water pollution and could be callednew fertilizer alternatives.

Table 1:Nanotechnological interventions in agriculture

Nutrient	Nanoparticles	Plant Species	Application Method	Concentration	Effect on Plant
Titanium	TiO_2	*Oryza sativa* (rice)	Root	750 mg kg^{-1}	Increased P in root, shoot and grain, amino acids, fatty acids
		Solanum lycopersicum (tomato)	Root	20 mg L^{-1}	Increased amino acids, total phenolics, antioxidant capacity
		Hordeum vulgare (barley)	Root	500 mg kg^{-1}	Increased P, Ca, Mg, Zn, Mn, amino acids
		Mentha piperita (peppermint)	Foliar	150 mg L^{-1}	Increased N, chlorophyll, menthol, menthone
		Solanum lycopersicum (tomato)	Root and foliar	100 mg kg^{-1}	Increased lycopene
Cerium	CeO_2	*Oryza sativa* (rice)	Root	500 mg kg^{-1}	Increased K, Ca, Na, protein albumin, total sugars
		Hordeum vulgare (barley)	Root	500 mg kg^{-1}	Increased P, K, Ca, Mg, S, Cu, Fe, Zn, Mn, amino acids, fatty acids
		Triticum aestivum (wheat)	Root	400 mg kg^{-1}	Increased P, K, Fe, amino acids, fatty acids, total sugars
		Cucumis sativus (cucumber)	Root	750 mg kg^{-1} 400 mg kg^{-1}	Increased K, Ca, Mg, S, P, Fe, Mn, Zn, total sugars, starches, proteins
		Coriandrum sativum (cilantro)	Root	125 mg kg^{-1}	Increased Ce, catalase, and ascorbate peroxidase activities
Zinc	ZnO	*Pisum sativum* (pea)	Root	250 mg kg^{-1}	Increased P, Fe, Zn, Mn, total sugars
		Cucumis sativus (cucumber)	Root	400 mg kg^{-1}	Increased K, Mg, Fe, Mn, Zn, S, prolamin, globulin, glutelin
		Zea mays (maize)	Foliar	100 mg L^{-1}	Increased Zn, germination, growth, yield
		Solanum lycopersicum (tomato)	Root and Foliar	10 mg L^{-1}	Increased lycopene
		Arachis hypogaea (peanut)	Foliar	1000 mg L^{-1}	Increased Zn, chlorophyll, root biomass, yield
	Zn-amino acid nano complex	*Ocimum basilicum* (sweet basil)	Foliar	1500 mg L^{-1}	Increased catechin, hesperetin
Copper	Cu	*Solanum lycopersicum* (tomato)	Root and Foliar	250 mg L^{-1}	Increased K, total proteins, vitamin C, total phenols, flavonoids, lycopene, antioxidant capacity
		Cucumis sativus (cucumber)	Root	400 mg kg^{-1}	Increased Cu, Fe, sugars, organic acids, amino acids, fatty acids
Iron	Fe_2O_3	*Arachis hypogaea* (peanut)	Root	1000 mg kg^{-1}	Increased Zn, growth, biomass
		Glycine max (soybean)	Foliar	750 mg L^{-1}	
Calcium	CaO	*Arachis hypogaea* (peanut)	Foliar	500 mg L^{-1}	Increased Ca, root development
	$CaCO_3$	*Vigna mungo* (Black gram)	Seed	750 mg L^{-1}	Increased root and shoot growth, biomass
Magnesium	Mg	*Vigna unguiculata* (cowpea)	Foliar	500 mg L^{-1}	Increased photosynthesis, growth, yield
Silver	Ag	*Cucumis sativus* (cucumber)	Foliar	3000 mg L^{-1}	Increased growth, fruit yield, biomass, total soluble solids in fruit
		Solanum lycopersicum (tomato)	Root	1000 mg L^{-1}	Increased superoxide dismutase activity
		Lactuca sativa (lettuce)	Foliar	100 mg kg^{-1}	Increased Ag content
Gold	Au	*Arabidopsis thaliana* (thale cress)	Root	10 mg L^{-1}	Increased seed germination, growth, yield
		Brassica juncea (brown mustard)	Foliar	10 mg L^{-1}	Increased germination, yield, protection from oxidative damage

Source: Chugh*et al.*, 2021

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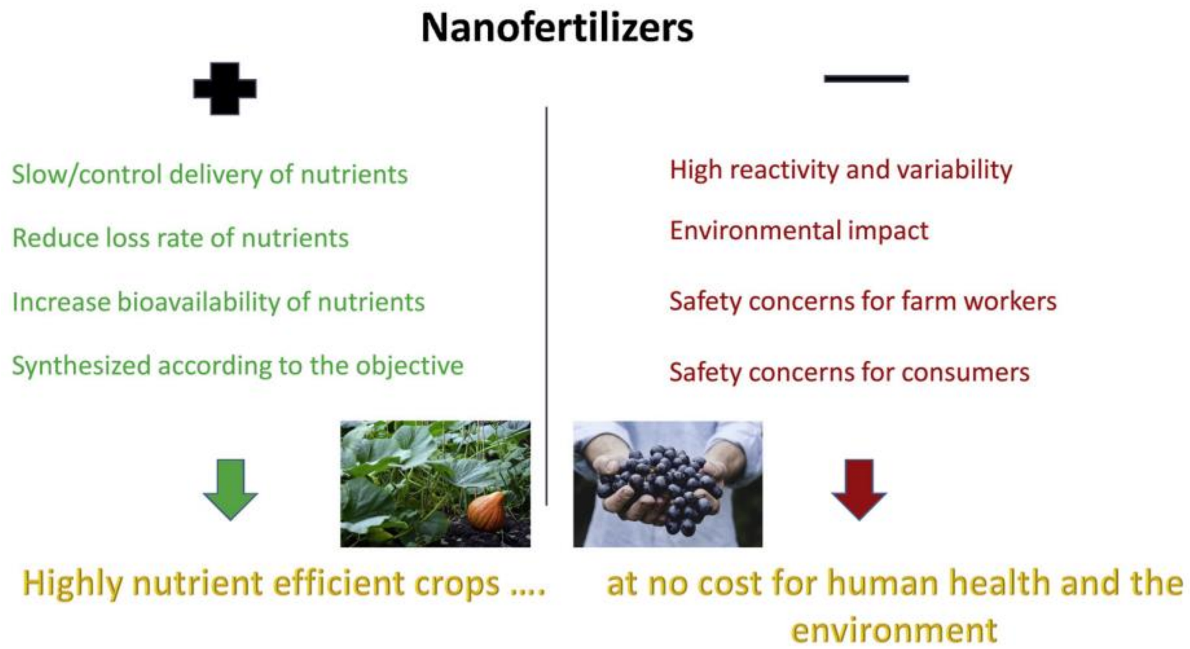
Advantages and limitations of nanofertilizers (Zulfiqar*et al.*, 2019)



The interaction between nano-materials and plant

The negative charge on the plant cell's surface allows the movement of negatively charged compounds into the cells via theirmembranes, allowing metal complexes toenter the cell (Tandy*et al.*, 2006) (Fig. 1).

Conclusion:

Nanofertilizers in the agriculture sector, is a smart approach for achieving enhanced productivity and resistance to abiotic stresses under the current climate change scenario. Thus, promising applications of nanofertilizers in the agri food biotechnology and horticulture sectors cannot be overlooked. Nanofertilizers have a potential to reduce leaching and volatilization associated with the use of conventional fertilizers. Simultaneously, the well-known positive impact on yield and product quality has a tremendous potential to increase growers' profit margin through the utilization of this technology. Though, uncertainty related to the interaction of nano materials with the environment and potential effects on human health must be explored in detail before spreading nano fertilizers at a commercial scale.

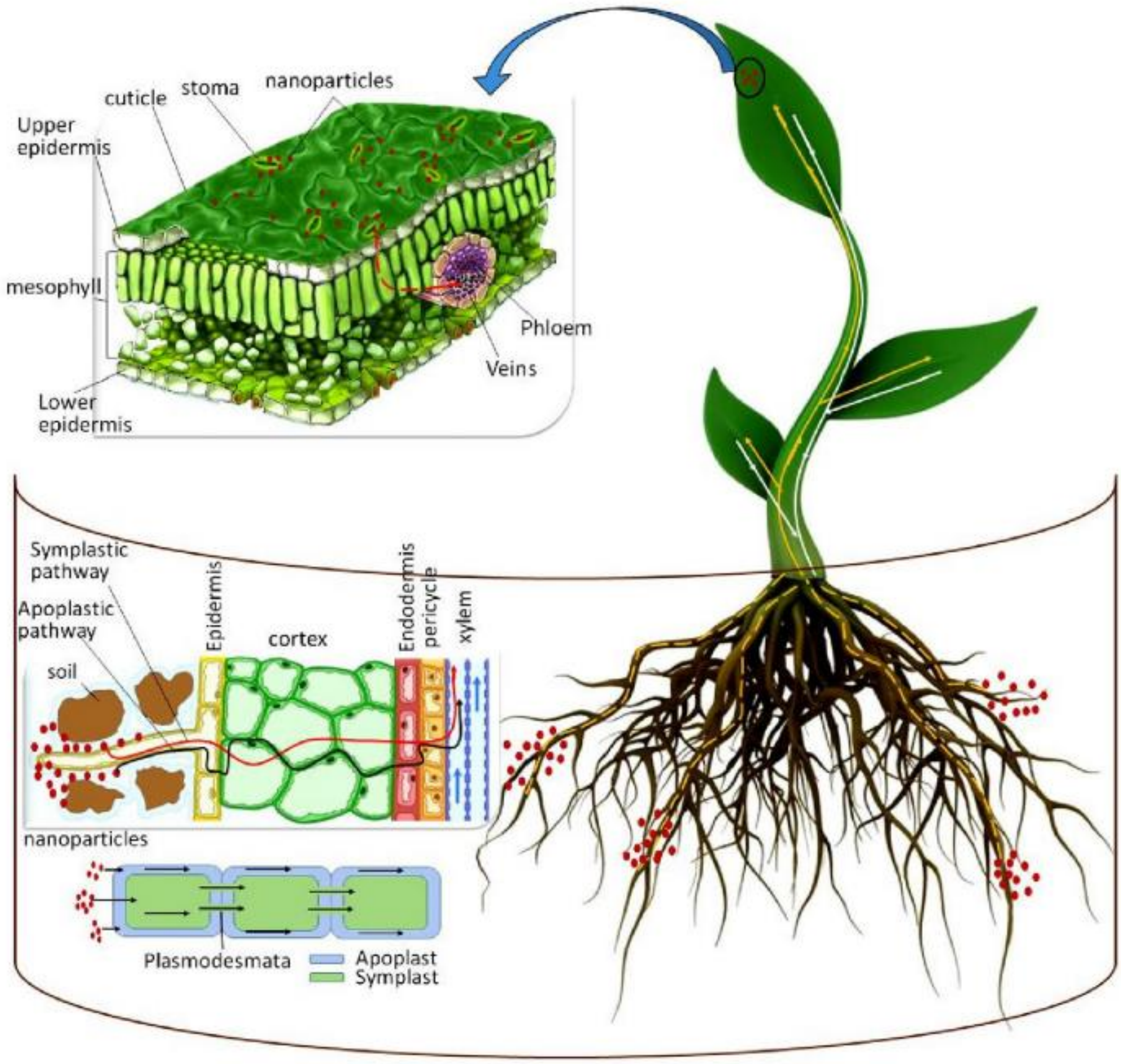


Fig. 1. Mechanism of action by nano-fertilizer

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