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Nanotechnology: An alternative approach to improve seed quality

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Abstract
Nanotechnology, a new budding and interesting field of science is presently applicable in many areas. It has great application in the field of biotechnology as well as in agriculture Nanotechnology deals with manipulation of matter with at least one dimension sized ranges from 1 to 100 nanometer. One nanometre (nm) is equal to one-billionth of a metre, 10^{-9} m. In modern agriculture, sustainable production and efficiency are unimaginable without the use of agrochemicals such as pesticides, fertilizers, etc. In the field of agriculture nanotechnology focuses currently on target farming that involves the use of nanoparticles with unique properties to boost crop and livestock productivity. Nanotechnology has the potential to increase food quality, plant protection, detection of plant and animal diseases, monitoring of plant growth, global food production and improving seed quality. In order to improve seed quality there are several seed quality enhancement techniques are used and having their own benefit. Through nanoparticles as a treatment seeds can speed up germination, increases seedling strength, vigour and improve seed quality. The present review is an attempt to summarize and assess the prospects of nanotechnology as an alternative approach to improving seed quality through nanoparicles.

Keywords: Nanoparticles, CNTs, Seed quality

Introduction
Nanotechnology, a new budding and interesting field of science is presently applicable in many areas. It has great application in the field of biotechnology as well as in agriculture. “Nanotechnology is the art and science of manipulating matter at nanoscale”. Nanotechnology deals with manipulation of matter with atleast one dimension sized ranges from 1 to 100 nanometer. One nanometre (nm) is equal to one-billionth of a metre, 10^{-9} m. In modern agriculture, sustainable production and efficiency are unimaginable without the use of agrochemicals such as pesticides, fertilizers, etc. However, every agrochemical has some potential issues including water contamination or residues on food products that are harmful to the human being and environmental health, thus the precise management and control of inputs could allow to minimize these risks (Kah, 2015) [11]. The explosive growth of world population demanding higher agricultural productivity to feed the increasing population. There is a need to use the modern or inovative technique which can help agriculture to improve the quality and increase yield. The development of the alternative approach with use of engineered smart nanotools could be excellent strategy to make a revolution in agricultural system and thus eliminate the effect of modern agriculture on the environment as well as to enhance both the quality and quantity of yields (Sekhon, 2014; Liu and Lal, 2015) [31, 16] Nanotechnology is the emerging fields which has incredible potentials to renovate agriculture and allied fields. No doubt that the sustainable growth of agriculture totally depends on the new and innovative techniques like nanotechnology. In the field of agriculture nanotechnology focuses currently on target farming that involves the use of nanoparticles with unique properties to boost crop and livestock productivity. Nanotechnology has the potential to increase food quality, plant protection, detection of plant and animal diseases, monitoring of plant growth, global food production and improving seed quality. The main objective of nanotechnology is to improve the effectiveness and sustainability of agricultural practices by putting less input and generating less waste than conventional products and approaches. Nanotechnology has immense potentials in agricultural uprising, high reactivity, better bioavailability, bioactivity and the surface effects of nanoparticles. There is a rising demand for intervention of ecologically safe and sound, environmentally compatible techniques in crop production which will provide global food security and improved agricultural produces. To accomplish this object, application of nanoparticles or nanomaterial is a potential alternative to traditional agricultural techniques which have severely damaged the agro-ecosystem. In order to improve seed quality there are several seed quality enhancement techniques are used and having their

own benefit. During seed storage, reduction in germination occurs subsequent to physiological changes like delayed germination, lower tolerance to adverse storage resulting in reduced seedling growth. The biochemical changes mainly observed during storage are lipid peroxidation mediated by free radicals, inactivation of enzymes, disintegration of cell membranes and genetic damage (Murthy *et al.*, 2003) [21]. Many researchers reported that mid-term hydration-dehydration treatments performed better in improving germination and seedling vigour after storage in soybean (Mandal *et al.*, 2000) [18]. However, it can be restricted to certain extent by adopting new alternative technologies. In order to improve the deterioration process and quality in seeds, nanotechnological approaches may offer a credible solution. The present review is an attempt to summarize and assess the prospects of nanotechnology as an alternative approach to improving seed quality through nanoparicles.

Nanoparticles

Nanoparticles (NPs) are the materials with at least two dimensions between 1-100 nm (Ball, 2002) [6]. Now the question arises ‘Why 100 nm and not 150 nm?’, or ‘Why not 1 to 1 000 nm?’ The reason behind this is that the definition itself focuses on the effect that the dimension has on a certain material. For example the insurgence of a quantum phenomenon — rather than at what exact dimension this effect arises. Nanoscience is not just the science of the small particles, but the science in which materials with small dimension show physical phenomena, collectively called quantum effects, which are size-dependent and dramatically different from the properties of bulk materials. Nanoparticles shows extraordinary properties for example, surface area, cation exchange capacity, ion adsorption, complexation that are not shown by bulk materials. A high proportion of the atoms in a nanoparticle are present on the surface which differs nanoparticle from bulk material (Maurice and Hochella, 2008) [19]. As compared to macroparticles, nanoparticles may have different surface compositions, different types and densities of sites, and different reactivity with respect to processes such as adsorption and redox reactions (Waychunas *et al.*, 2005; Hochella *et al.*, 2008) [38, 10] which could be used in synthesizing nanomaterials to improve seed quality.

Improving seed quality through nanotechnology

Seed quality includes readily measureable characteristics such as viability, seedlot purity, health, and mechanical damage, but a further essential component is the more enigmatic trait of seed vigour (Perry, 1980) [26]. Seeds carry the full genetic complement of the crop and are therefore the delivery system for agricultural biotechnology and crop improvement. To protect their investment in crop improvement, companies require seeds of high quality so that these benefits are not compromised when sown in the field. Several studies have documented beneficial effects of certain nanoparticles in improving seed quality of different crops. Nanoparticles has also given excellent results in improving quality of seed. From the recent literature, nanoparticles increased germination, vigour and quality of the seeds of the crops, including groundnut (Shyla and Natarajan 2016) [33], greengram (Sangli *et al.*, 2017) [29], onion (Anandaraj and Natarajan, 2017) [4], lettuce (Shah and Belozerova, 2009) [36], spinach. (Zheng *et al.*, 2005) [42], peanut (Prasad *et al.*, 2012) [27] and tomato (Sridhar, 2012) [35].

Effect of metal oxide nanoparticles on seed quality

(Shyla and Natarajan, 2014) studied the Synthesis of inorganic nanoparticles for the enhancement of seed quality in groundnut cv. VRI-2 they used inorganic nanoparticles (NPs) *viz.*, zinc oxide (ZnO), silver (Ag) and titanium dioxide (TiO2) which were synthesized by chemical method and characterized by using Scanning Electron Microscope (SEM) and Transmission Electron Microscope (TEM). Groundnut seeds were treated with ZnO, Ag and TiO2 nanoparticles each @ 750, 1000 and 1250 mg $kg^{-1}$of seed and stored for 12 months under ambient condition. They observed that seeds treated with ZnO NPs @ 1000 mg kg-1 enhanced germination (77%), vigour index (3067), electrical conductivity (0.347dSm-1), catalase (0.421 μg H2O2 mg-1 min-1) enzyme activity and reduced lipid peroxidation activity (0.089 OD value) over control. This study is in close agreement with the results reported by (Prasad *et al.*, 2012) [27] in groundnut. Scientists also found that Zinc oxide nanoparticle sized (40.59 nm) at 125 ppm improved seed quality parameters over untreated seeds in spinach (Sangli *et al.*, 2017) [29]. In onion the dose of 1000 mg kg-1 of Zinc oxide (ZnO), Silver (Ag), Copper oxide (CuO) and Titanium oxide (TiO2) enhanced the germination (72%), shoot length (7.5 cm), root length (6.4) and thereby the vigour index (998) as compared to control (60%, 6.0cm, 5.4cm and 692) respectively (Anandaraj and Natarajan, 2017) [4]. The beneficial effect of the ZnO NPs in improving the germination could be ascribed to higher precursor activity of nanoscale zinc in auxin production (Kobayashi and Mizutani, 1970) [15]. Zinc is one of the essential nutrients required for plant growth. It is an important component of various enzymes that are responsible for driving many metabolic reactions in all crops. Zinc oxide NPs are reported to also exhibit positive effect on the reactivity of phytohormones especially Indole Acetic Acid (IAA) facilitating in the phytostimulatory actions. Zinc-rich ZnO NPs could increase the level of IAA in roots (sprouts), which in turn can increase growth rate of seedlings (Pandey *et al.*, 2010) [24]. ZnO NPs could increase the level of IAA in roots (sprouts) thereby increasing growth rate of seedlings in *Cicer arietinum* (Pandey *et al.*, 2010) [25]. Enhanced physiological performance due to nano particles treatment could be attributed to the quenching of free radicals by the nano particles. Smaller size of the nanoparticles would have easily entered through the cracks present on the outer seed surface, reacted with free radicals resulting in enhanced seed vigour and viability. Biochemical constituent of seeds is an important factor which influences the physiological soundness of seed. Ageing induces progressive seed deterioration leading to lethal damage and inability of the seeds to germinate (Bouteau *et al.*, 2011) [7]. Seeds treated with ZnO nanorods and Zero valent iron (ZVI) nanoparticles enhanced the physiological and biochemical properties resulting in improved vigour and viability of aged seeds (Senthil Kumar, 2011) [32] in black gram and tomato (Sridhar, 2012) [35]. Damage to the membrane is one of causes for the loss of viability during storage, which under normal condition could have repaired by itself (Kaewnaree *et al.*, 2011). Seeds with the reduced activity of this repair system make the seeds to germinate slowly than the normal untreated seeds which can undergo self-repair rapidly. If the capacity for repairing is below a critical level, damage would continue to accumulate resulting in the death of seeds.

(Xiang *et al*., 2015) [39] Studied the toxicity level of the ZnO nanoparticles on seed germination of Chinese cabbage (*Brassica pekinensis* L.). They found that ZnO nanoparticles did not affect germination rate up to 80 ppm but significantly inhibited the root and shoot elongation, with the roots being more sensitive. The inhibition was evident mainly during seed incubation rather than the seed soaking process. Both the production of free hydroxyl groups OH and the Zn bioaccumulation in roots or shoots resulted in toxicity of nano ZnO in chinese cabbage seedlings. (Vinoth Kumar and Udaysoorian, 2014) [37] studied the potential toxic effect of three different metal oxide nanoparticles viz., Zinc oxide (nano ZnO), Alluminium oxide (nano Al2O3) and Titanium dioxide (nano TiO2) in maize at 500, 1000 and 2000 ppm. They resulted that all the nanoparticles had shown significant toxic effect on seed germination, vigour index, shoot and root length. Among the dfferent concentration 2000 ppm was found highly toxic followed by 1000 ppm and among the nanopaticles ZnO was found to be more toxic followed by TiO2 and Al2O3.

Adhikari *et al*. (2013) [2] studied the potential effects of SiO2 (10-20 nm) and Mo (<100 nm) nanoparticles on rice seed germination (%). They found that nanoparticles significantly increased germination. SiO2 nanoparticles showed no toxic effect on rice root growth, whereas root growth and elongation were arrested with Mo nanoparticles after 50 mg l-1. Nanoparticles caused both positive and negative effects on seedling growth. Mazumdar and Ahmed (2011) [20] studied the adverse effect of silver nanoparticles at different concentrations on seed quality parameters of paddy, green gram and mustard. They reported that silver nanoparticles showed adverse effect on seed germination, root and shoot length at 1000 ìg ml-1, 1200 ìg ml-1 and 1600 ìg ml-1 for paddy, green gram and mustard respectively. (Lu *et al*. (2002) [17] reported that a combination of nano-SiO2 and nano TiO2 could increase the nitrate reductase in soybean, increasd its abilities of absorbing and utilizing water and fertilizer, stimulate its antioxidant system and apparently speed up its germination and growth. Abdel-Azeem and Elsayed (2013) [1] studied the effect of different sizes of silver nanoparticles (65, 50 and 20 nm) on germination (%), root growth, mitotic index (MI) and chromosomal aberrations at 50 ppm for time intervals (6, 12 and 24 hr) in Vicia faba. As compared to the control (untreated), they found that the germination (%) was not affected whereas root length, mitotic indices as well as chromosomal morphology were much affected after nanoparticles treatment. Siddiqui and Mohamed (2014) [34] conducted an experiment to test the beneficial effects of nano silicon dioxide (nanoSiO2: size- 12 nm) on the seed germination of tomato (Lycopersicum esculentum Mill. cv Super Strain B). They reported that application of nanoSiO2 @ 8 g l^{-1} significantly enhanced seed germination (%), mean germination time, seed germination index, seedling vigour index, seedling fresh weight and dry weight. Zheng *et al*. (2005) [42] reported that the nano TiO2 treatment in proper concentration accelerated germination of aged seeds, increased vigour and also improved formation of chlorophyll and enhanced the rubisco activity and photosynthetic rate of spinach. Yang *et al*. (2007) [40] reported that TiO2 nanoparticles when applied @ 2.5 g- 4 g/kg soil improve the dry and fresh weight of spinach than TiO2 as a bulk.

Effect of carbon nanotube on seed quality

Khodakovskaya *et al*. (2009) [14] reported that Carbon nano tubes (CNTs) can penetrate thick seed coat and support water uptake by the seeds which could be responsible for the significantly faster germination and higher biomass production in tomato. The researchers hypothesized that the positive effect of multi walled Carbon Nano Tube (MWCNT) arose from the capability of CNTs to penetrate seed coat and therefore promote water uptake. Water uptake in seed germination is critical because mature seeds are relatively dry and need a substantial amount of water to initiate cellular metabolism and growth. The measured water moisture content of seeds and the detection of CNTs inside seeds supported the hypothesis; however, the specific penetration mechanisms through the coat and the enhancement of water uptake by CNTs were not reported. Canas *et al*. (2008) [8] reported that Single Walled Carbon Nano Tubes (SWCNTs) significantly affected root elongation in tomato, cabbage, carrot and lettuce, but promoted the growth of onion and cucumber in 24 to 48 hours. Tomato showed the highest degree of sensitivity to SWCNTs among the six species tested. Nair *et al*. (2010) [22] studied the effects of both SWCNTs (single walled carbon nanotubes) and MWCNTs (multi walled carbon nanotubes) on the germination of rice seeds and they observed that carbon nanotube increased seed germination Yugandhar and Savithramma (2013) [41] observed that CCNPs accelerates the seed germination and seedling growth and showed highest germination (92 %), seedling vigour index (892), root (2.3 cm) and shoot length (7.4 cm) and seedling dry weight (212 mg) as compared to control. Nanoparticles such as fullerene, carbon nanotubes, and metal oxides cause toxicity, while multi-walled carbon nanotubes MWCNTs positively affected germination and seedling growth of *Brassica juncea* and *Phaseolus mungo* (Ghodake *et al*., 2010) [9]. It was reported that multi wall carbon nanotubes (MWCNTs) were able to penetrate the seed coat by creating new pores; thereby enhances the water uptake and significantly increases seed germination, plant growth and biomass compared to control in wheat, maize, peanut and garlic (Anita and Rao, 2014) [5]. The researchers indicated that plant cell wall act as a barrier for entry of any external agents including nanoparticles into plant cells, as the sieving properties being determined by pore diameter of cell wall which ranged from 5 to 20 nm. Hence, only nanoparticles or nanoparticles aggregates with diameter less than the pore diameter of the cell wall could easily pass through and reach plasma membrane. A chance for enlargement of pores or induction of new cell wall pores upon interaction with engineered nanoparticles which in turn enhance nanoparticles uptake was also speculated. (Navarro *et al*., 2008) [23].

Table 1: Nanoparticles and their positive effect on seed quality of different crops

NPs	Optimum concentration	crop	Effect	References
CNTs	40 ug/ml	*Lycopersicum esculentum*	Increased germination and seedling growth	(Khodakovskaya *et al.*, 2009) [14]
ZnO NPs	1000 mg kg-1	Groundnut	enhanced germination, vigour index, electrical conductivity, catalase enzyme activity and reduced lipid peroxidation	(Shyla and Natarajan, 2014)
ZnO NPs	125 ppm	greengram (*Vigna radiata*)	early seedling growth and improved seed quality	(Sangli *et al.*, 2017) [29]
Fe NPs	25 ppm	Pigeonpea (*Cajanus cajan* L.)	significantly higher seed germination, speed of germination, seedling root length, seedling shoot length, seedling length, seedling dry weight, seedling fresh weight, seedling vigour index I, seedling vigour index II and lowest abnormal seedlings	(Raju and Rai, 2017) [28]
TiO2 NPs	0.03 %	Maize	Increased germination percentage, seedling vigour, seedling length and seedling dry weight	(Sani, 2012) [30]
Fe NPs	1.0 to 2.0 ppm	Wheat	Increased Seed germination and seedlings growth	(Alam *et al.*, 2015) [3]

Conclusion

It has been explained by the scientists that nanoparticles can effectively speed up germination, increases seedling strength, vigour and improve seed quality. Despite a lot of research done in nanoparticles in the field of agriculture, It is well understood that nanoparticles have both positive and negative effects on germination and seed quality. The toxicity level of many nanoparticles is still indefinable, it depends on the size, concentration and duration of the exposure of nanoparticles. Although this review explain the potential level of this technology for improving seed quality, there is need to further research to expend the application, defined toxicity level for the positive effect of nanoparticles which will give better picture of potential of this technology.

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