ISSN:0975-1459
Journal of Pharmaceutical Sciences and Research
www.jpsr.pharmainfo.in

Exploring Nanobiotechnology to Mitigate Abiotic Stress in Crop Plants

Raghvendra Saxena*, Rajesh Singh Tomar and Manish Kumar
Amity Institute of Biotechnology, Amity University Madhya Pradesh, Gwalior, MP

Abstract:
Abiotic stresses are major constrains which adversely affect the crop productivity and plant growth. Among all abiotic stresses, drought and salinity are most widespread and commonly experienced stresses. Realizing, the increased incidences of diverse abiotic stresses due to both natural as well as anthropogenic activities, scientific community has a major concern to mitigate their effect in order to increase the yield potential of crops. According to FAO reports, there is a major challenge among scientific community to increase 70% more food crop production towards world agriculture for an additional 2.3 billion people by 2050 worldwide. Therefore in such changing environmental scenario there is a constant need to identify the new area of research to overcome the technological challenges in addressing the yield barrier, resource use efficiency and development of environmentally accepted technology. In the recent years nanobiotechnology is gaining momentum to be occupying the promising position to mitigate the constraints associated with abiotic and biotic stress to obtain a sustainable and secure future of agriculture worldwide. Nanotechnology explores wide area and opens large scope for diverse applications in fields of biotechnology and agricultural sector and the potential benefits of nanotechnology could be exploited in the area of agricultural production. Nanoparticles can be synthesize from metal or metal oxide through various approaches i.e physical, chemical and biological. However, realizing the potential benefits of green synthesis of nanoparticles over other approaches there is a constant emphasis in this area. Nanoparticles, because of their extreme small size acquired some peculiar properties form their bulk counterpart opens new avenues in agriculture sector. Several metal or metal oxide based nanoparticles are being studied to assess their potential in plant growth and development, protection from biotic and abiotic stresses, production and role in modulating the various processes in plants. However, there is still a long way to develop the technology to achieve sustainable agriculture.

Keywords: Abiotic stress, Drought stress, Salinity stress, Nanoparticles, sustainable agriculture.

INTRODUCTION:

Plants being a sessile organism are constantly exposed to environmental variations and multiple stress factors in single or in combination throughout their life. However plants develop various mechanism to respond against adverse condition but their responses may vary considerably even in the same plant species. Therefore, identification of tolerant plant material or augmentation of stress tolerance in plants is always the prime concern towards sustainable agriculture and crop production. In the last decades nanobiotechnology based applications are attracting researcher's attention in this direction. Nanotechnology is an emerging multi-disciplinary area that involved technology of diverse fields at nano level i.e., Biological sciences, Physics, Chemistry, Engineering and Computer science and Material science etc. Nanotechnology, offers an opportunity to develop tools and technology for investigation and transformation of biological systems [1]. Nanotechnology explores wide area and opens large scope for diverse applications in fields of biotechnology and agricultural sector [2]. The most promising applications of nanotechnology could be exploited in area of agricultural sector, food processing industries, pathogen detection and diagnostics, food engineering, packaging materials and equipment etc. [3, 4]. Nanoparticles commonly referred as nano-scale particles (NSPs). They are small molecular aggregates of having dimensions between 1 and 100 nm [5]. Having extreme small size such nanoparticles (NPs) may acquire some peculiar and diverse physico-chemical properties as compared to their bulk material for example, increased reactivity, expended surface area, flexible pore size and diverse particle morphology [6]. Nanoparticles (NPs) possess a high surface energy and high surface to volume ratio which .enhances their reactivity and other biochemical activity, such bizarre features of NPs may exhibit diverse behaviour and impact than their bulk counterparts [7]. The term "nanobiotechnology" was first introduced by biophysicist Lynn W. Jelinski, Cornell University, USA. Nanotechnology opens the options to construct the novel material that exhibit some unique properties. In the current scenario nanoparticles can be a potential tool to be affectively used as plant growth and development promoters, herbicides, nano-pesticide, nanofertilizers etc. which can effectively release their content in required quantity to target cellular organelles in plants. There is a wide scope of nanotechnology is due in agriculture sector and the potential applications on nanoparticles (NPs) are still unexplored, especially their mechanism and role on plant growth and development [8]. Application of fertilizers in agriculture is common practice in order to increase the productivity and maintain growing food demand. Since fertilizers play a vital role in crop growth, development and production, they must applied in bulk quantity and most of their part remains unutilized by plants, due to many inherent factors i.e., leaching in soil, degradation by photolysis, hydrolysis, and decomposition.[9].Therefore, there is a constant need to develop novel applications with the help of nanotechnology and nanomaterials. Which not only increase the crop production and yield but also to minimize the nutrient loss of fertilizers and augment their effective availability to plants. Development of nanofertilzers or nano-encapsulated nutrients could be an effective tool in this direction towards sustainable agriculture that can regulate the plant growth and production substantially by effective release of nutrients and availability. Application of nanofertilizers may provide suitable alternative to increase resources use efficiency and also helps to reduce increased soil toxicity created due to accumulation of chemical fertilizers and pesticides in the soil. Most of the chemical fertilizer applied in the field remain unutilized by plants and get accumulated in the soil leading to increase soil toxicity therefore application of nanofertilizers could help to reduce such problems. [10,11]. Since plants are under constant exposure all weather conditions, irrespective of favourable or unfavourable, they develop diverse adaptive mechanisms at physiological and biochemical level to cope such adverse conditions. Despite advances of nanotechnology in other sectors, development of nanobiotechnology and its applications in agriculture sector is still at native stage. However, there is an increasing interest of researchers in this direction to use *ex-vivo* synthesis of nanoparticles (NPs) for diverse purposes in agriculture sector especially to ameliorate plant metabolic and physiologic functions for growth and development by utilizing the unique properties of NPs [12]. Although the diverse applications of nanoparticles (NPs) are exploiting in different fields i.e. in health care sector, medical treatments, industrial production, cosmetics or clothes and agriculture etc. [13,14,15]. Although the peculiar properties of nanoparticles in agriculture sector is gaining worldwide attention, but the knowledge of the exact mechanism of nanoparticle or nanoengineered material interaction with plants at various levels is still scanty [16,17].Therefore the present review is focused on the potential applications of nanoparticles in agriculture sector, exploiting peculiar properties of different nanoparticles and their impact on crop plants especially toward growth and mitigation of abiotic stress tolerance in plant to achieve sustainable agriculture.

NANOPARTICLES:

With emergence of nanotechnology and its wide spectrum applications in diverse fields, more attention is being paid on the synthesis of nanomaterial from metals (Au, Ag, Pd etc) or metal oxides (ZnO, SiO_2, TiO_2, etc). There are many methods are available through which nanoparticles can be synthesised i.e., physical, chemical or biological[18]. Thrust is not only on the chemical synthesis of nanoparticles but also on the biological synthesis (Green synthesis) of some metallic nanoparticles using plants or from their extracts, because all the plants irrespective of herbs, shrubs or tree that containing enzymes, sugars protein and phytochemicals like flavanoids, latex, phenolics, terpenoids, alcohols , amines and cofactor etc. These compounds act as reducing and stabilizing agent during synthesize of metal nanoparticles from the metal salts that helps in finding most promising and ecofriendly nanoparticle synthesis solutions, which provides a controlled synthesis with well-defined size and shape but also prevent the atmosphere pollution [19,20,21]. Nanoparticles (NPs) attain high surface to volume ratio which enhances their bioavailability, bioactivity and other biochemical activities ([22]. Therefore, with increased advances made by applying tools of nanobiotechnology in the agricultural sector, it is assumed that it will help to augment plant growth, development and productivity and biotic and abiotic stress tolerance. It was also observed that under certain conditions plants are capable of producing natural mineralized nano-materials (NMs) necessary to their growth [23]. It is also expected that as the understanding of nanotechnology will deepens, it will help to exploit nanotechnology to become a major economic driving force that will benefit consumers as well as farmers with no adverse effect on human and environment.

Silicon Nanoparticles (SNPs):

Silicon (Si) is most abundantly present in the soil and Earth's crust. Its role in plant defence and plant growth & development is most recognized and well documented. There are several studies which recognized its immense potential to mitigate effectively diverse abiotic stresses i.e. drought, salinity, cold stress and other heavy metal toxicities. However, there is scanty of information available on exact mechanisms of Si-mediated mitigation of abiotic stresses in plants [24, 25, 26]. Silicon nanoparicles can effectively spread in wide area. It was estimated that 1.0 gram of silica nanoparticles having size of 7.0 nm diameter exhibit wide absorption surface equal to 400 m^2. Furthermore, silica nanoparticles also exhibit its effect on xylum humidity, water translocation and enhance turgor pressure, thus leaf relative water content and water use efficiency will be increased in pants [27,28].

Si particles can also mediate several other important key effects in higher plants leading to enhance abiotic stress tolerance i.e., enhancement of antioxidant enzyme activation, enhanced uptake process, co-precipitation of toxic metal ions, immobilization of toxic metal ions in growth media and compartmentation of metal ions within plants. All such processes, increase plant capabilities to withstand abiotic stresses i.e., salinity, drought, heavy metal toxicity etc. [24]. Nanomaterials usually consist of particles smaller than 100 nm. Such nanoscale Si particles acquire new physical, chemical and biological properties [29]. Studies indicated that silica nanoparticles (SNPs) improves growth and yield in plants under stress, this tolerance is may be attributed by absorption of silicon- nanoparticles by root where they develop a fine layer in the cell wall which helps plant to resist various stresses and maintain yield [30]. Further, the study revealed that nano-SiO_2 particles absorbed better and faster than micro-SiO_2, Na_2SiO_3, and H_4SiO_4 when applied on root of maize and seeds, because of fast absorption of nanoparticles, they can be immediately utilized by plants to fulfil their growth needs ([31]. Apparently, no toxic effect was observed on plant biology when pear seedling irrigated with high concentrations of nano-SiO_2 [32]. Silica nanoparticles also exhibited its growth promoting effect on the development stages in *Zea mays* L. In the study Javad S. et.al., (2014) investigated the effects of silica nanoparticles (SiO_2) on developmental stages of *Zea mays* L. especially on seed germination, rate of root and stem elongation, relative water content (RWC) and photosynthetic pigment which revealed significant increase in these attributes when exposed with different concentrations (0, 400, 2000, and 4000 mg/L) of silica nanoparticles (SiO_2) as compared to the control [33].The impact of nanoparticles (SiO_2) further studied in tomato and squash under salinity stress, it is suggested that application of nanoparticles (SiO_2) enhance seed germination and the antioxidant system under salinity stress in tomato and squash when treated with nano-SiO_2 particle [34, 21]. Although usages of nanoparticles in different applications is increasing widely, but still very less information is available on actual consequences of plant interaction with nonmaterial.

Silver Nanoparticles (AgNPs):

Silver nanoparticles offers a wide range of engineered nanomaterials currently produces for application in wide range of commercial products. With the advent of nanotechnology, application of silver nanoparticle are successfully applied in wide array of applications such as food packaging, coating on domastic products, pesticides etc. Their (silver nanoparticles) applications in electronics, medical drug delivery and biological tagging medicine is widely appreciated [35,36,37,38,39,40].

As understanding of nanoparticles building up, their applications are increasing in the agriculture sector especially in crop improvement. Several studies revealed that application of appropriate concentrations of AgNPs has an additional mileage in plant growth and development including seed germination [41, 42].

The effects of synthesis of silver nanoparticles (AgNPs), was evaluated in seven varieties of *Lycopersicon esculentum* Mill (tomato) plants on the seed germination using different concentrations of AgNPs, the results indicated the AgNPs treated seeds sprouted early than seeds germinated in deionized water when treated with five different concentrations, *viz*, 0, 25, 50, 75 and 100 mg l^{-1}. However higher concentration of AgNPs exhibited inhibitory effect on seed germination [43].

The effect of silver metal nanoparticles assessed at various concentrations i.e., 0, 25, 50, 100, 200 and 400 ppm in *Brassica juncea* seedlings on the growth and antioxidative enzyme level. The findings suggested the induced level of specific antioxidant enzymes. There were increased chlorophyll content, root length and shoot length, at the same time level of proline and MDA were reduced. More over nanoparticles effect observed was concentration dependent where 50 ppm was found optimum for growth amelioration. [44].

Aluminum Oxide Nanoparticle (Al_2O_3 Nanoparticles):

Aluminum oxide is prime material, used by industry because it possesses good thermal conductivity, high strength and stiffness. It is also known to be easily moulds and given desired shapes. Aluminium oxide is widely used in various products produced by industries. it has a wide applications in products like high temperature electrical insulators, thermometry sensors, , high voltage insulators, ballistic armor, wear pads and grinding media. Application and utilities of nanoparticles in the industry is widely increasing as more and more products are integrated with them therefore, it is necessity to access the impact of nanoparticles in the environment that are released into the environment [45].

ZnO Nanoparticles:

Micronutrient fertilizers can increase the tolerance of plants towards environmental stress like drought and salinity [46]. Zinc (Zn) is among the important key micronutrient required for the optimum growth and development of plants which carries vital metabolic reactions within the plants to promote growth and development. Despite its role in the growth and development of plants, it is also play a vital role in reducing toxic heavy metals uptake by plants, thereby prevents plants from the heavy metal toxicity such as Cd [46]. In another study it was revealed that foliar application of ZnO nanoparticles at appropriate concentration (1.5mg/ml) on chick pea exhibited increased biomass production as compared to application of bulk $ZnSO_4$ [47]. Study indicated that ferrous and zinc paly a role in enhancing or prepare the plants to tolerate drought stress [48]. Application of ZnO nanoparticles on *Cicer arietinum* L seed imparted enhanced seed germination and seedling growth. Since ZnO nanoparticles increase the auxin (IAA) level in roots (sprouts) which promote the growth of plants. Moreover Zn is utilized by plant in very less quantity therefore availability at of Zn at nano level ensures a appropriate quantity of Zn delivery to the plant for its utilization by plants for growth and development. Hence, Zn toxicity can be avoided not only in plants but in soil too. Therefore, ZnO may be considered as eco-friendly and bio-friendly material which can be used as a green reagent [49].

TiO_2 Nanoparticles:

TiO_2 nanoparticle is photocatalytic in nature which can carry out an oxidation–reduction reaction leading to generate superoxide anion radical and hydroxide when exposed to light [50]. However, photosterilization by TiO_2 nanoparticles ameliorate plant growth and development. The significant effect of TiO_2 nanoparticles was estimated in photochemical reaction of chloroplasts of *Spinacia oleracea* upon application of TiO_2 nanoparticles [51]. A study revealed that TiO_2 nanoparticles (rutile phase) enhances antioxidant stress tolerance by modulating various processes like lowering of superoxide radicals accumulation, hydrogen peroxide, malonyldialdehyde (MDA)content, and inducing antioxidant enzymes activities within the plants i.e. superoxide dismutase, catalase, ascorbate peroxidase, and guaiacol peroxidase on the photochemical reaction of chloroplasts of *Spinacia oleracea* [52]. Jaberzadeh et al. (2013) reported that application TiO_2 nanoparticles have shown significant positive impact on growth and yield components in wheat under water deficit condition [53].

Further, Application of TiO_2 also affects positively on chick pea (*Cicer arietinum* L) genotypes differing in their sensitivity to cold stress (sensitive and tolerant). the study revealed the reduced electrolyte leakage index (ELI) and malondialdehyde (MDA) when subjected to cold stress (CS) 4°C [54].

Abiotic stress: Among the abiotic stresses, drought, salinity, alkalinity, submergence and mineral toxicity/ deficiencies are considered as major factors that contributes to decrease crop growth and productivity, however, among abiotic stresses, salinity, drought and low temperature mainly contribute to major reduction in crop yield [55]. Being sessile organism, plants left with no choice but to face various environmental stresses throughout their life cycle, therefore they develop their defence against environmental stresses at various levels by modulating molecular, biochemical and physiological pathways. In order to cope these stresses, plants adopt molecular routes by appropriate alteration of gene expressions.

There are several studies which indicated that nanoparticles mediated effect on plants growth and development is concentration dependent. Nanoparticles are involved in upregulating the activities of antioxidant enzymes like, SOD, CAT and POD. [56]. Laware (2014), conducted study to assess the impact on onion seedling when exposed with TiO_2 nanoparticles, the results suggested that TiO_2 nanoparticles increase SOD activity and it further increased with increasing NPs concentration. However, seed germination and seedlings growth in onion were enhanced at low concentration of TiO_2 Nanoparticles whereas effect reversed (suppressed) at higher concentrations. Beside Super oxide dismutase (SOD) which showed concentration dependent increase, there were significant induction of hydrolytic enzyme (Amylase) and antioxidant enzymes (CAT and POD) activities, although enzymes activity were higher at lower concentration (10-30 µg/ml) of TiO_2 and decreased at higher concentration (40 and 50 µgml-1) [56]. Some studies suggested that TiO_2 and SiO_2 nanoparticles have shown potential to enhance seed germination as well as growth of Glycine max seeds [57].

Nanoparticles in Salinity Stress:

Salinity is a major abiotic stress factor. It limits the food production and deteriorate the growing demand of food crops. Salinity is the major concern of scientific community to attain sustainable crop production, it is estimated that more than 20% of cultivated land worldwide is experiencing salinity stress and the amount is increasing day by day. Since, majority of major crop plants species belong to glycophyte category, they are susceptible to salt stress hence is most critical environmental stress that can cripple crop productivity worldwide [58, 59]. Salinity stress causes the negative impact on various biochemical and physiological processes which are associated with plant growth and yield. Lowering of soil osmotic potential, creation of nutritional imbalance, enhancing specific ionic toxicity (salt stress) or one or more combination of these factors, are some of the common implications of salinity stress experienced by plants [60]. Some other vital processes like photosynthesis, protein synthesis and lipid metabolisms etc. are badly affected by Salinity stress within a plant [61].

Nanotechnology is recently gaining attention of researchers because of their wide applications in diverse sectors including agriculture. Application of nanofertilizers are among the most promising method which can potentially enhance plant resource use efficiency and reduce environmental toxicity due to accumulation of unused chemical fertilizers and pesticides in the soil. Plant utilize much less amount chemical fertilizers and pesticides than the amount applied in the soil, therefore rest of the chemicals remain unused and accumulate in soil to increase soil toxicity. The Application of nanofertilizers could be a potential approach to address such issues of soil toxicity and other associated stress problems. It is reported that silicon nanoparticles and silicon fertilizer exhibited promising effects on physiological and morphological traits on vegetative features of basil under salinity stress. It was evident from results which indicated significant increase in growth and development indices, chlorophyll content (Chl-a) and proline level in basil (*Ocimum basilicum*) under salinity stress, when treated with silicon nanoparticles and silicon fertilizer. Results suggested could be due to tolerance induction in plants there by mitigating the effect of salinity stress in Basil (*Ocimum basilicum*), [62]. Other studies also revealed the salinity stress mitigation capability of nano-SiO_2. Application of Nano-SiO_2 particles have shown potential increase in chlorophyll content, leaf fresh weight , leaf dry weight, proline accumulation and upregulated antioxidant enzymes activity under salinity stress. Such increase various attributes may be corroborated to enhancing the abiotic stress tolerance in plants. [62, 21,63].

Application of silicon nano-particles on lentil (*Lensculinaris* Medik.) genotypes under salinity stress revealed significant increase in seed germination and seedling growth, whereas significant reduction in germination percent and seedling growth due to the salinity stress under without treatment of nanoparticles. Adding SiO_2 nanoparticles not only enhance seed germination and early seedling growth but also increase other related traits in lentil genotypes under salinity stress. Therefore, SiO_2 nano-particles ameliorate different defence mechanisms of plants against salt toxicity [64]. Stress mitigation effects of nanosilicon particle were also studied in tomato seeds and seedlings under salt stress. The results suggested the reduced salt toxicity impact on seed germination; root length and plant dry weight in basil (*Ocimum basilicum*), exposed under salinity stress [63]. Salinity stress reduce the crop growth and yield because of the Na^+ ion toxicity and nanoparticle (nanoSiO_2) have suggested to decreased the ionic toxicity leading to enhance crop growth and yield, thus helps crop improvement under adverse conditions [65].Other studies in maize suggested that increase in fresh soot fresh and weight under salinity stress when applied by nano SiO_2 [66]. One strategy which silica nanoparticles adopts to mitigate salinity stress in plants is to reduce Na^+ ion concentration, perhaps by reducing Na^+ ion absorption by plant tissues. Since primary impact of salinity stress on plant growth is due to reduction of osmotic potential and toxicity of Na^+ ion. Silica nanoparticles may help to improve plant growth under salinity stress following Na^+ ion toxicity [67].

Nanoparticles in Drought Stress:

Water is a vital component for plant survival and essentially required for transport of nutrients, therefore water deficiency leads to drought stress, which resulted into weakened vitality of plants [68]. Drought is among most frequently occurring abitoic stress, which significantly contributed to limit crop production in arid regions. Studies indicated that application of different fractions of silica nanoparticles improves the plant tolerance toward drought stress i.e., Hawthorns (*Crataegus* sp.) showed increased drought tolerance, the physiological and biochemical responses varies in hawthorn seedlings to different concentrations of silica nanoparticles at different level of drought stress from moderate to severe stress. The results suggested the positive effect on photosynthesis parameters, malondialdehyde (MDA), relative water content (RWC), membrane electrolyte leakage (ELI) as well as chlorophyll, carotenoid, carbohydrate and proline contents by pre-treatment of SNPs. Perhaps involvement of silicon nano particles in maintaining critical physiological and biochemical attributes in order to induce drought tolerance in hawthorn seedlings under drought stress, but exact mechanism is yet to be understood [69]. Application of silicon on two sorghum (*Sorghum bicolor* (L.) Moench) cultivars having different drought susceptibility showed improved drought tolerance irrespective of their drought susceptibility by lowering shoot to root (S/R) ratio, which perhaps suggested the improved root growth and the maintenance of the photosynthetic rate. These findings could be attributed to improve the drought tolerance of sorghum via the augmenting water uptake efficiency of plants [70]. Silicon can be potentially used to mitigate effects of drought stress impact up to some extant A study conducted by Pei, Z.I. (2010), suggested that application of appropriate concentration (1.0 mM) Si (sodium silicate) could partially mitigate the deleterious effects of drought stress in wheat. Although the exact mechanism is unclear but silicon partially improve shoot growth, increase the leaf chlorophyll contents, maintained leaf water potential in stressed plants. Moreover, it also reduces membrane lipid peroxidation in wheat [71]. Application of micronutrient like Zn could increases the radical growth in germinated seeds and high Zn content in grains can increase the seed viability and establishment especially in Zn – deficient areas [72, 48] Sedghi et.al (2013), demonstrated that nano zinc oxide have potential to increase seed germination percentage and germination rate in soybean as compared to those were subjected to water stress. It was further suggested that nano zinc oxide application under drought stress decrease seed residual fresh and dry weight, which shows that zinc nanoparticles were effective for using of seed reservoirs to seedling growth and enhance drought tolerance [73].

Iron is important micronutrient play a crucial role in plant growth and development, its deficiency leads to significant changes in plant metabolism and causes chlorosis. Therefore elements absorption of microelements (iron) in plants under drought stress may attribute pivotal role in drought tolerance. Several studies indicated that the application of micronutrients can be used to ameliorate the effects of drought stress and salinity stress . A study revealed the significant effect of iron nanoparticles under drought stress in plants on traits like number of boll per branch, number of seeds per boll, the thousand seed weight and yield at probability level of 1%. Foliar application of iron nanoparticles exhibited drought stress mitigating effects on yield components and oil percentage of Goldasht spring safflower cultivars. Application of Fe nanoparticles also enhance yield and yield components at two stages of flowering and granulation, although it was better at flowering stage than seed formation in contrast to drought stress conditions without Fe nanoparticles application [74]. The mitigation of adverse effect of drought stress using titanium nanoparticle foliar application on wheat has also shown promising results on certain agronomic traits like seed gluten and starch contents of wheat. The results suggested that application of 0.02% titanium dioxide nanoparticles exhibited enhancement in various agronomic traits i.e, Plant height, ear weight, ear number, seed number, 1000-seed weight, final yield, biomass, harvest index including gluten and starch content under drought stress [75].

Advances of silver nanoparticles (AgNPs) application were also appreciated in reducing negative effects of drought stress on lentil (*Lens culinaris* Medic). Study suggested the significant effect of different concentrations of PEG and silver nanoparticles on germination rate and germination percentage, root length, root fresh and dry weight in lentil seeds. Moreover application of silver nanoparticles (AgNPs) could be attributed towards mitigating water stress mediating loss of plant growth and yield [76].

CONCLUSION AND FUTURE PERSPECTIVE.

Nanotechnology is fast growing technology with latest updates and advancement in diverse sectors. However, the applications on nanotechnology and use of nanoparticles in sustainable agriculture and crop improvement are still at juvenile phase. Therefore, in order to harness the peculiar and unique properties of NPs in agriculture sector to get maximum potential advantages, it has become necessary to build up basic understanding regarding interaction of NPs with plants at cellular as well as molecular level. Moreover, with increased applications of nanotechnology in industries which makes their way to the environment, consequently accumulation of nanoparticles in the system and their effect needs to be assessed to prevent potential adverse effect on the environment. So far there are not much studies available on the phytotoxicity effects of nanoparticles on plants. Therefore it is essential to understand plant–nanoparticles interaction and optimization of size and concentration of NPs before practical applications in the fields so that their possible negative impact can be reduced on natural environment and crops as well.

ACKNOWLEDGEMENT

Author's extends their sincere acknowledgement to Amity University Madhya Pradesh for providing all necessary facilities and valuable support.

REFERENCES

1. Fortina P, Kricka LJ, Surrey S, Grodzinski P, Nanobiotechnology., "The promise and reality of new approaches to molecular recognition:, *Trends Biotechnol* 2005;,23, 168.
2. Robinson D.K.R., Morrison M et al., Nanotechnology developments for the agri food sector report,2009.
3. Perez-de-Luque A, Diego R, "Nanotechnology for parasitic plant control", *Pest Manag. Sci* 2009; 65:540–545.
4. Torney F, Trewyn BG, Lin VSY, Wang K.," Mesoporous silica nanoparticles deliver DNA and chemicals into plants", *Nat Nanotechnol* 2007, 2, 295–300.
5. Roco M.C, "Broader societal issue of nanotechnology", *Journal of Nanoparticle Research* 2003a, 5, 181-189.
6. Nel A., Xia T., Madler L., and Li N.,"Toxic potential of materials at the nanolevel". *Science*, 2006, 311, 622-627.
7. Dubchak, S, Ogar A , Mietelski, J.W., Turnau, K., "Influence of silver and titanium nanoparticles on arbuscular mycorrhiza colonization and accumulation of radiocaesium in *Helianthus annuus*",. *Span. J. Agric. Res*. 2010, 8, S103–S108.
8. Manzer H. Siddiqui, Mohamed H. Al-Whaibi, Mohammad Firoz and Mutahhar Y. Al-Khaishany, "Role of Nanoparticles in Plants", *book nanotechnology and plant science*, 2015, pp19-35.
9. Singh A, Singh NB, Imtiyaz Hussain I, Himani Singh H, and Singh SC.,"Plant-nanoparticle interaction: An approach to improve agricultural practices and plant productivity". *International Journal of Pharmaceutical Science Invention* , 2015, 4 , Issue 8, 25-40.
10. DeRosa MC, Monreal C, Schnitzer M, Walsh R, Sultan Y.," Nanotechnology in fertilizers". *Nat Nanotechnol*, 2010; 5:91. doi:10.1038/nnano.
11. Nair R, Varghese SH, Nair BG, Maekawa T, Yoshida Y, Kumar DS, "Nanoparticulate material delivery to plants", *Plant Sci*. 2010, 179,154–163.
12. Giraldo JP, Landry MP, Faltermeier SM, McNicholas TP, Iverson NM, Boghossian AA, Reuel NF, Hilmer AJ, Sen F, Brew JA, Strano MS., "Plant nanobionics approach to augment photosynthesis and biochemical sensing," *Nat Mater*. 2014, doi:10.1038/nmat3890.
13. Rogers, L., "Safety fears over ''nano'' anti-aging cosmetics," *The Sunday Times*.2005;
14. Lee WM., An YJ, Yoon H, Kweon, HS., "Toxicity and bioavailability of copper nanoparticles to the terrestrial plants mung bean (Phaseolusradiatus) and wheat (*Triticum aestivum*): plant agar test for water-insoluble nanoparticles," *Environ. Toxicol. Chem*. 2008, 27, 1915–1921.
15. Lee, WL, Mahendra S., Zodrow, K, Li, D, Tsai, YC., Braam, J, Alvarez, PJJ, "Developmental phytotoxicity of metal oxide nanoparticles to *Arabidopsis thaliana*," *Environ. Toxicol. Chem*.2010; 29: 669–675.
16. Barrena R, Casals E, Colon, J, Font, X, Sanchez, A, Puntes, V, "Evaluation of the ecotoxicity of model nanoparticles," *Chemosphere*, 2009, 7: 850–857.
17. Khodakovskaya MV., de Silva K, Nedosekin, DA, Dervishi E, Biris, AS, Shashkov EV, Ekaterina IG, Zharov, VP,. "Complex genetic, photo thermal, and photo acoustic analysis of nanoparticle-plant interactions". *Proc. Natl. Acad. Sci.* 2011,108 (3), 1028–1033.
18. Anita Singh, Shikha Singh and Sheo Mohan Prasad., "Scope of Nanotechnology in Crop Science: Profit or Loss," *RRJBS,* 2016; 5: (1).
19. Kumar V, Yadav SK: Plant-mediated synthesis of silver and gold nanoparticles and their applications. *J Chem Technol Biotechnol* 2009,84:151–157.
20. Sharma VK, Yngard RA, Lin Y, "Silver nanoparticles: Green synthesis and their antimicrobial activities," *Adv Colloid Interface Sci*, 2009, 145:83–96
21. Siddiqui MH, Al-Whaibi MH, Faisal M, Al Sahli AA , "Nano-silicon dioxide mitigates the adverse effects of salt stress on *Cucurbita pepo* L.," *Environ Toxicol Chem* , 2014, 33(11), 2429–
22. Dubchak S, Ogar A, Mietelski, JW, Turnau K, "Influence of silver and titanium nanoparticles on arbuscular mycorrhiza colonization and accumulation of radiocaesium in *Helianthus annuus*," *Span. J. Agric. Res*, 2010, 8, s103–S108.
23. Wang LJ, Guo ZM, Li TJ, Li M, "The nano structure SiO2 in the plants". *Chin. Sci. Bull*, 2001, 46, 625–631.
24. Liang Y, Sun W, Zhu YG, Christie P., "Mechanisms of silicon mediated alleviation of abiotic stresses in higher plants: a review," *Environmental Pollution,* 2007, 147, 422–428.
25. Ma JF., "Role of silicon in enhancing the resistance of plants to biotic and abiotic stresse,". *Soil Science and Plant Nutrition*, 2004, 50, 11–18.
26. Datnoff LE, Rodrigues FA, Seebold KW., "Silicon and plant disease," In Mineral Nutrition and Plant Disease, pp. 233–246. Eds L.E. Datnoff, W.H. Elmer and D.M. Huber. St Paul, MN, USA: *The American Phytopathological Society.*
27. Wang J, Naser N., "Improved performance of carbon paste ampermeric biosensors through the incorporation of fumed silica," *Electroanalysis*, 1994,6, 571- 575.
28. Rawson HM, Iong MJ, Munns R., "Growth and development in NaCl treated plants," *J Plant Physiol*.1998,15, 519-527.
29. Monica CR and Cremonini R., "Nanoparticles and Higher plants,"*Cryologia*, 2009; 62: no. 2: 161-165.
30. Derosa M.R., Monreal C., Schmitzer M., Walsh R.,Sultan Y., "Nanotechnology in fertilizers," *Nat Nanotechnol*. 2010, 1, 193-225.
31. Suriyaprabha R, Karunakaran G, Yuvakkumar R, Prabu P, Rajendran V, Kannan N., "Growth and physiological responses of maize (Zea mays L.) to porous silica nanoparticles in soil," *Journal of Nanoparticle Research*, 2012, 14, 1–14.
32. Zarafshar M, Akbarinia M, Askari H, Hosseini S.M, Rahaie M,Struve D., Striker GG., "Morphological, physiological and biochemical responses to soil water deficit in seedlings of three populations of wild pear tree (Pyrus boisseriana) Biotechnology," *Agronomy, Society and Environment*, 2014, 18, 353–366.
33. Javad S R, Javad K, Sasan Mohsenzadeh ,Majid Sharifi Rad Javad M., " Evaluating SiO2 Nanoparticles Effects on Developmental Characteristic and Photosynthetic Pigment Contents of *Zea mays L*, " *Bull. Env. Pharmacol. Life Sci*., 2014, 3 [6] ,194-201
34. Haghighi M, Pourkhaloee A., "Nanoparticles in agricultural soils: their risks and benefits for seed germination," *Minerva Biotecnologica*, 2013, 25,(2), 123-32.
35. Davies JC., "Nanotechnology Oversight: an Agenda for the New administration. Project on Emerging Technologies," *Woodrow Wilson International Center for Scholars, Washington*, DC, 2009.
36. Ahamed M, AlSalhi MS.; Siddiqui M., "Silver nanoparticle applications and human health," *Clin. Chim. Acta,* 2010, 411, 1841–1848.
37. Jo YK, Kim BH, Jung G., "Antifungal activity of silver ions and nanoparticles on phytopathogenic fungi," *Plant Dis*. 2009, 93, 1037–1043.
38. Kim SW, Jung JH, Lamsal K, Kim YS, Min JS, Lee Y.S., "Antifungal effects of silver nanoparticles (AgNPs) against various plant pathogenic fungi," *Mycobiology*, 2012, 40, 53–58.
39. Bechert T, Böswald M, Lugauer S, Regenfus A, Greil J, Guggenbichler JP., "The erlanger silver catheter: In vitro results for antimicrobial activity," *Infection* 1999, 27, S24–S29.
40. Korkin A, Rosei F., "Nanoelectronics and Photonics., From Atoms to Materials, Devices, and Architecture," *Springer Science & Business Media: Berlin, Germany,* 2008.
41. Barrena, R., E. Casals, J. Colon, X. Font, A. Sanchez and V. Puntes, "Evaluation of the ecotoxicity of model nanoparticles", *Chemosphere,*2009, *75*, 850-857.
42. Shelar GB and Chavan AM., "Myco-synthesis of silver nanoparticles from Trichoderma harzianum and its impact on germination status of oil seed.," *Biolife*, 2015, 3, 109-113.
43. Karami M,S., Heidari, R., Rahmani, F. Solnamaz N., "Effect of Chemical Synthesis Silver Nanoparticles on Germination Indices and Seedlings Growth in Seven Varieties of *Lycopersicon esculentum* Mill (tomato) Plants," *J Clust Sci* ,2016, 27, 327. doi:10.1007/s10876-015-0932-4.
44. Sharma P, Bhatt D, Zaidi MG, Saradhi PP, Khanna PK, Arora S., "Silver nanoparticle-mediated enhancement in growth and antioxidant status of *Brassica juncea," Appl Biochem Biotechnol.* 2012,167,(8), 2225-33.
45. Rittner MN, Abraham T., Nanostructed materials., "An overview and commercial analysis. Journal of the Minerals," *Metals and Materials Society,*1998, 50, 37–38.
46. Baybordi A., 2005. "Effect of zinc, iron, manganese and copper on wheat quality under salt stress conditions", *J.water Soil*, 2005, 140: 150-170.
47. Burman U, Saini M, Praveen-Kumar., "Effect of zinc oxide nanoparticles on growth and antioxidant system of chickpea seedlings," *Toxicol Environ Chem*, 2013, 95,(4), 605–612.

48. Cakmak I: Enrichment of cereal grains with zinc., "Agronomic or genetic biofortification", *Plant & Soil,* 2008, 30 (2), 1-17.
49. Pandey AC, Sanjay SS, Yadav RS., "Application of ZnO nanoparticles in influencing the growth rate of Cicerarietinum," *J Exp Nanosci,* 2010, 488–497.
50. Hong F, Yang F, Liu C, Gao Q, Wan Z, Gu F, Wu C, Ma Z, Zhou J, Yang P, " Influence of nano-TiO2 on the chloroplast aging of spinach under light," *Biol Trace Elem Res* 2005a,104:249–260
51. Hong F, Yang F, Liu C, Gao Q, Wan Z, Gu F, Wu C, Ma Z, Zhou J, Yang P., "Influence of nano-TiO2 on the chloroplast aging of spinach under light," *Biol Trace Elem Res*, 2005b, 104, 249–260.
52. Lei Z et.al., "Antioxidant stress is promoted by nano-anatase in spinach chloroplasts under UV-Beta radiation," *Biol Trace Elem Res*, 2008, 121, 69–79.
53. Jaberzadeh A, Moaveni P, Moghadam HRT, Zahedi H., "Influence of bulk and nanoparticles titanium foliar application on some agronomic traits, seed gluten and starch contents of wheat subjected to water deficit stress," *Not Bot Horti Agrobo*.2013,
54. Mohammadi R, Maali-Amiri R, Abbasi A., (2013) "Effect of TiO2 nanoparticles on chickpea response to cold stress," *Biol Trace Elem Res.* 2013, doi:10.1007/s12011-013-9631-
55. Boyer, J. S., "Plant productivity and environment", *Science* , 1982, 218, 4571, 443-448.
56. Laware SL, and Shilpa Raskar., "Effect of Titanium Dioxide Nanoparticles on Hydrolytic and Antioxidant Enzymes during Seed Germination in Onion,". *Int.J.Curr.Microbiol.App.Sci* , 2014, 3,(7), 749-760.
57. Lu CM, Zhang CY, Wen JQ, Wu GR, Tao MX., "Research of the effect of nanometer materials on germination and growth enhancement of Glycine max and its mechanism,". *Soybean Science*, 2002, 21, 168-172.
58. T. J. Flowers., "Improving crop salt tolerance," *Journal of Experimental Botany* , 2004, 55, no. 396, pp. 307–319.
59. Munns R, and Tester M., "Mechanisms of salinity tolerance," *Annual Review of Plant Biology*, 2008, 59, 651–681.
60. Ashraf M., "Organic substances responsible for salt tolerance in *Eruca sativa*," *Biol. Plant*., 1994, 36, 255–259.
61. Parida A.K., Das A.B., "Salt tolerance and salinity effect on plants: a review," *Ecotoxicol. Environ. Saf*.,2005, 60, 324–349.
62. Kalteh M, Zarrin TA, Shahram A, Maryam MA , Alireza FN., "Effect of silica nanoparticles on Basil (*Ocimum basilicum*) Under Salinity Stress," *Journal of Chemical Health Risks*, 2014, 4,(3), 49-55.
63. Haghighi M, Afifipour Z, Mozafarian M., "The effect of N–Si on tomato seed germination under salinity levels," *International Journal of Environmental Sciences*, 2012, 6, 87–90.
64. Sabaghnia N, Janmohammad M., "Effect of nano-silicon particles application on salinity tolerance in early growth of some lentil genotypes," *Annales UMCS, Biologia*. 2015, 69, 2, 39–55.
65. Savvasd G.,Giotes D., Chatzieustratiou E.,Bakea M.,Patakioutad G., "Silicon supply in soilless cultivation of Zucchini alleviates stressinduced by salinity and powdery mildew infection" , *Environmental and experimental botany*,2009,65,11-17.
66. Gao X, Zou CH, Wang L, Zhang F., "Silicon decreases transpiration rate and conductance from stomata of maize plants," *J Plant Nutr*. 2006, 29, 1637- 1647.
67. Raven J.A., "Transport and function of silicon in plants. Biological Reviews,"1982, 58, 179-207.
68. Martínez-Vilalta J., Piñol J., " Drought-induced mortality and hydraulic architecture in pine populations of the NE Iberian Peninsula," Forest Ecology and Management 2002, 161, 247–256.
69. Peyman Ashkavand , Masoud Tabari , Mehrdad Zarafshar , Ivana Tomášková , Daniel Struve : "Effect of SiO2 nanoparticles on drought resistance in hawthorn seedlings," *Leśne Prace Badawcze / Forest Research Papers Grudzień*, 2015; 76, (4), 350–359.
70. Hattori T, Inanaga S, Araki H, An P., Morita S, Luxová M, Lux A., "Application of silicon enhanced drought tolerance in *Sorghum bicolour,". Physiologia Plantarum,* 2005,123, 459–466.
71. Pei ZF, Ming DF, Liu D, Wan GL, Geng XX, Gong HJ, Zhou WJ., "Silicon improves the tolerance to water-deficit stress induced by polyethylene glycol in wheat (*Triticum aestivum* L.) seedlings," *Journal of Plant Growth Regulation*, 2010, 29,106–115.
72. Cakmak I., Yilmaz A, Torun B., Erenoglu B, Broun H.J., "Zinc deficiency as a critical nutritional problem in wheat production in central Anatolia," *Plant&Soil*. 1996,180, 165-172.
73. Sedghi, M., M. Hadi and S.G. Toluie., "Effect of nano zinc oxide on the germination parameters of soybean seeds under drought stress," *Ann. WUT-ser. Biol*., 2013,XVI, 73-78.
74. Davar F. Zareii, Arash R., Amir H., "Evaluation the effect of water stress and foliar application of Fe nanoparticles on yield, yield components and oil percentage of safflower (*Carthamus tinctorious* L.)," *Int J Adv Biol Biom Res*. 2014, 2 ,(4), 1 150 - 1 159.
75. Jaberzadeh A, Payam M., Hamid R., Tohidi M.,, Hossein Z., "Influence of Bulk and Nanoparticles Titanium Foliar Application on some Agronomic Traits, Seed Gluten and Starch Contents of Wheat Subjected to Water Deficit Stress", *Not Bot Horti Agrobo*, 2013, 41(1), 201-207.
76. Hojjat., "The Effect of silver nanoparticle on lentil Seed Germination under drought stress", *Intl J Farm & Alli Sci.* 2016, 5 (3): 208-212, 2016.FAO, High Level Expert Forum—How to Feed the World in 2050, Economic and Social Development, Food and Agricultural Organization of the United Nations, Rome, Italy, 2009.