Journal of Scientific Research and Advances

ISSN 2395-0226

Nano carriers and their potential use in Agriculture

Rita Choudhary[1, 2] and Pannalal Dey[1]
[1]*TERI-DEAKIN Nano Biotechnology Centre, Sustainable Agriculture Division, The Energy and Resources Institute (TERI), DS Block, Indian Habitat Centre, Lodhi Road, New Delhi-110003*
E-mail address: justrita86@gmail.
[2] *Institute for Frontier Materials, Deakin University, Waurn Ponds, Victoria, 3216, Australia*

In recent years, nanotechnology has extended its applicability in agriculture. Development of new generation of nanomaterials and their use in agriculture has improved ways for solving numerous agricultural problems like detection of plant diseases, soil remediation by constructing 'nanoarchitects", controlled delivery of agrochemicals by synthesising "nanocarriers" and their application in developing sensors. This articles highlights on the work that has been so far on the development and usage of such nano carriers in delivering nutrients in context to agriculture.

Keywords: Nanotechnology, Agriculture, nutrients, Nanocarriers

I. INTRODUCTION

Nanotechnology has left no field untouched by its scientific innovations. Nano science has elbowed itself in agriculture and is now re-shaping our agricultural system. Transforming materials into Nano-scale will change their physical, chemical and biological properties and may be it will increase their solubility and penetration into cell membrane [1]. Many research groups are working on connecting the dots between Nanotechnology and Agriculture has proved successful at a certain level. Nutrient imbalances in soil and crop plants have attracted many scientists to look for the solution. Although the research in this area is at very nascent stage but still, in period of time, few products have been developed like "Nualgi" – a nano nutrient. It contains all micronutrients in the nano form and is biologically available for plant adsorption (www.nualgi.com). It has increased the crop yield. In 2011, a study was conducted at Ferdowsi University of Mashhad, Iran, which showed that nano iron oxide (25-250 nm) increased the adsorption of Fe by plant roots as compared to normal iron oxide (0.02-0.06 mm). Many studies were conducted on both positive and negative effects of introducing the Nano nutrients in to plants. Summary of these studies is given below: the application of nano-TiO_2 increases the photosynthesis, nitrogen metabolism and growth of spinach at proper concentration [2-4]. Another study reported that uncoated alumina particles (nano-Al_2O_3) inhibited the root elongation of corn, cucumber, soybean, cabbage and carrot [5]. Lin and Xing [6], conducted a study on phytotoxicity of nanoparticles on seed germination and root growth of six higher plant species. Results demonstrated significant inhibition on seed germination and growth during incubation process. Prasad et al. [7], conducted a study on effect of Nano scale zinc oxide particles on the germination, growth and yield of peanut, results showed that foliar application of Nano scale ZnO particles increased the pod yield by 29.5% as compared to chelated $ZnSO_4$.

II. NANOCARRIERS: SMART NUTRIENT DELIVERY SYSTEMS FOR AGRICULTURAL APPLICATIONS

The application of mesoporous silica nanoparticles as a drug delivery tool in mammalian systems is more advanced compared to their use in agriculture which is still a relatively new concept [8-12]. However, the application of nanotechnology to agricultural field has recently expanded much attention with one such application being the controlled release of agrochemicals [13]. In particular, silica-based nanoparticles have spawned importance as a potential delivery agent of agrochemicals in plants. This is mainly due to their structure flexibility in forming nanoparticles of various sizes and shapes, and also their ability to form pores for loading biomolecules [14-16]. In addition, silica is known for its role as a micronutrient involved in plant growth, regulation and stress [17-21].

III. MESOPOROUS SILICA NANOPARTICLES AS A "NANO-CARRIERS"

In the past decades, mesoporous silica nanoparticles (MSNs) have attracted great attention because of their high surface area, ordered porous structure, stability, controllable pore diameter and excellent biocompatibility. Mesoporous silica nanoparticles can be classified as hexagonal, cubic, lamella and biocontinuous [22, 23]. Most commonly used MSNs are MCM-41, MCM-48 and SBA-15.

IV. LOADING OF NUTRIENTS INTO NANO-CARRIERS

The majority of soils in the world are micronutrient deficient. Most plant nutrients are human nutrients too. Therefore, for the production of nutritious food with balanced contents of essential macro and micronutrients, a good and consistent supply of nutrients from the soil to the plant is very crucial. But implementing strategies to overcome them remains a challenge in many parts of the world.

Over the past two decades, experts have realised that the conventional agronomic technologies would not be able to enhance farm productivity any further. New innovations are needed to be integrated in the present agricultural systems to increase the capacity of global agriculture [34]. To eliminate the micronutrient deficiencies from crops, there is an urgent need to develop smart systems to deliver precise quantities of nutrients or other agrochemicals required by plants [35]. Numerous studies have suggested that nanotechnology has a tremendous potential to revolutionize agriculture and other fields [36, 37]. Additionally, this technology holds the promise of controlled release of agrochemicals and site specific delivery of various micronutrients needed for enhanced plant growth and efficient nutrient utilization [38]. Recent advances in nanotechnology application in agriculture like nano-carriers are being developed for delivering various nutrients and agrochemicals. Nano-carriers, are the nano delivery systems carrying nutrients or other agrochemicals, making nutrients more available to plants and therefore resulting in efficient nutrient use [39]. Nano encapsulation by loading nutrients and other agrochemicals into nano-carriers is better when compared with conventional microencapsulation technologies as the conventional micro encapsulations do not provide a controlled release of active agrochemical ingredient to the targeted plants. Whereas, nano-carriers help the slow release of loaded chemicals to biological systems through slow release mechanisms that include dissolution, biodegradation, diffusion, and osmotic pressure [40]. In research and development stage, nano sized agrochemicals are mostly nano reformulations of existing agrochemicals [41]. Nano formulations are generally expected to increase the apparent solubility of poorly soluble active ingredients, to release the active ingredient in a slow/targeted manner, and to protect against premature degradation [42]. Agrochemical companies are reducing the particle size of existing chemical emulsions to the nano scale. The use of smaller sized nanoparticles in agrochemicals is intended will make them more effective. Many companies make formulations that contain nanoparticles within the 100-250nm size range that are able to dissolve in water more effectively than the existing ones of large size, thus increasing their activity [35]. The lack of water solubility is one of the limiting factors in the development of crop protecting agents. Nano-sized silica materials provide not only excellent intrinsic properties, such as low toxicity, excellent chemical stability and versatile functionalization chemistry, but also have the capability of being platforms to be integrated with, other nanomaterials [24]. Silica based nanomaterials with new functionalities have been continuously developed [25]. There have been attempts to incorporate inorganic nanoparticles into the siliceous matrix without the loss of the ordered structure. Integrating inorganic nanoparticles into ordered mesoporous materials without disrupting the structure of the matrix is a challenge. Only few reports on one-pot synthesis processes exists [26, 27]. Chelated forms of micronutrients, especially iron and zinc, are considered to be a rich and reliable source of bivalent ion plants because they are stable and can prevent them from deposition of these chelated forms for a reasonable period of time. Though, these chelated forms of Fe and Zn increase nutrients uptake from soil, the chelated forms have a problem as they are very costly [28]. Also, slow release nano-forms of the chelated nutrients are the excellent alternatives to chelated forms of nutrients as nutrients are released at a slower rate throughout the crop growth; plants are able to take up most of the nutrients without waste by leaching. Slow release of the nutrients in the environments could be achieved by loading them onto nano-carriers like MSNs. There are reports which show the nontoxic nature of MSNs but little work has been published on the effect of MSNs when they are exposed to the beneficial microbes present in rhizosphere. Among all the controlled release technologies under development, the use of silica nanoparticles is of special interest in agricultural context [43]. The materials which are used as carrier substances in this application are important as this determines the release of the desired amount of nutrients over a period of time. There are some key features of choosing the materials in designing the coating or transport carrier. This includes the biodegradability, long-term retention, safety for both living and non-living nature, formation of nontoxic by-products upon degradation and the feasible transformation into different forms to meet current methodologies and technologies [44]. The surface porosity is also an important aspect in controlling the release mechanism of agro-chemicals [45]. The biodegradation of nano-carriers/nanoparticles is greatly affected by their geometry. The X-ray structural analysis showed that amorphous phase (disordered phase) of the polymer is distinguished at a faster rate, compared to the crystalline phase (ordered). The reason behind this phenomenon could have been due to the preference of the depolymerases to attack the amorphous regions of the polymer matrix, rather than the ordered phase [46, 47]. Also, to use MSNs as a nano-carrier for agrochemical applications it is very essential to assess their effect on those organisms which directly or indirectly comes under their zone of action in soil.

V. IMPACT ON NANOMATERIALS ON ENVIRONMENT

Nano-formulations are claimed to boost the efficacy of agricultural chemicals, improve delivery systems, promote plant nutrient uptake and yield, and enhance food quality at minimal impact to the environment. In fact, nano-agricultural inputs like nano-pesticides and nano-fertilizers have been commercially available for several years already, and new products are expected to inundate the market as thousands of patent applications are currently in the pipeline. Unfortunately, the difference between the potential benefits and harm from nano-enabled products may be quite subtle and a large knowledge gap exists on the long-term impacts of nanomaterials to the environment, crop production, and human health. But more research is needed to justify their non-toxicity with plants as well as with biologicals and for proper application method of these Nano materials into the agriculture.

VI. BENEFITS OF NANOTECHNOLOGY IN AGRICULTURE

Globally, many companies are producing innovative products with the help of nanotechnology (Table 1). In recent years, a cumulative number of government, scientific, and institutional reports have established that nanotechnology could make a significant contribution to improving poverty and achieving the Millennium Development Goals. Furthermore, nanofabrication involving technology is a distinct field, because it departs from the conventional field of nanotechnology (e.g., nanoelectronics, nanomaterials), and is far more challenging than conventional applications (e.g., mobiles, computers, biosensors, textile, and other industrial products). This is because technology is an interface between the physical world and biological world, and soil is the central domain of geosphere, biosphere, atmosphere, and the hydrosphere, so soil scientists have the responsibility to support life and protect environment. Nano fertilizers must be capable of releasing nutrient ions in plant-available forms. One of the key aspects of nanofabrication could possibly be manipulation of bonds, which is a common occurrence in soil minerals.

VII. FIGURES

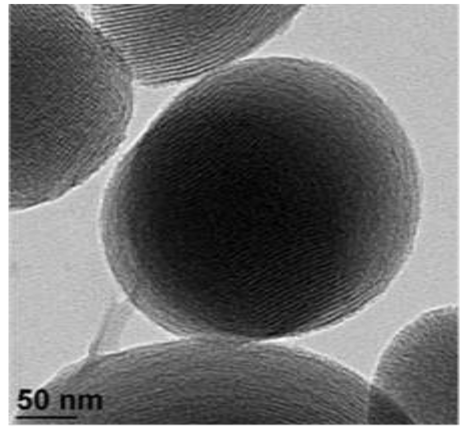

Figure 1. TEM image of honeycomb-like MSNs having 2-D channel in axial direction

VIII. CONCLUSIONS

Supplementing plants with macro and micro nutrients by using direct spraying methods in fields not only benefits the targeted crops but are also taken up by the weed plants present in the fields. In such case, nutrient loaded nano-carrier can be a useful approach for supplying nutrients only to the targeted crops with a slow release mechanism. Therefore, to maintain an optimum and precise supply of nutrients to the targeted crops, the construction of biodegradable nano-carrier is imperative for today's agricultural systems.

1. ACKNOWLEDGEMENTS

The authors would like to thank The Energy and Resources Institute (TERI) and Deakin University. Also we would like to thanks Dr.Alok Adholeya and Prof. Lingxue Kong for providing the facility.

1. Mazaherinia, S., Astaraei, A.R., and Fotovat, A. (2010). Nano iron oxide particles efficiency on Fe, Mn, Zn and Cu concentrations in wheat plant. World Applied Sciences Journal *7*.
2. Zheng, L., Hong, F., Lu, S., and Liu, C. (2005). Effect of nano-TiO2 on strength of naturally aged seeds and growth of spinach. Biological trace element research *104*, 83-91.

3. Yang, F., Hong, F., You, W., Liu, C., Gao, F., Wu, C., and Yang, P. (2006). Influence of nano-anatase TiO2 on the nitrogen metabolism of growing spinach. Biological trace element research *110*, 179-190.
4. Hong, F., Zhou, J., Liu, C., Yang, F., Wu, C., Zheng, L., and Yang, P. (2005). Effect of nano-TiO2 on photochemical reaction of chloroplasts of spinach. Biological trace element research *105*, 269-279.
5. Yang, C., Hamel, C., Vujanovic, V., and Gan, Y. (2011). Fungicide: modes of action and possible impact on nontarget microorganisms. ISRN Ecology *2011*.
6. Lin, D., and Xing, B. (2007). Phytotoxicity of nanoparticles: inhibition of seed germination and root growth. Environmental Pollution *150*, 243-250.
7. Prasad, T., Sudhakar, P., Sreenivasulu, Y., Latha, P., Munaswamy, V., Reddy, K.R., Sreeprasad, T., Sajanlal, P., and Pradeep, T. (2012). Effect of nanoscale zinc oxide particles on the germination, growth and yield of peanut. Journal of plant nutrition *35*, 905-927.
8. Kurepa, J., Paunesku, T., Vogt, S., Arora, H., Rabatic, B.M., Lu, J., Wanzer, M.B., Woloschak, G.E., and Smalle, J.A. (2010). Uptake and distribution of ultrasmall anatase TiO2 Alizarin red S nanoconjugates in Arabidopsis thaliana. Nano letters *10*, 2296-2302.
9. Nair, R., Varghese, S.H., Nair, B.G., Maekawa, T., Yoshida, Y., and Kumar, D.S. (2010). Nanoparticulate material delivery to plants. Plant science *179*, 154-163.
10. Slomberg, D.L., and Schoenfisch, M.H. (2012). Silica nanoparticle phytotoxicity to Arabidopsis thaliana. Environmental science & technology *46*, 10247-10254.
11. Wang, Z., Xie, X., Zhao, J., Liu, X., Feng, W., White, J.C., and Xing, B. (2012). Xylem-and phloem-based transport of CuO nanoparticles in maize (Zea mays L.). Environmental science & technology *46*, 4434-4441.
12. Zhu, H., Han, J., Xiao, J.Q., and Jin, Y. (2008). Uptake, translocation, and accumulation of manufactured iron oxide nanoparticles by pumpkin plants. Journal of Environmental Monitoring *10*, 713-717.
13. Hussain, H.I., Yi, Z., Rookes, J.E., Kong, L.X., and Cahill, D.M. (2013). Mesoporous silica nanoparticles as a biomolecule delivery vehicle in plants. Journal of nanoparticle research *15*, 1-15.
14. Campbell, J.L., Arora, J., Cowell, S.F., Garg, A., Eu, P., Bhargava, S.K., and Bansal, V. (2011). Quasi-cubic magnetite/silica core-shell nanoparticles as enhanced MRI contrast agents for cancer imaging. PLoS One *6*, e21857.
15. Jang, H.R., Oh, H.-J., Kim, J.-H., and Jung, K.Y. (2013). Synthesis of mesoporous spherical silica via spray pyrolysis: pore size control and evaluation of performance in paclitaxel pre-purification. Microporous and Mesoporous Materials *165*, 219-227.
16. Shi, Y.-T., Cheng, H.-Y., Geng, Y., Nan, H.-M., Chen, W., Cai, Q., Chen, B.-H., Sun, X.-D., and Yao, Y.-W. (2010). The size-controllable synthesis of nanometer-sized mesoporous silica in extremely dilute surfactant solution. Materials Chemistry and Physics *120*, 193-198.
17. Kauss, H., Seehaus, K., Franke, R., Gilbert, S., Dietrich, R.A., and Kröger, N. (2003). Silica deposition by a strongly cationic proline-rich protein from systemically resistant cucumber plants. The Plant Journal *33*, 87-95.
18. Bélanger, R., Benhamou, N., and Menzies, J. (2003). Cytological evidence of an active role of silicon in wheat resistance to powdery mildew (Blumeria graminis f. sp. tritici). Phytopathology *93*, 402-412.
19. Chérif, M., Asselin, A., and Bélanger, R. (1994). Defense responses induced by soluble silicon in cucumber roots infected by Pythium spp. Phytopathology *84*, 236-242.
20. Fawe, A., Abou-Zaid, M., Menzies, J., and Bélanger, R. (1998). Silicon-mediated accumulation of flavonoid phytoalexins in cucumber. Phytopathology *88*, 396-401.
21. Rodrigues, F., Vale, F., Korndörfer, G., Prabhu, A., Datnoff, L., Oliveira, A., and Zambolim, L. (2003). Influence of silicon on sheath blight of rice in Brazil. Crop Protection *22*, 23-29.
22. Selvam, P., Bhatia, S.K., and Sonwane, C.G. (2001). Recent advances in processing and characterization of periodic mesoporous MCM-41 silicate molecular sieves. Industrial & Engineering Chemistry Research *40*, 3237-3261.
23. Wang, S. (2009). Ordered mesoporous materials for drug delivery. Microporous and mesoporous materials *117*, 1-9.
24. Piao, Y., Burns, A., Kim, J., Wiesner, U., and Hyeon, T. (2008). Designed fabrication of silica-based nanostructured particle systems for nanomedicine applications. Advanced Functional Materials *18*, 3745-3758.
25. Suteewong, T., Sai, H., Cohen, R., Wang, S., Bradbury, M., Baird, B., Gruner, S.M., and Wiesner, U. (2010). Highly aminated mesoporous silica nanoparticles with cubic pore structure. Journal of the American Chemical Society *133*, 172-175.
26. Nooney, R.I., Thirunavukkarasu, D., Chen, Y., Josephs, R., and Ostafin, A.E. (2002). Synthesis of nanoscale mesoporous silica spheres with controlled particle size. Chemistry of materials *14*, 4721-4728.
27. Lin, Y.-S., and Haynes, C.L. (2009). Synthesis and characterization of biocompatible and size-tunable multifunctional porous silica nanoparticles. Chemistry of Materials *21*, 3979-3986.
28. Malakooti, M., and Lotf, A. (1998). Effect of zinc on increasing of quantitive and quality of productions. Karaj, Iran.

Table 1 Some examples of recent breakthroughs in nanotechnology in agriculture

Product name	**Manufacturer**	**Particulars**	**Web address or reference**
Nafertino organic Nanofertilizers	Naftertino Biotechnology Co., Ltd.-Taiwan	Not disclosed by the company Nafertino organic Nanofertilizers can be uptake by both leaves and roots, enhances plant growth enhancer, seed starter, yield enhancer, basal application and soil conditioner.	http://www.nafertino.com.
Primo MAXX plant growth regulator	Syngenta	100nm particle size emulsion (“microemulsion concentrate”) The extremely small particle size allows PrimoMAXX to mix completely with water and not settle out in a spray tank	http://www.syngentapp.com/prodrender
Geohumus Soil Wetting Agent	Geohumus	Biocompatible high performance polymer Soil enhancer with water storage capacity based on nanotechnology	http://www.geohumus.com/download
Irrigation emmitter/ plastic pipe	Geoflow	Nanoclay platelets (PolyOne’s NanoblendMB)	http://www.ptonline.com/articles html
Nano Green Tonic	Nano Green Technology, Inc.	The nano Green tonic is has a uniform particle size of 8 angstroms to 4 nanometers. Nano Green claims to have developed a Plant Tonic based on nanotechnology to boost agriculture	http://nanoall.blogspot.in
Nano Guard	Vision Mark Biotech, Pune, India	Organic nanofungicide	http://www.visionmarkbiotech.in/nano-fungicide.htm
Nanocides	BASF, Ludwigshafen, Germany	Pesticides encapsulated in nanoparticles for controlled release	http://www2.basf.us
Nano5 (biofertilizer and pesticide)	UNO Fortune Inc., Taiwan	G-protein based formulation with G-protein molecules in Nano form	http://unofortune.en.taiwantrade.com/product/nano-5-3-in-1-natural-mucilage-organic-fertilizer-294455.html
Nano-Gro	Agro Nanotechnology Inc.	Micronutrients in nanoformulation	http://www.agronano.com/nanogro.htm
4G Nano	Prathishta Industries, India	Protein-lacto gluconates based organic carbon fertilizers to meet nutritional needs of all crops supplemented with Nano Zn, Fe, Mg and P, NUE is ~ 58%	http://www.prathista.com/