EFFECTS OF NANO SILVER AS BACTERICIDE ON BENEFICIAL BACTERIA, UPTAKE BY PLANT AND IMPACT ON PLANT GROWTH

POOPAK SOTOODEHNIA

EFFECTS OF NANO SILVER AS BACTERICIDE ON BENEFICIAL BACTERIA, UPTAKE BY PLANT AND IMPACT ON PLANT GROWTH

By

POOPAK SOTOODEHNIA

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

January 2019

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

EFFECTS OF NANO SILVER AS BACTERICIDE ON BENEFICIAL BACTERIA, UPTAKE BY PLANT AND IMPACT ON PLANT GROWTH

By

POOPAK SOTOODEHNIA

January 2019

Chairman : Norida Mazlan, PhD
Faculty : Agriculture

Nanotechnology refers to the use of nano –size particles (measuring < 100 nm) in various fields including agriculture. Nanoparticles can be in the form of nano pesticide, nano fertilizer, waxing and sensors that are currently being used in agriculture. However, there is little information on the effects of these particles on microorganisms in soil and its impact on the environment. Therefore, this study was undertaken to evaluate the effect of nano-silver as bactericides on selected plant growth-promoting bacteria, residue in soil and its uptake in plant and impact on plant growth. In the initial study, the minimum inhibitory concentration (MIC) of nano-silver on beneficial microbes from the soil and pathogen was determined. To evaluate the MIC of silver nanoparticles (AgNPs), the size and shape of nanoparticles were determined by transmission electron microscopy (TEM) and scanning electron microscopy (SEM). To evaluate the effect of nano-silver on beneficial microbes, a total of 13 beneficial microbes tested for this study by using microdilution broth method. In the second study the effect of nano-silver against *Ralstonia solanacearum* and its effect on seed germination was studied. Based on the MIC results 40 ppm of nano- silver was used while different treatments were set for this study. On the third study the leaching potential of nano- silver in different soils samples were investigated. For leaching study, 196 µl of nano- silver was added to the two soils samples and leachate were collected every day for 14 days. Three replications including control were arranged as a completely randomized design (CRD) experiment and later the silver were measured by inductively coupled plasma optical emission spectrometry (ICP–OES). The forth study was aimed to analyze the residue of nano- silver in plant and also effect of nano-silver on plant growth. In this study *Cucumis sativus's* seed were soaked with different concentration of nano- silver (16, 24, 32 and 40 ppm) and control was not treated with nano-silver. This study was conducted in a glasshouse and the treatments were chosen based on the MIC results and the Munchong series soil, sand and organic matter were used as mixture for this study. Samples were analyzed with ICP-OES to detect the residue of silver using destructive sampling. Three different time (3WAP, 6WAP and 8WAP) were used for sampling time. Results showed that nanoparticles were pure spherical entities with 16 ± 6 nm in size. Nano- silver inhibited the activity of bacteria and pathogen on the range of 12 – 40 ppm. Results showed that silver nano particles increased the seed germination and protect the seed from pathogen. The physico- chemical data indicated that Munchong series soil sample was acidic (pH~ 5) and the amount of clay was approximately 70 %. However, the reference soil sample (with ratio of 2:2:1 Munchong series soil, sand and organic matter) was slightly acidic (pH ~ 6.6) and the amount of sand was 60 %. Results showed that the cation exchange capacity (CEC), electrical conductivity (EC), micro and macro elements were higher in the reference soil sample which could be due to the organic matter (cow dung) that was used. Results also showed that no silver was detected in leachate of all treatments that might be due to the amount of clay, organic matter in samples. However, another possibility could be due to less amount of silver that was applied to the soil. For the uptake study, results showed that residue of silver was detected in root, stem, flower and fruit during different sampling times. Results also indicated that by increasing the concentration of nano-silver the dry weight of plant was also increased. However, nano- silver did not affect the length of stem, root length. Silver nanoparticles is shown to affect root diameter (RD) and root volume (RV) and leaf area index (LAI) which depends on the time of exposure. Thus at the third sampling, silver increased the LAI, RD and RV.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

KESAN NANO PERAK SEBAGAI PEMBUNUH BAKTERIA ATAS BAKTERIA BERFAEDEH, PENYERAPAN OLEH TUMBUHAN DAN IMPAK KEPADA PERTUMBUHAN FLORA

Oleh

POOPAK SOTOODEHNIA

Januari 2019

Pengerusi : Norida Mazlan, PhD
Fakulti : Pertanian

Nanoteknologi merujuk kepada penggunaan partikel yang bersaiz nano (kiraan < 100nm) dalam pelbagai industri termasuk industri pertanian. Partikel-partikel nano terdapat dalam bentuk pembunuh serangga nano, baja nano, penggilap dan penderia yang sekarang digunakan dalam arena pertanian. Namun begitu, terdapat kekurangan maklumat tentang kesan nanopartikel kepada mikroorganisma dalam tanah dan akibatnya kepada alam semula jadi. Oleh itu, kajian ini diambil untuk menilai kesan nano-perak sebagai pembunuh bakteria terhadap beberapa bakteria yang menggalakkan pertumbuhan flora. Dalam kajian permulaan, konsentrasi penghalang minimum (MIC) bagi nano-perak terhadap mikrob berfaedah daripada tanah dan patogen telah ditetapkan. Bagi menilai MIC nanopartikel perak (AgNPs), bentuk dan saiz nanopartikel telah ditentukan melalui mikroskop transmisi elektron (TEM) dan mikroskop elektron pengimbas (SEM). Bagi menilai kesan nanopartikel perak atas mikrob berfaedah, sebanyak 13 mikrob berfaedah telah dikaji untuk kajian ini dengan menggunakan kaedah mikropencairan kaldu. Dalam kajian kedua, kesan nano-perak terhadap *Ralstonia solanacearum* dan kesannya terhadap percambahan biji benih telah dikaji. Berdasarkan atas keputusan MIC, 40 ppm nano-perak telah digunakan sementara rawatan yang berlainan ditetapkan bagi kajian ini. Dalam kajian ketiga, potensi melarut resap nano-perak dalam pelbagai sampel tanah telah disiasat. Bagi kajian melarut resap, 196 µl nano-perak telah ditambahkan kepada dua sampel tanah, dan larut resapan telah dikumpulkan setiap hari sepanjang 14 hari. Tiga replika termasuk satu replika kawalan telah digunakan, disusun sebagai eksperimen “completely randomized design” (CRD) dan selepas itu, perak telah diukur dengan kaedah “inductively coupled plasma optical emission spectrometry” (ICP-OES). Kajian keempat bertujuan untuk menganalisis residu nano-perak dalam tumbuhan dan juga kesan nano-erak atas ketumbuhan flora. Dalam kajian ini, benih

Cucumis sativus's telah direndam dengan konsentrasi nano-perak yang berbeza (16, 24, 32, dan 40 ppm) dan biji benih kawalan tidak dirawat dengan nano-perak. Kajian ini dijalankan dalam sebuah rumah kaca dan rawatan-rawatan telah dipilih berdasarkan atas keputusan MIC, serta tanah, pasir dan bahan organik siri Munchong digunakan sebagai campuran untuk kajian ini. Sampel telah dianalisis dengan ICP-OES untuk mengesan residu perak menggunakan pensampelan merosakkan (destructive sampling). Tiga waktu berbeza (3WAP, 6WAP dan 8WAP) telah digunakan sebagai waktu kajian. Keputusan menunjukkan bahawa nanopartikel perak adalah entiti sfera tulen bersaiz 16 ± 6 nm. Nano-perak menghalang aktiviti bakteria dan patogen dalam julat 12-40 ppm. Keputusan menunjukkan bahawa nanopartikel perak telah menambahkan percambahan benih dan melindungi benih daripada patogen. Data fisio-kimia menunjukkan bahawa siri sampel tanah Munchong adalah berasid (pH ~ 5) dan jumlah tanah liat adalah lebih kurang 70%. Namun begitu, sampel tanah rujukan (dengan ratio 2:2:1 siri tanah, pasir dan bahan organik Munchong) adalah sedikit berasid (pH ~ 6.6) dan jumlah pasir adalah 60%. Keputusan menunjukkan bahawa kapasiti pertukaran kation (CEC), konduksian elektrik (EC), serta elemen mikro dan makro adalah lebih tinggi dalam sampel tanah rujukan. Ini mungkin disebabkan oleh bahan organik (tinja lembu) yang digunakan. Keputusan juga menunjukkan bahawa tiada perak yang dikesan dalam larut resapan daripada semua rawatan, ini mungkin disebabkan oleh jumlah tanah liat atau bahan organik di dalam sampel. Walau bagaimanapun, kemungkinan lain boleh disebabkan oleh kekurangan jumlah perak yang digunakan dalam tanah. Bagi kajian penyerapan, keputusan menunjukkan bahawa residu perak telah dikesan di akar, batang, bunga dan buah tumbuhan semasa waktu pensampelan berbeza. Keputusan juga menunjukkan bahawa apabila konsentrasi nano-perak dinaikkan, keberatan kering tumbuhan juga menaik. Namun begitu, nano-perak tidak dapat mempengaruhi kepanjangan batang dan akar. Nanopartikel perak telah ditunjukkan untuk memberi kesan kepada diameter akar (RD), isi padu akar (RV) dan indeks luas daun (LAI) yang bergantung kepada masa pendedahan. Oleh itu, perak menaikkan LAI, RD dan RV.

ACKNOWLEDGEMENTS

In this journey I had many ups and downs, but it was because of those who have been encouraging me that I managed to finish my work. First of all I would like to thank God in helping me out from this journey. Special thanks go to my supervisor Dr Norida Mazlan, for her great supervision and kind support and also to my co-supervisors Dr Halimi Mohd Saud and Dr Samsuri Abd Wahid. I really appreciate their support.

I would like to thank Dr Ahmad Selamat and Dr Pedram Kashani for their guidance in the analysis of results. Nevertheless, I would like to thank Prof Sharifah Bee Hamid and Dr Samira Bagheri from NANOCAT, UM, Prof Dr Anders Baun from University Technology Denmark and Dr George Lowry from Mellon University, for their great advice during my PhD programme.

Last but not least my thanks to my great family, my husband and my kids who always encouraged me during this study and also to my wonderful parents, my sister and brother, as without their support I could not have completed this journey.

This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Norida binti Mazlan, PhD
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Chairman)

Halimi Mohd Saud, PhD
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

Samsuri Abd, PhD
Senior Lecturer
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software

Signature: ______________________________ Date: _______________

Name and Matric No: Poopak Sotoodehnia GS34779

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

Signature: ________________________
Name of Chairman of Supervisory Committee: Associate Professor Dr. Norida binti Mazlan

Signature: ________________________
Name of Member of Supervisory Committee: Associate Professor Dr. Halimi Mohd Saud

Signature: ________________________
Name of Member of Supervisory Committee: Dr. Samsuri Abd

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CB	Carbon Base
CeO2	Cerium Oxide
CNT	Carbon Nano Tube
CRD	Completely Randomized Design
DOM	Dissolved Organic Matter
EPA	Environmental Protection Agency
FIFRA	Federal Insecticide, Fungicide and Rodenticide Act
ICTA	International Centre of Technology Assessment
MIC	Minimum Inhibitory Concentration
NFB	Nitrogen Fixation Bacteria
NM	Nano Material
NP	Nanoparticles
TiO2	Titanium Dioxide

CHAPTER 1

INTRODUCTION

1.1 Introduction

Nanotechnology refers to the use of nano –size particles (measuring < 100 nm) in various fields including agriculture. Nanotechnology is used in the entire food production chain, during cultivation (e.g. pesticides, fertilizer), industrial processing, and packaging of food. Moreover, nanotechnology is utilized to enhance the nutritional aspects of food through nano-scale additives and nutrients as well as nano-sized delivery systems for bioactive compounds (Senjen, 2007; Abbasian et al, 2012). Nanotechnology in agriculture could in theory enhance the yield of crop and protect plants from diseases. Researchers have reported the effect of nanoparticles on rice, corn and tomatoes whereby their application increased yield of crop. Nanoparticles in the form of pesticides are being used from cultivation up till storage. Nano-pesticides reduce the application rate and losses through the small size of the particles and in turn this reduces environmental contamination (Müller et al, 2007; Moorman et al, 2001).

Pesticides containing nanoparticles might contaminate the soil and groundwater due to its longer persistence and increased toxicity. These particles could be taken up by plants when it is applied in the form of pesticides or fertilizer and easily enter into the food chain. The NPs uptake by plants is dependent upon several factors, such as the type and age of the plant, the duration of exposure, the size, type, chemical composition, solubility and the surface structure of the nanoparticles. Some plants will be able to take up and accumulate the NPs. Therefore, the risk of using NPs in agriculture, especially in the form of pesticides and fertilizers, is fast becoming the topic of interest in the context of preserving the quality of both the food chain and the environment. Among all nano particles, silver nano particles are used as bactericides and herbicides due to its antibacterial properties (Navarro et al, 2008).

The most obvious problem from the use of silver nano particles is its impact on the environment, especially to ecological organisms (Drake and Hazelwood, 2005). Once released into the environment, NPs will be able to move from one environmental compartment to another, i.e. from water to sediment, soil to groundwater, from water to microorganisms, fishes, insects, or mammals. One of the major challenges of nanotechnology is the development of a protocol to detect and investigate the behavior of NPs in the environment and how they impact biological systems. It is unclear how much nano silver have been released into the environment, and it is imperative that the environmental risks of these particles are properly determined for the protection of the people and the environment. The lack of data and knowledge pertaining to the risk of nano silver to humans and the environment remains an important issue in agriculture (Wickson et al, 2011).

Nanoparticles are more effective vis-à-vis its cleansing effect compared to its larger counterparts (Lkhagvajav et al, 2011). The usage of nano silver results in faster growth and increased length of plant roots (Nia, 2009; Abbasian et. al, 2012). The application of nano- silver on olive trees prior to its cultivation decreased the incidence of root diseases, while its application on strawberry plants increased their resistance to diseases and increased the size of the fruits and leaves (Pulit et al, 2011). Nowadays, nano-Ag is used in pesticides despite the risk that it may contaminate the soil and groundwater. Plants are capable of absorbing these particles and accumulating them in plant tissue. The risk of plants as a source of nourishment increases with the uptake of NPs which might be passed on to the food chain, and subsequently consumed by humans. Therefore, it is important that the environmental effect of these NPs be determined.

1.2 Objectives

The objectives of this study are:

1. To characterize nano silver bactericide and determine the minimum inhibitory concentration of nano-silver on beneficial microbes as well as its effect on seed germination in Japanese Cucumber (*Cucumis sativus)* against *Ralstonia solanacearum*,
2. To determine the leaching potential of nano-silver in two different soils samples,
3. To determine the uptake and distribution of nano-silver in cucumber and its effect on plant growth.

REFERENCES

Abbasian.M, Kashani.A, Ardakani.M.R, Rejali.F, Timajchi.M, Seifi.S.M &Mafakheri.S. (2012). The effect of chemical, Biological and nano fungicides on Mycorrhizal Colonization and quality of sunflower. *Scholars Research Library*, 3(8), pp 4239-4245.

Aghajani, Z. & Ekhtiyari, R. (2013). Effect of nano-silver on stages of plant growth and yield and composition of essential oil of Thymus kotschyanus Boiss. Hohen. *African Journal of Agricultural Research*, 8(8), 707-710.

Al mutairi. Z. M. & Al Harbi. A. (2015). Effect of nano silver nano particles on seed germination of crop plant. *International Journal of Biological, Biomolecular Agricultural, Food & Biotechnological Engineering*, 9(6), 594-598.

Albanese, A., Tang, P. S. & Chan, W. C. (2012). The effect of nanoparticle size, shape, and surface chemistry on biological systems. *Annual Review of Biomedical Engineering*, 14, 1-16.

Albersheim, P., Darvill, A., Roberts, K., Sederoff, R & Staehelin, A. (2011). Plant Cell Walls: from Chemistry to Biology (Garland Science, New York, NY).

Arias-Estévez, M., López-Periago, E., Martínez-Carballo, E., Simal-Gándara, J., Mejuto, J. C. & García-Río, L. (2008). The mobility and degradation of pesticides in soils and the pollution of groundwater resources. *Agriculture, Ecosystems & Environment*, 123(4), 247-260.

Aslani, F., Bagheri, S., Muhd Julkapli, N., Juraimi, A. S., Hashemi, F. S. G. & Baghdadi, A. (2014). Effects of engineered nanomaterials on plants growth: an overview. *The Scientific World Journal*, 2014.

Bali, R., Siegele, R. & Harris, A. T. (2010). Biogenic Pt uptake and nanoparticle formation in *Medicago sativa* and *Brassica juncea*. *Journal of Nanoparticle Research*, 12(8), 3087-3095.

Barrena, R., Casals, E., Colón, J., Font, X., Sánchez, A. & Puntes, V. (2009). Evaluation of the ecotoxicity of model nanoparticles. *Chemosphere*, 75(7), 850-857.

Basavaraju, P., Shetty, N. P., Shetty, H. S., De Neergaard, E. & Jørgensen, H. J. L. (2009). Infection biology and defence responses in sorghum against Colletotrichum sublineolum. *Journal of Applied Microbiology*, 107(2), 404-415.

Begum. P., Ikhtiari, R. & Fugetsu, B. (2011). Graphene phytotoxicity in the seedling stage of cabbage, tomato, red spinach, and lettuce. *Carbon*, 49(12), 3907-3919.

Belimov. A. A. & Dietz, K. J. (2000). Effect of associative bacteria on element composition of barley seedlings grown in solution culture at toxic cadmium concentrations. *Microbiological Research*, 155(2), 113-121.

Bell. R. A. & Kramer, J. R. (1999). Structural chemistry and geochemistry of silver-sulfur compounds: Critical review. *Environmental Toxicology & Chemistry*, 18(1), 9-22.

Ben. Moshe. T, Dror. T. & Berkowitz. B. (2010). Transport of metal oxide nano particles in saturated porous media. *Journal of Chemsphere*, 81, 387-393.

Benn, T. M. & Westerhoff, P. (2008). Nanoparticle silver released into water from commercially available sock fabrics. *Environmental Science & Technology*, 42(11), 4133-4139.

Bialek. A, Moszczynski. W. & Urszula.W (2011). The pathto development and chances for the restoration of plant protection products industry after the accession of Poland to the European Union. *Przemysł Chemiczny,* 95(12), 2396-2398.

Black, C. A. (1965). Method of soil analysis. Part 1. Physical and mineralogical properties, *Agronomy Monograph*, 9(1), 50-53.

Bondada, B. R., Tu, S. & Ma, L. Q. (2004). Absorption of foliar-applied arsenic by the arsenic hyper accumulating fern (*Pteris vittata* L.). *Science of the Total Environment*, 332(1), 61-70.

Bouwmeester, H. Marvin, H. J., Bouzembrak, Y., Janssen, E. M., van der Zande, M., Murphy, F. & Sheehan, B. (2017). Application of Bayesian Networks for hazard ranking of Nanomaterials to Support Human Health Risk Assessment. *Nanotoxicology*, (1), 1-34.

Bouwmeester, H., Dekkers, S., Noordam, M. Y., Hagens, W. I., Bulder, A. S., De Heer, C. & Sips, A. J. (2009). Review of health safety aspects of nanotechnologies in food production. *Regulatory Toxicology & Pharmacology*, *53*(1), 52-62.

Cañas, J. E., Long, M., Nations, S., Vadan, R., Dai, L., Luo, M., Ambikpathi, R., Lee, H.E. & Olszyk, D. (2008). Effects of functionalized and nonfunctionalized single-walled carbon nanotubes on root elongation of select crop species. *Environmental Toxicology & Chemistry*, 27(9), 1922-1931.

Chen, B. & Beckett, R. (2001). Development of SdFFF-ETAAS for characterising soil and sediment colloids. *Analyst*, 126(9), 1588-1593.

Chen, G., Liu, X. & Su, C. (2012). Distinct effects of humic acid on transport and retention of TiO2 rutile nanoparticles in saturated sand columns. *Environmental Science & Technology*, 46(13), 7142-7150.

Chen, K. L. & Elimelech, M. (2006). Aggregation and deposition kinetics of fullerene (C60) nanoparticles. *Langmuir*, 22(26), 10994-11001.

Chen, K. L. & Elimelech, M. (2007). Influence of humic acid on the aggregation kinetics of fullerene (C 60) nanoparticles in monovalent and divalent electrolyte solutions. *Journal of Colloid & Interface Science*, 309(1), 126-134.

Cho, K.H., Park, J.E., Osaka, T., Park, S.G. (2005). The study of antimicrobial activity and preservative effects of nanosilver ingredient. *Electrochimica Acta*, 51(5), 956-960.

Choat, B., Cobb, A. R. & Jansen, S. (2008). Structure and function of bordered pits: new discoveries and impacts on whole-plant hydraulic function. *New Phytologist*, 177(3), 608-612.

Choi, O. & Hu, Z. (2008). Size dependent and reactive oxygen species related nano silver toxicity to nitrifying bacteria. *Environmental Science & Technology*, 42(12), 4583-4588.

Chung, Y. C., Su, Y. P., Chen, C. C., Jia, G., Wang, H. L., Wu, J. G. & Lin, J. G. (2004). Relationship between antibacterial activity of chitosan and surface characteristics of cell wall. *Acta Pharmacologica Sinica*, 25, 932-936.

Colman, B. P., Arnaout, C. L., Anciaux, S., Gunsch, C. K., Hochella Jr, M. F., Kim, Lowry, G.V., McGill, B.M., Reinsch, B.C., Richardson, C.J. & Unrine, J. M. (2013). Low concentrations of silver nanoparticles in bio solids cause adverse ecosystem responses under realistic field scenario. *PLOS One*, 8(2), 57189-57110.

Colvin, V. L. (2003). The potential environmental impact of engineered nanomaterials. *Nature Biotechnology*, 21(10), 1166-1170.

Cornelis, G., Doolette Madeleine Thomas, C., McLaughlin, M. J., Kirby, J. K., Beak, D. G. & Chittleborough, D. (2012). Retention and dissolution of engineered silver nanoparticles in natural soils. *Soil Science Society of America Journal*, 76(3), 891-902.

Cornelis, G., Kirby, J.K., Beak, D., Chittleborough, D. & McLaughlin, M. (2010). A method for determination of retention of silver and cerium oxide manufactured nano particles in soil. *Journal of Environmental Chemistry*, 7, 298-308.

Cornelis, G., Pang, L., Doolette, C., Kirby, J. K., & McLaughlin, M. J. (2013). Transport of silver nanoparticles in saturated columns of natural soils. *Science of the Total Environment*, 463, 120-130.

Cui, D., Zhang, P., Ma, Y. H., He, X., Li, Y. Y., Zhao, Y. C. & Zhang, Z. Y. (2014). Phytotoxicity of silver nanoparticles to cucumber (*Cucumis sativus*) and wheat (*Triticum aestivum*). *Journal of Zhejiang University Science*, 15(8), 662-670.

Da Silva, L. C., Oliva, M. A., Azevedo, A. A. & De Araújo, J. M. (2006). Responses of restinga plant species to pollution from an iron pelletization factory. *Water, Air, and Soil Pollution*, 175(1-4), 241-256.

Dagmara. M, Agnieszka. S. & Zbignien. W. (2010). Risk Assessment for Silver Nanoparticles in Environment. *Minaralia Slovaca*, 42, 337-341.

DeRosa, M. C., Monreal, C., Schnitzer, M., Walsh, R. & Sultan, Y. (2010). Nanotechnology in fertilizers. *Nature nanotechnology*, 5(2), 91-91.

Dhoke.S, Mahajan.P, Kamble.R. & Khanna .A. (2013). Effect of nano particles suspension on the growth of mung (*vigna radiata*) seedling by foliar spray method. *Journal of Nano Technology Development*, 3(1), 1-5.

Dinesh, R., Anandaraj, M., Srinivasan, V., Hamza, S. (2012). Engineered nanoparticles in the soil and their potential implication of microbial activity. *Geoderma*, 173, 19-27.

Drake, P. L. & Hazelwood, K. J. (2005). Exposure-related health effects of silver and silver compounds: a review. *Annals of Occupational Hygiene*, 49(7), 575-585

Driouich, A., Follet-Gueye, M. L., Vicré-Gibouin, M. & Hawes, M. (2013). Root border cells and secretions as critical elements in plant host defense. *Current Opinion in Plant Biology*, 16(4), 489-495.

Ehsanpour, A. A. & Nejati, Z. (2013). Effect of nanosilver on potato plant growth and protoplast viability. *Biological Letters*, 50(1), 35-43.

Eisvand, H. R. & Ashouri, P. (2010). Physiology of stress. *Lorestan University Publication, Lorestan*, 230.

Ek, K. H., Morrison, G. M. & Rauch, S. (2004). Environmental routes for platinum group elements to biological materials—a review. *Science of the Total Environment*, 334, 21-38.

El -Badawy, A. M., Silva, R. G., Morris, B., Scheckel, K. G., Suidan, M. T. & Tolaymat, T. M. (2010). Surface charge-dependent toxicity of silver nanoparticles. *Environmental Science & Technology*, 45(1), 283-287.

El- Khashen. A. & El-Rab, S. F. G. (2012). Effect of reducing and protecting agents on size of silver nanoparticles and their anti-bacterial activity. *Der Pharma Chemica*, 4(1), 53-65.

El- Temsah & Joner .E.J. (2012). Impact of Fe and Ag nano particles on seed germination and differences in bioavailability during exposure in aqueous suspension and soil. *Journal of Environmental Toxicology*, 27(1), 42-9.

Elder, A., Jiang, J., Oberdörster, G., Gelein, R., Mercer, P. & Biswas, P. (2008). Does nanoparticle activity depend upon size and crystal phase? *Nanotoxicology*, 2(1), 33-42.

Elzey, S. & Grassian, V. H. (2010). Agglomeration, isolation and dissolution of commercially manufactured silver nanoparticles in aqueous environments. *Journal of Nanoparticle Research*, 12(5), 1945-1958.

Erickson, P.J., Ingram, J. S., Liverman, D.M. (2009). Food security and global environmental changes emerging challenges. Environmental Science and Policy, 12(1), 373-377.

Farahani, G. H. N., Sahid, I. B., Zakaria, Z., Kuntom, A. & Omar, D. (2008). Study on the downward movement of carbofuran in two Malaysian soils. *Bulletin of Environmental Contamination and Toxicology*, 81(3), 294-298.

Farré, M., Gajda- Schrantz, K., Kantiani, L. & Baeceló, D. (2009). Ecotoxicity and analysis of nano materials in the aquatic environment. *Journal of Analysis Bioanalysis Chemistry*, 393, 81-95.

Fauziah. C, Jamilah. I. & Syed Omar. S. R. (1997). An evaluation of cation exchange methods for acid tropical soils. *Pertanika Journal of Tropical Agriculture Science*, 20 (2/3), 113-119.

Feng, L. Q. J., Chen, G.Q., Cui, F.Z., Kim, T.N. & Kim, J.O. (2000). A Mechanistic Study of the antibacterial effect of silver ions on *Escherichia coli* and *Staphylococcus Aureus*. *Journal of Biomedical Materials Research,* 52, 662-668.

Fishal, E. M. M., Meon, S. & Yun, W. M. (2010). Induction of tolerance to Fusarium wilt and defense-related mechanisms in the plantlets of susceptible berangan banana pre-inoculated with *Pseudomonas* sp. (UPMP3) and *Burkholderia* sp. (UPMB3). *Agricultural Sciences in China*, 9(8), 1140-1149.

Fleischer, A., O'Neill, M. A. & Ehwald, R. (1999). The pore size of non-graminaceous plant cell walls is rapidly decreased by borate ester cross-linking of the pectic polysaccharide rhamnogalacturonan II. *Plant Physiology*, 121(3), 829-838.

Franke, M. E., Koplin, T. J. & Simon, U. (2006). Metal and metal oxide nanoparticles in chemiresistors: does the nanoscale matter. *Small*, 2(1), 36-50.

Gambino, M., Marzano, V., Villa, F., Vitali, A., Vannini, C., Landini, P. & Cappitelli, F. (2015). Effects of sublethal doses of silver nanoparticles on *Bacillus subtilis* planktonic and sessile cells. *Journal of Applied Microbiology*, 118(5), 1103–1115.

Garba. J, Samsuri. A. W, Hamdani. A. S. & Othman. R (2017). Carbon and phosphorus mineralization from soils amended with cow dung or rice husk ash. *Journal of Environmental and Agricultural Sciences* (10), 84-94.

Gardea-Torresdey, J. L., Rico, C. M. & White, J. C. (2014). Trophic transfer, transformation, and impact of engineered nanomaterials in terrestrial environments. *Environmental Science & Technology*, 48(5), 2526-2540.

Geckeis, H., Manh, T. N., Bouby, M. & Kim, J. I. (2003). Aquatic colloids relevant to radionuclide migration: characterization by size fractionation and ICP-mass spectrometric detection. Colloids and Surfaces A*. Physicochemical & Engineering Aspects*, 217(1), 101-108.

Gee, G. W., Bauder, J. W. & Klute, A. (1986). Particle-size analysis. Methods of soil analysis. Part 1. *Physical & Mineralogical Methods*, 383-411.

Ghayoor.E and Karamzadeh. S. (2002). Plant physiology, *Sanjesh Publication, Tehran*, 243-250.

Ghormade, V., Deshpande, M. V. & Paknikar, K. M. (2011). Perspectives for nano-biotechnology enabled protection and nutrition of plants. *Biotechnology Advances*, 29(6), 792-803.

Giraldo, J. P., Landry, M. P., Faltermeier, S. M., McNicholas, T. P., Iverson, N. M., Boghossian, A. A., & Strano, M. S. (2014). Plant nanobionics approach to augment photosynthesis and biochemical sensing. *Nature Materials*, 13(4), 400-408

Glenn, J. B., White, S. A. & Klaine, S. J. (2012). Interactions of gold nanoparticles with freshwater aquatic macrophytes are size and species dependent. *Environmental Toxicology & Chemistry*, 31(1), 194-201.

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Pretty ,J., Robinson, .S, Thomas , M.S. & Toulmin, C. (2010). Food security: the challenge of feeding 9 billion people. *Science*, 327(5967), 812-818.

Gottschalk, F., Sonderer, T., Scholz, R. W. & Nowack, B. (2009). Modeled environmental concentrations of engineered nanomaterials (TiO2, ZnO, Ag, CNT, fullerenes) for different regions. *Environmental Science & Technology*, 43(24), 9216-9222.

Govorov, A. O. & Carmeli, I. (2007). Hybrid structures composed of photosynthetic system and metal nanoparticles: plasmon enhancement effect. *Nano letters*, 7(3), 620-625.

Grolimund, D., Elimelech, M. & Borkovec, M. (2001). Aggregation and deposition kinetics of mobile colloidal particles in natural porous media. *Colloids and Surfaces A: Physicochemical & Engineering Aspects*, 191(1), 179-188.

Gruyer. N, Dorais. M, Bastein. C, Dassylva. N. & Triffault-Bouchet. G. (2013). Interaction between silver nano particles and plant growth. International Symposium on New Technology for Environment Control, Energy, Saving and Crop Production in Greenhouse &Plant, 1037, 795-800.

Gulson, B. & Wong, H. (2006). Stable isotopic tracing: A way forward for nanotechnology. *Environmental Health Perspectives*, 114 (10), 1486-1488.

Habib, S. H., Kausar, H. & Saud, H. M. (2016). Plant growth-promoting rhizobacteria enhance salinity stress tolerance in okra through ROS-scavenging enzymes. *BioMed Research International*, 6284547, 1-10.

Haghighi M, Afifipour. Z. & Mozafarian. M. (2012). Effect of N-Si on tomato seed germination under salinity levels. *Journal of biological Environment Science*, 6 (16), 87-90.

Hajipour, M. J., Fromm, K. M., Akbar Ashkarran, A., Jimenez de Aberasturi, D., Larramendi, I. R. D., Rojo, T. & Mahmoudi, M. (2012). Antibacterial properties of nanoparticles. *Trends in Biotechnology*, 30(10), 499-511.

Hall, J. L. & Williams, L. E. (2003). Transition metal transporters in plants. *Journal of Experimental Botany*, 54(393), 2601-2613.

Hänsch, M. & Emmerling, C. (2010). Effects of silver nanoparticles on the microbiota and enzyme activity in soil. *Journal of Plant Nutrition and Soil Science*, 173(4), 554-558.

Harajyoti. M. & Ahmed, G. U. (2011). Phytotoxicity effect of silver nanoparticles on *Oryza sativa*. *International Journal of Chemistry Technology. Research*, 3(3), 1494-1500.

Harris, A. T. & Bali, R. (2008). On the formation and extent of uptake of silver nanoparticles by live plants. *Journal of Nanoparticle Research*, *10*(4), 691-695.

Hawes, M. C., Gunawardena, U., Miyasaka, S. & Zhao, X. (2000). The role of root border cells in plant defense. *Trends in Plant Science*, 5(3), 128-133.

Hefnawy, A. E. G. & Tórtora-Pérez, J. L. (2010). The importance of selenium and the effects of its deficiency in animal health. *Small Ruminant Research*, 89 (2), 185-192.

History of silver. (2010). http://www.painreliefwellness.com/clients/2842/documents/History_of_Silver_Usage.pdf. Viewed on October 2013.

Hojjat. S. S. & Hojjat. H. (2015). Effect of nano silver on seed germination and seedling growth in Fenugreek seed. *International Journal of Food Engineering*. 1(2), 106-110.

Holden, P. A., Schimel, J. P. & Godwin, H. A. (2014). Five reasons to use bacteria when assessing manufactured nanomaterial environmental hazards and fates. *Current Opinion in Biotechnology*, 27, 73-78.

Hosseinzadeh, Z., Honisch, S., Schmid, E., Jilani, K., Szteyn, K., Bhavsar, S., Singh, Y., Palmada, M., Umbach, A.T., Shumilina, E., Lang, F. (2015). The Role of Janus kinase 3 in the regulation of Na^+/K^+ ATPase under energy depletion.Cell Physilogy Biochemestry, 36(2), 727-740.

Huang, B., Chen, F., Shen, Y., Qian, K., Wang, Y., Sun, C. & Cui, H. (2018). Advances in Targeted Pesticides with Environmentally Responsive Controlled Release by Nanotechnology. *Nanomaterials*, *8*(2), 102-117.

Humberto. L, Nilda. V, Ayala. N, Liliana. D.C.I.T. & Padill. C.R.G. (2009). Bactericidal effect of silver nanoparticles against multidrug resistant bacteria. *Springer Science and Business Media.*

Information and history of silver. 2010. http://www.cctechnologies.com.au/PDF/Information%20and%20history%20of%20 silver.pdf. (viewed on August 2013).

Irannejad, H. & Shahbazian, N. (2006). Resistance of crop plants to environmental stresses. *Karno Publication, Tehran*, 230.

Isla, R. & Aragüés, R. (2010). Yield and plant ion concentrations in maize (*Zea mays* L.) subject to diurnal and nocturnal saline sprinkler irrigations. *Field Crops Research*, 116(1), 175-183.

Jabarzadeh, A., Moaveni, P., Moghadam, H. R. T. & Zahedi, H. (2013). Influence of bulk and nanoparticles titanium foliar application on some agronomic traits, seed gluten and starch contents of wheat subjected to water deficit stress. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 41(1), 201-207.

Jia, G., Wang, H., Yan, L., Wang, X., Pei, R., Yan, T. & Guo, X. (2005). Cytotoxicity of carbon nanomaterials: single-wall nanotube, multi-wall nanotube, and fullerene. *Environmental Science & Technology*, *39*(5), 1378-1383.

Jones Jr, J.B., Wolf, B. & Mills, H.A. (1991). Plant Analysis Hand Book: a practical sampling, preparation, analysis and interpretation guild. *Micro-Macro Publishing*, 23-26, Inc.

Jones, K. C. & Peterson, P. J. (1986). The influence of humic and fulvic acids on silver uptake by perennial ryegrass, and its relevance to the cycling of silver in soils. *Plant & Soil*, 95(1), 3-8.

Joseph, T. & Morrison, M. (2006). Nanotechnology in Agriculture and Food: a Nano forum Report. Nano forum. org. Available on www.nanoforum .org.

Judy, J. D., Unrine, J. M. & Bertsch, P. M. (2010). Evidence for biomagnification of gold nanoparticles within a terrestrial food chain. *Environmental Science & Technology*, *45*(2), 776-781.

Judy, J. D., Unrine, J. M., Rao, W., Wirick, S. & Bertsch, P. M. (2012). Bioavailability of gold nanomaterials to plants: importance of particle size and surface coating. *Environmental Science & Technology*, *46*(15), 8467-8474.

Jung, J.-H., Kim, S.-W., Min, J.-S., Kim, Y.-J., Lamsal, K., Kim, K. S. & Lee, Y. S. (2010). The Effect of Nano-Silver Liquid against the White Rot of the Green Onion Caused by *Sclerotium cepivorum*. *Mycobiology*, 38(1), 39-43.

Jung, W. K., Koo, H. C., Kim, K. W., Shin, S., Kim, S. H. & Park, Y. H. (2008). Antibacterial activity and mechanism of action of the silver ion in Staphylococcus aureus and Escherichia coli. *Applied & Environmental Microbiology*, 74(7), 2171-2178.

Kafi. M, Borzooei. A, Salehi. M, Kamandi. A, Maasomi. A. & Nabati. J (2010).Physiology of environmental stress in plants. *Jahad University Publication*, Mashhad, 502-600.

Kalishwaralal, K., BarathManiKanth, S., Pandian, S. R. K., Deepak, V. & Gurunathan, S. (2010). Silver nanoparticles impede the biofilm formation by *Pseudomonas aeruginosa* and *Staphylococcus epidermidis*. *Colloids and Surfaces B: Biointerfaces*, *79*(2), 340-344.

Kammer, V.D. F. & Förstner, U. (1998). Natural colloid characterization using flow-field-flow-fractionation followed by multi-detector analysis. *Water Science and Technology*, 37(6), 173-180.

Kanhed. P, Birla. S, Gaikwad. S, Gade .A, Sabra. A. B, Rubilar. O, Duran. N. & Rai .M. (2014). In vitro antifungal efficiency of copper nano particles against selected crop pathogen fungi. *Material Letters,* 115, 13-17.

Karimi, N., Minaei, S., Almassi, M. & Shahverdi, A. R. (2012). Application of silver nano-particles for protection of seeds in different soils. *African Journal of Agriculture Research*, *7*, 1863-1869.

Karunakaran, G., Manivasakan, P., Yuvakkumar, R., Prabu, P., Suriyaprabha, R., Kannan, N. & Rajendran, V. (2013). Effect of nano silica and silicon sources on plant growth promoting rhizobacteria, soil nutrients and maize seed germination. *IET Nanobiotechnology*, 7(3), 70–77.

Ke, W., Xiong, Z. T., Chen, S. & Chen, J. (2007). Effects of copper and mineral nutrition on growth, copper accumulation and mineral element uptake in two *Rumex japonicus* populations from a copper mine and an uncontaminated field sites. *Environmental & Experimental Botany*, *59*(1), 59-67.

Keller, A. A., McFerran, S., Lazareva, A. & Suh, S. (2013). Global life cycle releases of engineered nanomaterials. *Journal of Nanoparticle Research*, *15* (6), 1-17.

Khodakovskaya, M. V., de Silva, K., Biris, A. S., Dervishi, E. & Villagarcia, H. (2012). Carbon nanotubes induce growth enhancement of tobacco cells. *American Chemical Society Nano*, *6*(3), 2128-2135.

Khodakovskaya. M, Derivishi. E., Mohammad. M, Xu. Y, Li. Z, Watanabe. F. & Bris. A.S. (2009). Carbon nanotubes are able to penetrate plant seed coat and dramatically affect seed germination and plant growth. *ACS Nano*, 3 (10), 3221-3227.

Kim, J. S., Kuk, E., Yu, K. N., Kim, J.-H., Park, S. J., Lee, H. J. & Cho, M.-H. (2007). Antimicrobial effects of silver nanoparticles. Nanomedicine: *Nanotechnology, Biology & Medicine*, 3(1), 95–101.

Kinnersley, R. P. & Scott, L. K. (2001). Aerial contamination of fruit through wet deposition and particulate dry deposition. *Journal of Environmental Radioactivity*, *52*(2), 191-213.

Klaine, S. J., Alvarez, P. J., Batley, G. E., Fernandes, T. F., Handy, R. D., Lyon, D. Y. & Lead, J. R. (2008). Nanomaterials in the environment: behavior, fate, bioavailability, and effects. *Environmental Toxicology & Chemistry*, *27*(9), 1825-1851.

Kloepper, J. W. (1980). Effects of Rhizosphere Colonization by Plant Growth-Promoting Rhizobacteria on Potato Plant Development and Yield. *Phytopathology*, 70(11), 1078.

Kool, P. L., Ortiz, M. D. & van Gestel, C. A. (2011). Chronic toxicity of ZnO nanoparticles, non-nano ZnO and ZnCl 2 to Folsomia candida (Collembola) in relation to bioavailability in soil. *Environmental Pollution*, 159(10), 2713-2719.

Kooshan, M (2015) *Molecular and biochemical characterization of phosphate-solubilizing Pseudomonas sp. isolated from oil palm soil.* Master thesis, Universiti Putra Malaysia.

Korcak, R. F. & Fanning, D. S. (1985). Availability of applied heavy metals as a function of type of soil material and metal source. *Soil Science*, *140*(1), 23-34.

Kouvaris, P., Delimitis, A., Zaspalis, V., Papadopoulos, D., Tsipas, S. A. & Michailidis, N. (2012). Green synthesis and characterization of silver nanoparticles produced using *Arbutus unedo* leaf extract. *Materials Letters*, *76*, 18-20.

Kretzschmar, R., Robarge, W. P. & Amoozegar, A. (1995). Influence of natural organic matter on colloid transport through saprolite. *Water Resources Research*, *31*(3), 435-445.

Krutyakov, Y. A., Kudrinskiy, A. A., Olenin, A. Y. & Lisichkin, G. V. (2008). Synthesis and properties of silver nanoparticles: advances and prospects. *Russian Chemical Reviews*, *77*(3), 233-257.

Kuan, K. B. (2015). Plant growth-promoting rhizobacteria inoculation to enhance vegetative growth, nitrogen fixation and nitrogen remobilisation and plant growth promotion in maize (*Zea Mays*.L). Master thesis, Universiti Putra Malaysia.

Kurepa, J., Paunesku, T., Vogt, S., Arora, H., Rabatic, B. M., Lu, J., Wanzer, B., Woloschak, G.E. & Smalle, J. A. (2010). Uptake and distribution of ultra-small anatase TiO2 Alizarin red S nano conjugates in *Arabidopsis thaliana*. *Nano letters*, *10*(7), 2296-2302.

Lee, G., & Kim, B. S. (2014). Biological reduction of graphene oxide using plant leaf extracts. *Biotechnology Progress*, 30(2), 463-469.

Lee, P.C. & Meisel, D. (1982). Adsorption and surface-enhanced Raman of dyes on silver and gold sols. *Journal of Physical Chemistry* 86, 3391 – 3395.

Lee, W. M., Kwak, J. I. & An, Y. J. (2012). Effect of silver nanoparticles in crop plants *Phaseolus radiatus* and *Sorghum bicolor:* media effect on phytotoxicity. *Chemosphere*, *86*(5), 491-499.

Lei, Z., Mingyu, S., Xiao, W., Chao, L., Chunxiang, Q., Liang, C. & Fashui, H. (2008). Antioxidant stress is promoted by nano-anatase in spinach chloroplasts under UV-B radiation. *Biological Trace Element Research*, *121*(1), 69-79.

Levard, C., Hotze, E. M., Lowry, G. V. & Brown Jr, G. E. (2012). Environmental transformations of silver nanoparticles: impact on stability and toxicity. *Environmental Science & Technology*, 46(13), 6900-6914.

Lin, D. & Xing, B. (2007). Phytotoxicity of nanoparticles: inhibition of seed germination and root growth. *Environmental Pollution*, *150*(2), 243-250.

Lin, D. & Xing, B. (2008). Root uptake and phytotoxicity of ZnO nanoparticles. *Environmental Science & Technology*, *42*(15), 5580-5585.

Lin, S., Reppert, J., Hu, Q., Hudson, J. S., Reid, M. L., Ratnikova, T. A. & Ke, P. C. (2009). Uptake, translocation, and transmission of carbon nanomaterials in rice plants. *Small*, *5*(10), 1128-1132.

Lippard, S. J. & Berg, J. M. (1994). *Principles of bioinorganic chemistry*. University Science Books, Mill Valley, California.

Liu, J. & Hurt, R. H. (2010). Ion release kinetics and particle persistence in aqueous nano-silver colloids. *Environmental Science & Technology*, *44*(6), 2169-2175.

Liu, J., Pennell, K. G. & Hurt, R. H. (2011). Kinetics and mechanisms of nano silver oxysulfidation. *Environmental Science & Technology*, *45*(17), 7345-7353.

Liu. Q, Chen. B, Wang .Q, Shi. X, Xiao. Z, Liu. J. & Fang .X. (2009).carbon nanotubes as molecular transporters for walled plant cell. *Nano Letter*, 9, 1007-1010.

Lkhagvajav, N. I., Yasa, E., Celik, M. & Koizhaiganova, O. S. (2011). Antimicrobial activity of colloidal silver nanoparticles prepared by Sol-Gel method. *Journal of Nanomaterials &Biostructures*, 6(1), 149-54.

Loke, W. (2011). Effect of Chromobacterium Violaceum and Quorum Sensing on the Growth of Green Bean (*Vigna Radiata*) and Plant Growth Promoting Rhizobacteria (PGPR).Master thesis, Universiti Putra Malaysia.

Lombi, E., Donner, E., Taheri, S., Tavakkoli, E., Jämting, Å.K., McClure, S., Naidu, R., Miller, B.W., Scheckel, K.G. & Vasilev, K. (2013). Transformation of four silver/silver chloride nanoparticles during anaerobic treatment of wastewater and post-processing of sewage sludge. *Environmental Pollution*, 176, 193-197.

Lowry, G. V., Gregory, K. B., Apte, S. C. & Lead, J. R. (2012). Transformations of nanomaterials in the environment. *Environmental Science & Technology*, 46(13), 6893-6899.

Lu, C.M., Zhang, C.Y., Wen, J.Q., Wu, G. R., Tao, M.X. (2002). Research of effect of nanometer materials on germination and growth enhancement of glycine max and its mechanism. *Soybean Science*, 21, 168-172.

Ma, X., Geiser-Lee, J., Deng, Y. & Kolmakov, A. (2010). Interactions between engineered nanoparticles (ENPs) and plants: phytotoxicity, uptake and accumulation. *Science of the Total Environment*, *408*(16), 3053-3061.

Mahajan, P., Dhoke, S. K. & Khanna, A. S. (2011). Effect of nano-ZnO particle suspension on growth of mung (*Vigna radiata*) and gram (*Cicer arietinum*) seedlings using plant agar method. *Journal of Nanotechnology*, 2011, 7-12.

Mahakham, W., Sarmah, A. K., Maensiri, S. & Theerakulpisut, P. (2017). Nanopriming technology for enhancing germination and starch metabolism of aged rice seeds using phytosynthesized silver nanoparticles. *Scientific Reports*, *7*(1), 8263.

Manolopoulos, H. (1997). Silver mobility in the presence of iron sulfids and oxidizing condition, the 5th international conference proceeding: transport, fate and effect of silver in environment, University of Wisconsin, Wisconsin.

Marambio-Jones, C. & Hoek, E. M. (2010). A review of the antibacterial effects of silver nanomaterials and potential implications for human health and the environment. *Journal of Nanoparticle Research*, *12*(5), 1531-1551.

McCauley, A., Jones, C. & Jacobsen, J. (2005). Basic soil properties.*Montana State Univ. Ext. Serv., Bozeman*.

McGrath, S. P. & Zhao, F. J. (2003). Phytoextraction of metals and metalloids from contaminated soils. *Current Opinion in Biotechnology*, *14*(3), 277-282.

Mckenzie, B. M., Mullins, C. E., Tisdall, J. M. & Bengough, A. (2013). Root–soil friction: quantification provides evidence for measurable benefits for manipulation of root-tip traits. *Plant, Cell & Environment*, *36*(6), 1085-1092.

McLean, J. E. & Bledsoe, B. E. (1996). Behavior of Metals in Soils1. EPA/540/S-92/018 October 1992.

McNear Jr, D. H. (2013). The rhizosphere-roots, soil and everything in between. *Nature Education Knowledge*, *4*(3), 1-20.

Mehlich, A. (1978). New extractant for soil test evaluation of phosphorus, potassium, magnesium, calcium, sodium, manganese and zinc 1. *Communications in Soil Science & Plant Analysis*, *9*(6), 477-492.

Menno. L.W. & Koole. H.L. (2011). New strategies in the development of antimicrobial coatings: The example of increasing usage of silver and silver nanoparticles. *Journal of Polymers*, (3), 340-366.

Mishra. V. K. & Kumar. A (2009). Impact of Metal Nanoparticles on the Plant Growth Promoting Rhizobacteria. *Journal of Nanomaterials & Biostructures*, 3(4), 587-592.

Monica, R. C. & Cremonini, R. (2009). Nanoparticles and higher plants. *Caryologia*, *62*(2), 161-165.

Moore, M. N. (2006). Do nanoparticles present ecotoxicological risks for the health of the aquatic environment? *Environment International*, *32*(8), 967-976.

Moorman, T. B., Jayachandran, K. & Reungsang, A. (2001). Adsorption and desorption of atrazine in soils and subsurface sediments. *Soil Science*, *166* (12), 921-929.

Nair, R., Varghese, S. H., Nair, B. G., Maekawa, T., Yoshida, Y. & Kumar, D. S. (2010). Nanoparticulate material delivery to plants. *Plant Science*, 179 (3), 154-163.

Nano Health Solutions, 2010. http://www.fulvic.org/html/nano_silver.html.

Navarro, E., Baun, A., Behra, R., Hartmann, N. B., Filser, J., Miao, A. J. & Sigg, L. (2008). Environmental behavior and ecotoxicity of engineered nanoparticles to algae, plants, and fungi. *Ecotoxicology*, 17(5), 372-386.

Neal, A.L. (2008). What can be inferred from bacterium-nanoparticle interaction about the potential consequences of environmental exposure to nanoparticles? *Ecotoxicology*, 17(5), 362-370.

Neethirajan, S. & Jayas, D. S. (2011). Nanotechnology for the food and bioprocessing industries. *Food & Bioprocess Technology*, *4*(1), 39-47.

Nejatzadeh-Barandozi, F., Darvishzadeh, F. & Aminkhani, A. (2014). Effect of nano silver and silver nitrate on seed yield of (*Ocimum basilicum* L.). *Organic & Medicinal Chemistry Letters*, 4(1), 11-15.

Nia, J. (2009). Inventor (19 March). Nano silver for preservation and treatment of diseases in agriculture field. U.S. patent 2009/0075818 A1.

Niederberger, M. (2007). Nonaqueous sol–gel routes to metal oxide nanoparticles. *Accounts of Chemical Research*, 40(9), 793-800.

Noack, A. G., Grant, C. D. & Chittleborough, D. J. (2000). Colloid movement through stable soils of low cation-exchange capacity. *Environmental Science & Technology*, 34(12), 2490-2497.

Nowack, B. & Bucheli, T. D. (2007). Occurrence, behavior and effects of nanoparticles in the environment. *Environmental Pollution*, 150(1), 5-22.

Nyberg, L., Turco, R. F. & Nies, L. (2008). Assessing the impact of nanomaterials on anaerobic microbial communities. *Environmental Science & Technology*, 42(6), 1938-1943.

Oberdörster, G., Sharp, Z., Atudorei, V., Elder, A., Gelein, R., Kreyling, W. & Cox, C. (2004). Translocation of inhaled ultrafine particles to the brain. *Journal of Inhalation Toxicology*, 16(7), 437-445.

Odum, L. M. (2007). Effect of silver nanoparticles on tomato plant and development of a plant monitoring system. Master thesis. Aubun University.

Olchowik, J., Bzdyk, R., Studnicki, M., Bederska, M., Urban, A., Aleksandrowicz, M. (2017). The effect of silver and copper nanoparticles on the condition of English Oak (*Quercus robur* L.) seedlings in a container nursery experiment. *Forests*, 8(9), 310.

Pal, S., Tak, Y. K. & Song, J. M. (2007). Does the antibacterial activity of silver nanoparticles depend on the shape of the nanoparticle? A study of the gram-negative bacterium Escherichia coli. *Applied & Environmental Microbiology*, 73(6), 1712-1720.

Pan, B. & Xing, B. (2010). Chapter three-manufactured nanoparticles and their sorption of organic chemicals. *Advances in Agronomy*, 108, 137-181.

Pan, B. & Xing, B. (2012). Applications and implications of manufactured nanoparticles in soils: a review. *European Journal of Soil Science*, 63(4), 437-456.

Panyala, N.R., Eladia, M.P.M. & Havel, J. (2008). Silver or silver nanoparticles: A hazardous threat to the environment and human health? *Journal of Applied Biomedicine*, (6), 117-129.

Paramananthan, S. (2000). Soils of Malaysia: Their Characteristics and Identification*, 1*. Academy of Sciences Malaysia.

Parata, P., Choudhury, S.R., Mandel, S., Basu, A., Goswami, A., Gogoi, R., Srivastava, C., Kumar, R. & Gopal, M. (2013). Effect of sulfur and ZnO nano particles on stress physiology and plant (*Vigna radiata*) nutrition. *Journal of Advanced Nanomaterial & Nano Technology*, 143, 301-309.

Parfitt, G. D. & Smith, A. L. (1963). Conductance of silver, potassium and lithium nitrates in ethanol-water mixtures. *Transactions of the Faraday Society*, 59, 257-267.

Petosa, A. R., Jaisi, D. P., Quevedo, I. R., Elimelech, M. & Tufenkji, N. (2010). Aggregation and deposition of engineered nanomaterials in aquatic environments: role of physicochemical interactions. *Environmental Science & Technology*, 44(17), 6532-6549.

Phenrat, T., Kim, H. J., Fagerlund, F., Illangasekare, T., Tilton, R. D. & Lowry, G. V. (2009). Particle size distribution, concentration, and magnetic attraction affect transport of polymer-modified Fe0 nanoparticles in sand columns. *Environmental Science & Technology*, 43(13), 5079-5085.

Piper, C.S. (1942). Soil and plant analysis. A laboratory manual of methods for the examination of soils and the determination of the inorganic constituents of plants. A monograph from Waite Agric. Res. Inst. Adelaide: University of Adelaide press.

Prabhu, S. & Poulose, E. K. (2012). Silver nanoparticles: mechanism of antimicrobial action, synthesis, medical applications, and toxicity effects. *International Nano Letters*, *2*(1), 1-10.

Presley, B. J., Taylor, R. J. & Boothe, P. N. (1990). Trace metals in gulf on Mexico oysters. *Science of the Total Environment*, 97, 551-593.

Price, O. T., Asgharian, B., Miller, F. J., Cassee, F. R. & De Winter-Sorkina, R. (2002). Multiple Path Particle Dosimetry model (MPPD v1. 0): A model for human and rat airway particle dosimetry. *RIVM rapport 650010030*.

Pronk, M. E.J., Wijnhoven, S. W. P., Bleeker, E. A .J. Heugens, E. H. W., Peijnenburg. W.J.G.M., Luttik, R. & Hakkert, B. C. (2009). Nano materials under RESARCH; Nano silver as a case study. RIVM report. Project number M/601780.

Pulit, J., Marcin, B. & Zygmunt, K. (2011). Nano silver-Making difficult decision. *Journal of Ecological Chemistry & Engineering.*18 (2), 186-195.

Qian, H., Pretzer, L. A., Velazquez, J. C., Zhao, Z. & Wong, M. S. (2013). Gold nanoparticles for cleaning contaminated water. *Journal of Chemical Technology & Biotechnology*, 88(5), 735-741.

Racuciu, M. & Creanga, D. E. (2007). TMA-OH coated magnetic nanoparticles internalized in vegetal tissue. *Romanian Journal of Physics*, 52(3/4), 395.

Raffi, M., Hussain, F., Bhatti, T. M., Akhter, J. I., Hameed, A. & Hasan, M. M. (2008). Antibacterial characterization of silver nanoparticles against E. coli ATCC-15224. *Journal of Materials Science & Technology*, 24(2), 192-196.

Raliya, R., Nair, R., Chavalmane, S., Wang, W. N. & Biswas, P. (2015). Mechanistic evaluation of translocation and physiological impact of titanium dioxide and zinc oxide nanoparticles on the tomato (*Solanum lycopersicum* L.) plant. *Metallomics*, 7(12), 1584-1594.

Reeuwijk, L.P. V. (2002). Procedures for soil analysis. Technical paper, sixth edition. International soil reference and information center, ISRIC, Wageningen, Netherlands.

Rezvani, N., Sorooshzadeh, A. & Farhadi, N. (2012). Effect of nano-silver on growth of saffron in flooding stress. *World Academic Science. Engineering. Technology,* 6(1), 517-522.

Rico, C. M., Majumdar, S., Duarte-Gardea, M., Peralta-Videa, J. R. & Gardea-Torresdey, J. L. (2011). Interaction of nanoparticles with edible plants and their possible implications in the food chain. *Journal of Agricultural & Food Chemistry*, 59(8), 3485-3498.

Sahandi, S. M., Sorooshzadeh, A., Rezazadeh, H. S. & Naghdibadi, H. A. (2011). Effect of nanosilver and silver nitrate on seed yield of borage. *Journal of Med Plants Research*, 5, 706-710.

Salama, H. M. (2012). Effect of silver nano particles in some crop plants, common bean (*Phaseolus volgars*) and corn (*Zea mays* .L). *International Research Journal of Biotechnology*, 3(10), 190-197.

Sarkar, S., Jana, A. D., Samanta, S.K. & Mostafa, G. (2007). Facile synthesis of silver nano particles with highly efficient anti-microbial property. *Polyhedren*, 26, 4419-4426.

Savithramma, N., Ankanna, S. & Bhumi, G. (2012). Effect of nanoparticles on seed germination and seedling growth of *Boswellia ovalifoliolata* an endemic and endangered medicinal tree taxon. *Nano Vision*, *2*(1), 61-68.

Scown, T. M., Van Aerle, R. & Tyler, C. R. (2010). Review: do engineered nanoparticles pose a significant threat to the aquatic environment? *Critical Reviews in Toxicology*, 40(7), 653-670.

Senjen, R. (2007). Nano silver- A Threat to Soil, Water and Human Health? Friends of the Earth. (www.nano.Foe.org.au)

Servin, A. D., Castillo-Michel, H., Hernandez-Viezcas, J. A., Diaz, B. C., Peralta-Videa, J. R. & Gardea-Torresdey, J. L. (2012). Synchrotron micro-XRF and micro-XANES confirmation of the uptake and translocation of TiO2 nanoparticles in cucumber (*Cucumis sativus*) plants. *Environmental Science & Technology*, 46(14), 7637-7643.

Shaheen, S. M. (2009). Sorption and lability of cadmium and lead in different soils from Egypt and Greece. *Geoderma*, 153(1-2), 61-68.

Shahrokh, S. & Emtiazi, G. (2009). Toxicity and unusual biological behavior of nano silver on gram positive and negative bacteria assayed by microtiter-plate. *European Journal of Biological Sciences,* 1(3), 28-31.

Shameli, K., Bin Ahmad, M., Jaffar Al-Mulla, E. A., Ibrahim, N. A., Shabanzadeh, P., Rustaiyan, A, Abdollahi, Y., Bagheri .S, Abdolmohammadi, S. M. S. & Usman, Z. M. (2012). Green biosynthesis of silver nanoparticles using *Callicarpa maingayi* stem bark extraction. *Molecules*, 17(7), 8506-8517.

Sharifah. B., Nazirah. A. & Poopak. S. (2011).Nanotechnology in halal industry: a New Frontier in Technology. World Halal Research, 6-7 April 2011. Kl, Malaysia.

Sharon .M, Chudhary .A.K, Kumar. R. (2010). Nano technology in agricultural disease and food safety. *Journal of Phytology*, 2(4), 83-92.

Shin, Y. J., Kwak, J. I. & An, Y. J. (2012). Evidence for the inhibitory effects of silver nanoparticles on the activities of soil exoenzymes. *Chemosphere*, 88(4), 524-529.

Shrivastava, S., Bera, T., Roy, A., Singh, G., Ramachandrarao, P. & Dash, D. (2007). Characterization of enhanced antibacterial effects of novel silver nanoparticles. *Nanotechnology*, 18(22), 225103.

Siddigui, M.H., Al-Whaibi, M.H, Firoz, M., Al-Khaishany, M.Y. (2015). Role of nanoparticles in plants. *Nanotechnology and Plant Sciences*, 19-35.

Siddiqui, M. H., Al-Whaibi, M. H., Firoz, M. & Al-Khaishany, M. Y. (2015). Role of Nanoparticles in Plants. *Nanotechnology and Plant Sciences*. Springer International Publishing, 19-35.

Silver Mining (2010). http://www.infomine.com/commodities/silver.asp.

Simonin, M. & Richaume, A. (2015). Impact of engineered nanoparticles on the activity, abundance, and diversity of soil microbial communities: a review. *Environmental Science & Pollution Research*, 22(18), 13710-13723.

Soltangheisi, A. (2015). Agronomic and Biological Expression of Zinc, Manganese and phosphorus interaction in sweet corn plant (Zea Mays.L). PhD thesis. University Putra Malaysia.

Sondi, I., & Salopek-Sondi, B. (2004). Silver nanoparticles as antimicrobial agent: a case study on E. coli as a model for Gram-negative bacteria. *Journal of Colloid & Interface Science*, 275(1), 177-182.

Sorooshzadeh, A., Hazrati, S., Oraki, H., Govahi, M. & Ramazani, A. (2012). Foliar application of nano-silver influence growth of safforn under flooding stress. In Proceeding of the 4th international conference "*Nanocon,* 2012*,* 510-512*.*

Sotiriou, G. A. & Pratsinis, S. E. (2011). Engineering nano silver as an antibacterial, biosensor and bioimaging material. *Current Opinion in Chemical Engineering*, 1(1), 3–10.

Southgate, D. (2009). Population growth, increases in Agricultural production and trends in food Prices. *Journal of Sustainable Development*, 1(3), 30-35.

Sparks, D.L. (2003). Environmental soil chemistry.2nd edition, Academic press, San Deigo.

Stone, V., Nowack, B., Baun, A., Brink, N., Kammer, F., Dusinska, M., Handy, R., Hankin, S., Hasselov, M., Joner, E. & Fernandes, TF. (2010). Nano materials for environmental studies classification, reference material issue, strategies for physico- chemical characterization. *Journal of Science Total Environment*, 408, 1745-1754.

Sun, T. Y., Gottschalk, F., Hungerbühler, K. & Nowack, B. (2014). Comprehensive probabilistic modelling of environmental emissions of engineered nanomaterials. *Environmental Pollution*, 185, 69-76.

Sweet, M.J., Singleton, I. (2015). Soil contamination with silver nanoparticles reduces bishop pine growth and ecomycorrizhal diversity on pine roots. *Journal of nanoparticles research*, 17(11), 448-451.

Syu, Y. Y., Hung, J. H., Chen, J. C. & Cheuang, H. W. (2014). Impacts of size and shape of silver nano particles on Arabidopsis plant growth and gene expression. *Journal of plant Physiology Biochemistry*, 83, 57-64.

Tan, K.H. (2005). Soil Sampling, Preparation and Analysis, CRC Press.

Tariq, F. S. (2016). Stabilization and remediation of heavy metals in mine tailings using *Vetiveria zizanioodes (*L.) Nash amended with rice husk and iron coated rice husk ash. PhD thesis, Universiti Putra Malaysia.

Teh, C. B. S. & Talib, J. (2006). Soil physics analyses: volume 1. Universiti Putra Malaysia Press.

Theivasanthi, T. & Alagar, M. (2011). Anti-bacterial Studies of Silver Nanoparticles. *ArXiv preprint arXiv: 1101.0348*.

Thio, B. J. R., Zhou, D. & Keller, A. A. (2011). Influence of natural organic matter on the aggregation and deposition of titanium dioxide nanoparticles. *Journal of Hazardous Materials*, 189(1), 556-563.

Torney, F., Trewyn, B. G., Lin, V. S. Y. & Wang, K. (2007). Mesoporous silica nanoparticles deliver DNA and chemicals into plants. *Nature Nanotechnology*, *2*(5), 295-300.

Tourinho, P. S., Van Gestel, C. A., Lofts, S., Svendsen, C., Soares, A. M. & Loureiro, S. (2012). Metal-based nanoparticles in soil: Fate, behavior, and effects on soil invertebrates. *Environmental Toxicology & Chemistry*, 31(8), 1679-1692.

Trop, M., Novak, M., Rodl, S., Hellbom, B., Kroell, W. & Goessler, W. (2006). Silver-coated dressing acticoat caused raised liver enzymes and argyria-like symptoms in burn patient. *Journal of Trauma & Acute Care Surgery*, 60(3), 648-652.

Uzu, G., Sobanska, S., Sarret, G., Munoz, M. & Dumat, C. (2010). Foliar lead uptake by lettuce exposed to atmospheric fallouts. *Environmental Science & Technology*, 44(3), 1036-1042.

Vaidyanathan, R., Kalishwaralal, K., Gopalram, S. & Gurunathan, S. (2009). Retraced: Nano silver—The burgeoning therapeutic molecule and its green synthesis. *Biotechnology Advances*, 27(6), 924-937.

Vandevoort, A. R. R. (2012). *Fate and reactivity of natural and manufactured nanoparticles in soil/water environments,* PhD thesis, Clemson University.

Vervaeke, P., Tack, F. M. G., Lust, N. & Verloo, M. (2004). Short-and longer-term effects of the willow root system on metal extractability in contaminated dredged sediment. *Journal of Environmental Quality*, 33(3), 976-983.

Voegelin, A., Pfister, S., Scheinost, A. C., Marcus, M. A. & Kretzschmar, R. (2005). Changes in zinc speciation in field soil after contamination with zinc oxide. *Environmental Science & Technology*, 39(17), 6616-6623.

Voigt, C. A. (2014). Callose-mediated resistance to pathogenic intruders in plant defense-related papillae. *Frontiers in Plant Science*, 5,168-180.

Wang, D., Song, C., Hu, Z. & Zhou, X. (2005). Synthesis of silver nanoparticles with flake-like shapes. *Materials Letters*, 59(14), 1760-1763.

Wang, Y., Miao, A. J., Luo, J., Wei, Z. B., Zhu, J. J. & Yang, L. Y. (2013). Bioaccumulation of CdTe quantum dots in a freshwater alga *Ochromonas danica*: a kinetics study. *Environmental Science & Technology*, 47(18), 10601-10610.

Wang, Y., Westerhoff, P. & Hristovski, K. D. (2012). Fate and biological effects of silver, titanium dioxide, and C 60 (fullerene) nanomaterials during simulated wastewater treatment processes. *Journal of Hazardous Materials*, 201, 16-22.

Wauchope, R.D., Yeh, S., Linders, J.B.H.J., Kloskowski, R., Tanaka, K., Rubin, B., Katayama, A., Kördel, W., Gerstl, Z., Lane, M. & Unsworth, J.B.(2002). Pesticide soil sorption parameters: theory, measurement, uses, limitations and reliability. *Pest Management Science*, 58(5), 419-445.

Whanger, P. D. (2002). Selenocompounds in plants and animals and their biological significance. *Journal of the American College of Nutrition*, *21*(3), 223-232.

Wickson, F., Nielsen, N.K. & Quist, D. (2011). Nano and the environment: potential risks, real uncertainties and urgent issues. Biosafety Brief, 2011. Centre for Biosafety, Tromso, Norway.

Wiesner, M. R., Lowry, G. V., Jones, K. L., Hochella, Jr, M. F., Di Giulio, R. T., Casman, E. & Bernhardt, E. S. (2009). Decreasing uncertainties in assessing environmental exposure, risk, and ecological implications of nanomaterials. *Environmental Science & Technology*, 43, 6458-6462.

Wijnhoven, S. W., Peijnenburg, W. J., Herberts, C. A., Hagens, W. I., Oomen, A. G., Heugens, E. H., Roszek, B., Bisschops, J., Gosens, I., Van De Meent, D.& Dekkers, S. (2009). Nano-silver–a review of available data and knowledge gaps in human and environmental risk assessment. *Nanotoxicology*, 3(2), 109-138.

Wu, S. G., Tang, Y. J., Huang, L., Head, J., Chen, D. & Kong, I. C. (2012). Phytotoxicity of metal oxide nanoparticles is related to both dissolved metals ions and adsorption of particles on seed surfaces. *Journal of Petroleum & Environmental Biotechnology*, 3(4), 126.

Xia, Y., Xiong, Y., Lim, B. & Skrabalak, S. E. (2009). Shape- Controlled Synthesis of Metal Nanocrystals: Simple Chemistry Meets Complex Physics? *Angewandte Chemie International Edition*, *48*(1), 60-103.

Xu, R., Wang, D., Zhang, J. & Li, Y. (2006). Shape-dependent catalytic activity of silver nano particles for the oxidation of styrene. *Chemistry–An Asian Journal*, 1(6), 888-893.

Yang, F., Hong, F., You, W., Liu, C., Gao, F., Wu, C. & Yang, P. (2006). Influence of nano-anatase TiO 2 on the nitrogen metabolism of growing spinach. *Biological Trace Element Research*, 110(2), 179-190.

Zakry, F. A. (2013). *In vitro* and in silico investigation of the plant growth-promoting rhizobacteria from pepper *(Piper nigrum* L*.).*PhD thesis, Universiti Putra Malaysia.

Zarei, M., Jamnejad, A. & Khajehali, E. (2014). Antibacterial effect of silver nanoparticles against four foodborne pathogens. *Jundishapur Journal of Microbiology*, 7(1).

Zhang, W. X. (2003). Nanoscale iron particles for environmental remediation: an overview. *Journal of Nanoparticle Research*, 5(3-4), 323-332

Zhao, L., Peralta-Videa, J.R., Varela-Ramirez, A., Castillo-Michel, H., Li, C., Zhang, J., Aguilera, R.J., Keller, A.A. & Gardea-Torresdey, J.L. (2012). Effect of surface coating and organic matter on the uptake of CeO 2

NPs by corn plants grown in soil: insight into the uptake mechanism. *Journal of Hazardous Materials*, 225,131-138.

Zheng, L., Hong, F., Lu, S. & Liu, C. (2005). Effect of nano-TiO2 on strength of naturally aged seeds and growth of spinach. *Biological Trace Element Research*, 104(1), 83-91.

Zhu, H., Han, J., Xiao, J. Q. & Jin, Y. (2008). Uptake, translocation, and accumulation of manufactured iron oxide nanoparticles by pumpkin plants. *Journal of Environmental Monitoring*, 10(6), 713-717.