Review Article

Nanomaterials Used As A Plants Growth Enhancer: An Update

Syed Salman Abbas[1], Mohd Haneef*[1], Mohtashim Lohani[2], Heena Tabassum[1], Ahamad Faiz Khan[1]

1. Department of Bioengineering, Integral University, Lucknow-226026, India.
2. Department of Biosciences, Integral University, Lucknow-226026, India.

ABSTRACT

Across the world, a heavenly use of chemical fertilizer is major environmental issue in agricultural fields for sustainable growth of plants. Hence, the chemical fertilizers show adverse environmental effects in human life along with degrade the quality of soil fertility and polluting the water. So there is a need to develop an alternative approach to minimize the high consumption of chemical fertilizers. Now nanotechnology is an alternate approach, touching nearly all aspect of modern life of human welfare as well as plants growth. In the various fields of sciences, nanotechnology based devices are frequently used for the sustainable development of agriculture, clinical medicine, environmental cleaning, food processing, targeted drug delivery and enhancer of plant growth with safe and successful by different ways. However, use of nanomaterials in agriculture field especially for plant protection and production, is an under-explored area in the research community. This review summarizes the utility the known nanomaterials in plant growth from seeds to complete plant in agricultural production. This review also highlights the key role of mode of action of nanoparticles/nanomaterials in plants growth enhancer. The appropriate elucidation of physiochemical, biological and molecular mechanistic approach of nanoparticles in plant leads to better growth in plant with safe and eco-friendly agriculture.

Keywords: Nanoparticles, nanotechnology, nanomaterials, plant growth enhancer

Received 13 May 2016 Received in revised form 8 June 2016 Accepted 10 June 2016

***Address for correspondence:**
Mohd Haneef,
Department of Bioengineering, Integral University, Lucknow-226026, India.
E-mail: haneef@iul.ac.in

INTRODUCTION

Nanotechnology is an effective tool in the field of productive science, utilization of agricultural food waste into bio energy, development of chemical biosensors, purification of water, and development of plant growth [1, 2]. In Indian agriculture plant growth is mainly depend on by using maximum chemical fertilizers but they show adverse effecting quality of soil in terms of leaching, hydrolysis, and decomposition of organic compounds. It is necessary to minimize nutrient losses in soil, and to increase the yield by the utilization of new applications of nanotechnology and nanomaterials. Nanomaterials have single physicochemical properties and the potential to improve the plant metabolism. According to Galbraith (2007) and Torney et al. (2007) engineered nanomaterials are capable in easy transfer into leaves, DNA part and other biomolecules into plant cells. The appearance of nanomaterials has seen expanded generation as of late, and its cooperation with living beings is a significant reason for concern [3].

The engineered nanoparticles (ENPs) have been generally used in various fields of science like bio-engineering, electronics, textile, chemical industry, development of ecofriendly environment, drug delivery system in military equipment. The unique properties of ENPs can be described as large surface area, high surface energy, and efficient quantum confinement. Along with Merits and demerits of ENPs connected to environmental consequences with biological impacts. When nanoparticles exposed into the environment, ENPs may alter mobility through physical, biochemical, and biological transformations, in that way self-importance a hazard to ecological species [4, 5]. In case of phytotoxicity, a number of studies have paying attention on terrestrial plant species showing to MWNTs (Multi walled nanotubes), but no multigenerational life-cycle studies show in the literature, representing the need for wide-ranging study of relations between carbon nanoparticles and terrestrial plants, the interaction between MWNTs (Multi walled nanotubes) and the vegetable/commercial crops, red spinach, lettuce, rice, cucumber, chili, lady's finger, and soybean, focusing on root and shoot growth and cell death at the seedling stage. The most sensitive plant species were then used in phytotoxicity studies in the presence of MWNTs. *T. foenum-graecum* (Fenugreek) belongs to the family Leguminosae that grows predominantly in Asia, Northern Africa and the Middle East. Fenugreek seed contains 23% - 26% protein, 6% - 7% fat and 58% carbohydrates of which 25% is dietary fiber, saponins and rich in flavonoids. Fenugreek has been widely used as a flavoring agent and in folk medicine. Several beneficial effects, such as appetite stimulation, anti-inflammatory, anti-pyretic, antimicrobial, antioxidant, antidiabetic, anticancer and antiatherogenic properties have been reported. C. cyminum, an aromatic plant from the family Umbelliferae is used as a flavoring and seasoning agent in foods [6]. To our knowledge no studies have been carried out to find out, whether seeds of *T. foenum-graecum and C. cyminum* can serve as water coagulant. Hence, this study was ventured to investigate the applicability of natural coagulants extracted from seeds of above plants that are abundantly available in Asia.

- **Nanomaterials:**

Generally, nanomaterials refer to a colloidal particulate system, with size ranging from 1 to 100 nm, possessing unique properties such as high surface-to-volume ratio and promising optical behaviors [7, 8]. The main categories of nanomaterials are carbonaceous [9], semiconductor, metal oxides [10, 11], lipids [12], zero-valent metals [13], quantum dots, nanopolymers [14], and dendimers [15], with different kinds of features including nanofibers, nanowires and nanosheets. A direct and synthetic route that yields nanoparticles in the nanosize range followed by the application of grinding or milling, high pressure homogenization and sonication to decrease its size [16, 17]. The bottom-up process in synthesizing nanomaterials involved reactive precipitation and solvent displacements [18]. It is very important to realize that the drawback of nanomaterials due to their improved contact surface area might be toxic, as result in an open agricultural ecosystem.

Table 1: Classification of Nanomaterials

Sr. No.	Classes of Nanomaterials	Explanation of Nanoparticles	References
1	Nanoparticles	Nanoparticles are commonly accepted as materials with at least two dimensions between 1-1000 nm	(Ball P.,2002)
2	Nanotubes and nanofibers	A fibers of less than 1μm in size. Nanometer size long linear material, optical materials micro conductors, microfibers, nanotubes of PEEK, PET, and PTFE	(R. H. Baughman., 2002)
3	Nanofilm	Nanofilms utilized as gas catalyst materials	(N. A. Malvadkar., 2010)
4	Nanoblock	Nanometer crystalline product produced by substantial accuracy, developing controlled crystallization or Nanoparticles	(L. Kong., 2009.)
5	Nanocomposites	Composite nanomatererials, which use nanosize reinforcements instead of conventional fibers or particulates	(P, Podsiadlo, 2007)
6	Nanocrystalline solids	Polycrystals with the size of 1 to 10nm and 50% or more of solid consists of inherent interface between crystals and different orientations. The clusters that formed through homogenous nucleation and grow by coalescence and incorporation of atoms	(Y. Vasquez, 2008)

- **Engineered Nanomaterials:**

The engineered nanomaterials are metal containing materials, such as various metal oxides. The production of metal oxides and metal nanoparticles could be achieved via several routes. Bulk materials are to be grinded is the usual practice for synthesizing metal oxide nanoparticles [19]. They are various range of nanoparticulate metal oxides includes both individual (CeO_2, TiO_2, ZnO, CrO_2, MoO_3, and Bi_2O_3) and binary oxides ($BaTiO_2$, $LiCoO_2$, and in SnO).This series of metal oxide having an industrial applications like ultraviolet blocking ability and visible transparency of nanoparticle foam, ZnO and TiO2 are extensively being used in cosmetics, suncream and bottle coatings [20]. It was reported in 2005–2010, the production of ZnO and TiO_2 for exclusively of skin care products [21]. While, CeO_2 utilization in combustion catalyst in diesel fuels to enhance emission quality, as well as in oxygen pumps, gas sensor, solar cells, and metallurgical ceramic/gas applications [22].

IMPACTS OF NANOMATERIALS IN PLANTS SYSTEM:

Nanomaterial exposes in plant system via multiple routes, such as incidental discharge from industry outlet in sewer-to-wastewater treatment plants [23, 24]. In bio-solids from waste water treatment fields, pesticides applied to agricultural, paints, fabrics, personal health care, and accidental drop of materials during manufacturing consumer products, and straight infiltration [25]. When nanomaterials certain release from diesel emission, waste water arrive at agriculture land have the great potential to pollute soil, fertility transfer into surface/ground water, and interact with normal biota. Further these nanoparticles can also be transported to an aquatic system by rainwater bodies aggregation may lead to its buoyancy's increment leaching.

ROLE OF ENGINEERED NANOMATERIALS IN PLANT GROWTH BY VARIOUS WAYS-

- **Carbon Based Engineered Nanomaterials:**

A large production of carbon-based nanomaterials has led to its potential discharge in living systems, either intentionally, accident in spillages, and showing more potential of the adverse environmental effects [26]. Among carbon-based nanomaterials, the most studied materials are fullerene C70, fullerol (C60(OH)20), and carbon nanotubes. Generally carbon-based nanomaterials are measured highly hydrophobic with the propensity to aggregate, and expected to settle in the living system [27].

- **Fullerene: On Plant Growth**

The fullerene in the form of black aggregates is more plentiful in seeds and roots growth as compared to the leaves and stems of rice seeds [28]. While in mature plants, healthy translocation from the roots to aerial part of plant has become reported. Thus, fullerene aggregates was mostly present in or near the stems vascular system and leaves, whereby the roots have been devoid of fullerene [29]. The aggregation of fullerene in leaves also indicates that route of nutrients and water through the xylem [30]. It is reported that individual fullerene nanoparticles entered into the plant roots through osmotic pressure, capillary forces, and pores in the cell walls by the intercellular plasmodesmata, or by means of the very much regulated symplastic routes [31, 32]. Only the fullerene particles with a diameter of a smaller amount than the pore diameter of the cell wall could simply pass and reach to the plasma membrane.

- **Multi Walled Carbon Nanotubes (MWCNTs): On Plant Growth:**

The Multi walled carbon nanotubes (MWCNTs) are 1mm long and 20 nm in diameter [33-36]. And use by the seeds and roots system via the formation of new pores and water uptake in order to build up tomato seedlings [37, 38]. Also on the root surface visualized before finally shooting the epidermal and root hair cell walls and cap of the seedlings [39]. It is also reported that MWCNTs permeate tomato seeds and enhance the germination rate by improving the seed water uptake. The MWCNTs elevated the germination of seed to up to 90% in 20 days compared to 71% in the control sample and the plants' biomass [40].

- **Single Walled Carbon Nanotube (SWCNTs): On Plant Growth**
The dimension of single walled carbon

nanotube (SWCNTs) is about 1 to 2 nm in diameter and 0.1 μm in length. water column stability in cucumber seedling after handling for 84 h the SWCNTs were found adhere to the external surface of the main and secondary roots [41,42]. However, current outcome are lacking to determine the translocation of SWCNTs from the root systems to the aerial parts of the plant [43].

- **Titanium oxide (TiO_2): On Plant Growth:**

The titanium oxide Nanoparticles (TiO_2) are extensively utilized in daily life products, but the research of their uptake and translocation in the plant is limited, particularly on food crops [44-46]. Tio_2 size (<5nm), TiO2, tend to form a covalent bond with most of the no-conjugate ordinary organic matter, translocate, and following the tissue and cells' [45-47]. TiO_2 nanoparticles with nitrate exposed in Soybean (Glycine max), enhance the ability to absorb/use water, and excite the antioxidant system. For example, TiO_2 nanoparticles resulant plants show 73% more dry weight, three times higher photosynthetic rates, and 45% chlorophyll improvement as compared to the control over the germination period of 30 days. Some studies claimed that the TiO_2 nanoparticles ow high potential in absorption of inorganic nutrients, accelerated the breakdown of organic substances, quenching by oxygen free radicals formed during the photosynthetic process, consequently improving the photosynthetic rate [48, 49]. It is reported that toxicity of TiO_2 nano particles low.due to particle agglomeration and subsequent sedimentation. The toxic effect of TiO_2 nano particles is possibly not attributed by the released Ti_2+ ions from particles that are uncertainly proved by the limited dissolution of Ti from a TiO_2 sample [50]. Genomic DNA quantification was detect in the root tips of cucumber after seven days and indicated that plants treated with 2000–4000mgL−1 of TiO_2 nano particles reduced the genomic DNA compare to the control sample [51, 52].

PHYTOTOXICITY TEST:

TEM observation:

The samples of nano particle were prepared by protocol used at RSIC, Shilling (Model-JEOL JSM 100 CX). and fixed in 1% glutaraldehde than washed in 0.1 M buffer, 1% Osmium tetraoxide was used for post-fixations and again washed with 0.1 M buffer. At least prepared samples were dehydrated in acetone, infiltrated and finally fixed in epoxy resin. There observe in TEM Result of nanoparticles lying on T. foenum-graecum roots at the finish of Phytotoxicity period was calculated by TEM analysis.

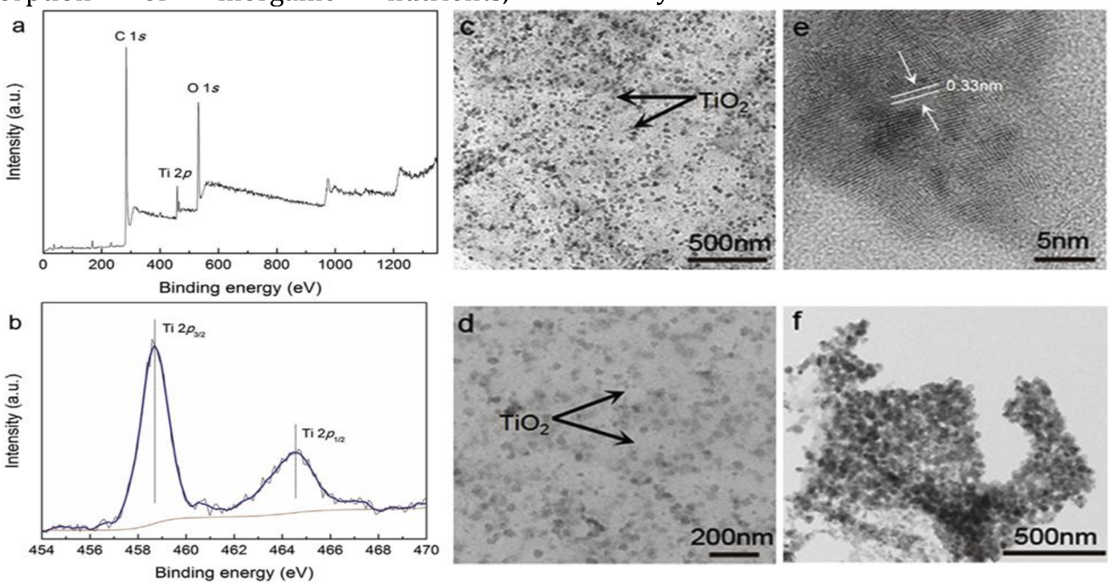

Figure 1: Characterizations for G-TiO_2: (a) wide-survey XPS spectrum of the TiO_2 nanocomposites; (b) Ti 2p XPS spectrum; (c) and (d), TEM images of G-TiO_2 nanocomposites; (e) HRTEM image of the composites. The right inset is an electron diffraction of the denoted rectangular area. (f) TEM images of TiO_2 nanoparticles. [53]

SEM observation:

SEM analysis was conducted using FESEM Model Supra 55VP (Zees, Germany). When nanoparticles of different sizes were found inside the cell however regular size of 25 nm was mostly recorded. These small particles had caused adverse result on damage to outer and inside portions of cells. There may be penetrations of particles by breaking the cell walls. SEM analysis was conducted after 42 days of exposure. The resultant of scanning electron microscope (SEM) analysis objective is to find the impact of nanomaterials on tissue of roots, stems and leaves of the plant.

CONCLUSION

There is no any doubt, nanotechnology is an evolutionary science and has introduced many novel applications in the field of science. This work evidences that certain nanomaterials could employ chemical or physical toxicity on plants depending on its particulate size, chemical composition, energy, and species, leading to different techniques. An extensive research on the toxic effects of nanomaterials could help by exploiting and disposing nonmaterial for the reduction the adverse effects in both of agricultural development and of environmental systems.

ACKNOWLEDGEMENT

The author is thankful to Integral University, Lucknow for providing the necessary facilities.

REFERENCES

1. Carmen IU, Chithra P, Huang Q, Takhistov P, Liu S, Kokini JL: Nanotechnology: a new frontier in food science, Food Technol 2003, 57:24–29.
2. Nair R, Varghese SH, Nair BG, Maekawa T, Yoshida Y, Kumar DS: Nanoparticulate material delivery to plants. Plant Sci 2010, 179:154–163.
3. Zhang L, Fang M, "Nanomaterials in pollution trace detection and environmental improvement: Nano Today, 2010, vol. 5, no. 2, pp. 128–142.
4. Oberdörster G, Oberdörster E, Oberdörster J, Nanotoxicology: An emerging discipline evolving from studies of ultrafineparticles: Environ Health Perspect 2005, 113:823–839.
5. Maynard AD, Aitken RJ, Butz T, Colvin V, Donaldson K, Oberdörster G, Philbert MA, Ryan J, Seaton A, Stone V, et al: Safe handling of nanotechnology 2006, Nature 444:267–269.
6. Lu, F.R., Shen, L, Qin Y, et al. Clinical observation on Trigonella foenum-graecum L. Total Saponins In Combination With Sulfonylureas In The Treatment Of Type 2 Diabetes Mellitus: Chinese Journal of Integrative Medicine 2008, 14, 56-60.
7. V Dutschk, Karapantsios T, Liggieri L, McMillan N, Miller R, and. Starov VM, "Smart and green interfaces: from single bubbles/drops to industrial environmental and biomedical applications," Advances in Colloid and Interface Science 2014, vol. 209, pp. 109–126.
8. Al-Halafi AM, "Nanocarriers of nanotechnology in retinal diseases: Saudi Journal of Ophthalmology 2014.
9. Baughman RH, Zakhidov AA, and W. A. de Heer, "Carbon nanotubes—the route toward application. Science 2002, vol. 297, no. 5582, pp. 787–792.
10. Lang X, Hirata A, Fujita T, Chen M, "Nanoporous Metal/Oxide Hybrid Electrodes For Electrochemical Supercapacitors," Nature Nanotechnology 2011, vol. 6, no. 4, pp. 232–236.
11. Rizzello L, Pompa PP, "Nanosilver-based antibacterial drugs and devices: mechanisms, methodological drawbacks, and guidelines," Chemical Society Reviews 2014, vol. 43, no. 5, pp. 1501–1518.
12. Yang K, Ma Y, "Computer simulation of the translocation of nanoparticles with different shapes across a lipid bilayer," Nature Nanotechnology 2010, vol. 5, no. 8, pp. 579–583,
13. Diao M, and Yao M, "Use of zero-valent iron nanoparticles in inactivating microbes," Water Research 2009, vol. 43 No. 20,pp. 5243–5251.
14. Ljubimova JY, Holler E, "Biocompatible nanopolymers: the next generation of breast cancer treatment?" Nanomedicine 2012, vol. 7, no. 10, pp. 1467–1470.
15. Astruc D, "Electron-transfer processes in dendrimers and their implication in biology, catalysis, sensing and nanotechnology," Nature Chemistry 2012, vol. 4, no. 4, pp. 255–267.
16. Podsiadlo P, Kaushik AK, Arruda EM, et al., "Ultrastrong and stiff layered polymer nanocomposites," Science, 2007, vol. 318, no.5847, pp. 80–83.
17. Vasquez Y, Henkes AE, Bauer JC, Schaak RE, "Nanocrystal conversion chemistry: a unified and materials general strategy for the template-based synthesis of nanocrystalline solids," Journal of Solid State Chemistry 2008, vol. 181, no. 7, pp. 1509–1523.

18.Mehta RJ, Zhang Y, Karthik C, et al., "A new class of doped nanobulk high-figure-of-merit thermoelectrics by scalable bottom-up assembly," Nature Materials 2012, vol. 11, no. 3, pp. 233–240.
19.Alexis DO, Tyronne M, Joseph C, Indy H, Barbara HH, "Nanotoxicology: characterizing the scientific literature, 2000– 2007," Journal ofNanoparticle Research 2009, vol. 11,no. 2, pp. 251–257.
20.Lid´en G, "The European commission tries to define nanomaterials," Annals of Occupational Hygiene 2011, vol. 55, no. 1, pp. 1–5.
21.Nair R, Varghese SH, Nair BG, Maekawa T, Yoshida Y, Kumar D, "Nanoparticulate material delivery to plants," Plant Science2010, vol. 179, no. 3, pp. 154–163.
22.Zhang N, Ring Q, Huang G, Han X, Cheng Y, Xu W, "Transport characteristics of wheat germ agglutinin-modified insulin-liposomes and solid lipid nanoparticles in a perfused rat intestinal model," Journal of Nanoscience and Nanotechnology 2006, vol. 6, no. 9-10, pp. 2959–2966.
23.Grieger KD, Hansen SF, Baun A, "The known unknowns of nanomaterials: describing and characterizing uncertainty within environmental, health and safety risks," Nanotoxicology 2009, vol. 3, no. 3, pp. 222–233.
24.Zhang L, Fang M, "Nanomaterials in pollution trace detection and environmental improvement," Nano Today 2010, vol. 5, no. 2, pp. 128–142.
25.Alexis DO, Tyronne M, Joseph C, Indy H, Barbara HH, "Nanotoxicology: characterizing the scientific literature, 2000– 2007," Journal of Nanoparticle Research 2009, vol. 11,no. 2, pp. 251–257.
26.Baughman RH, Zakhidov AA, de Heer WA, "Carbon nanotubes—the route toward applications," Science, vol. 297 2002, no. 5582, pp. 787–792.
27.R. De La Torre-Roche. Hawthorne J, Deng Y et al., "Multiwalled carbon nanotubes and C60 fullerenes differentially impact the accumulation of weathered pesticides in four agricultural plants," Environmental Science and Technology 2013, vol. 47, no. 21, pp. 12539–12547.
28.Liu Q, Zhang X, Zhao Y et al., "Fullerene-induced increase of glycosyl residue on living plant cell wall," Environmental Science and Technology 2013, vol. 47, no. 13, pp. 7490–7498.
29.Santos SMA, Dinis AM, Rodrigues DMF, Peixoto F, RA. Videira, and A. S. Jurado, "Studies on the toxicity of an aqueous suspension of C60 nanoparticles using a bacterium (gen. Bacillus) and a n aquatic plant (Lemna gibba) as in vitro model systems," Aquatic Toxicology 2013, vol. 142–143, pp. 347–354.
30.De La Torre-Roche R, Hawthorne J, Deng Y et al., "Fullerene enhanced accumulation of p, p-DDE in agricultural crop species," Environmental Science and Technology 2012, vol. 46, no. 17, pp. 9315–9323.
31.Gao J, Wang Y, Folta KM et al., "Polyhydroxy fullerenes (fullerols or fullerenols): beneficial effects on growth and lifespan in diverse biological models," PLoS ONE 2011, vol. 6, no. 5, Article ID e19976.
32.Liu Q, Zhao Y, Wan Y et al., "Study of the inhibitory effect of water-soluble fullerenes on plant growth at the cellular level,"CS Nano 2010, vol. 4, no. 10, pp. 5743–5748.
33.Lin Y, Rao AM, Sadanadan B, Kenik EA, and Sun YP, "Functionalizing multiple-walled carbon nanotubes with aminopolymers," Journal of Physical Chemistry 2002, B, vol. 106, no.6, pp. 1294–1298.
34.Muller J, Huaux , Moreau N et al., "Respiratory toxicity of multi-wall carbon nanotubes," Toxicology and Applied Pharmacology 2005, vol. 207, no. 3, pp. 221–231.
35.Kong H. Gao C, and Yan D, "Controlled functionalization of multiwalled carbon nanotubes by in situ atom transfer radical polymerization," Journal of the American Chemical Society 2004, vol. 126, no. 2, pp. 412–413,.
36.Li HJ, Lu WG, Li JJ, Bai XD, Gu CZ, "Multichannel ballistic transport in multiwall carbon nanotubes," Physical Review Letters 2005, vol. 95, no. 8, Article ID086601.
37.Chekin F, Bagheri S, Arof AK, and. Hamid SBA, "Preparation and characterization of Ni(II)/ and carbon nanotube composite modified electrode and application for carbohydrates electrocatalytic oxidation," Journal of Solid State Electrochemistry 2012, vol. 16, no. 10, pp. 3245–3251.
38.Wang X, Han H, Liu X, Gu X, Chen K, and Lu D, "Multiwalled carbon nanotubes can enhance root elongation of wheat (Triticum aestivum) plants," Journal of Nanoparticle Research 2012, vol. 14, no. 6, article 841.
39.Smirnova E,. Gusev A, Zaytseva O et al, "Uptake and accumulation ofmultiwalled carbon nanotubes change themorphometric and biochemical characteristics of Onobrychis arenaria seedlings," Frontiers of Chemical Science and Engineering 2012, vol. 6,no. 2, pp. 132–138.

40. X.-M. Tan, Fugetsu B, "Multi-walled carbon nanotubes interact with cultured rice cells: evidence of a self-defense response," Journal of Biomedical Nanotechnology 2007, vol. 3, no. 3, pp. 285–288.
41. Lou JC, Jung MJ, Yang HW, Han JY, Huang WH, "Removal of dissolved organic matter (DOM) fromraw water by single-walled carbon nanotubes (SWCNTs)," Journal of Environmental Science and Health—Part A Toxic/Hazardous Substances and Environmental Engineering 2011, vol. 46, no. 12, pp. 1357–1365.
42. Yuan H, Hu S, Huang P et al., "Single walled carbon nanotubes exhibit dual-phase regulation to exposed Arabidopsis mesophyll cells," Nanoscale Research Letters 2011, vol. 6, no. 1,pp. 1–9.
43. Soylak M, and, Unsal YE, "Chromium and iron determinations in food and herbal plant samples by atomic absorption spectrometry after solid phase extraction on single-walled carbon nanotubes (SWCNTs) disk," Food and Chemical Toxicology 2010, vol.48, no. 6, pp. 1511–1515.
44. M. S. Eva, B. Anders, K. Matthias, and T. Stefan, "Insignificant acute toxicity of TiO2 nanoparticles to willow trees," Journal of Soils and Sediments, vol. 9, no. 1, pp. 46–53, 2009.
45. Feizi H, Rezvani Moghaddam P, Shahtahmassebi N, and A. Fotovat, "Impact of bulk and nanosized titaniumdioxide (TiO2) on wheat seed germination and seedling growth," Biological Trace Element Research 2012, vol. 146, no. 1, pp. 101–106.
46. Mingfang Q, Yufeng L, Tianlai L, "Nano-TiO2 improve the photosynthesis of tomato leaves under mild heat stress, biological trace element research," Biological Trace Element Research 2013, vol. 156, no. 1, pp. 323–328.
47. Uhram S, Minjoo S, Gisuk L, Jinkyu R, Younghun K, and Eun JL, "Functional analysis of TiO2 nanoparticle toxicity in three plant species," Biological Trace Element Research 2013, vol. 155, no. 1, pp. 93–103.
48. Zheng L, Hong, Lu S, Liu C, "Effect of nano-TiO2 on strength of naturally aged seeds and growth of spinach,"Biological Trace Element Research 2005, vol. 104, no. 1,pp. 83–91.
49. Yang F, Hong F, You W et al., "Influences of nano-anatase TiO2 on the nitrogen metabolism of growing spinach," Biological Trace Element Research 2006, vol. 110, no. 2, pp. 179–190.
50. Castiglione M, Giorgetti L, Geri C, Cremonini R, "The effects of nano-TiO2 on seed germination, development and mitosis of root tip cells of Vicia narbonensis L. and Zea mays L,"Journal of Nanoparticle Research 2011, vol. 13, no. 6, pp. 2443–2449.
51. Kurepa J, Paunesku T, S. Vogt et al, "Uptake and distribution of ultrasmall anatase TiO2 alizarin red S nanoconjugates in arabidopsis thaliana," Nano Letters 2010, vol. 10,no. 7, pp. 2296–2302.
52. Wang S, Kurepa J, Smalle JA, "Ultra-small TiO2 nanoparticles disrupt microtubular networks in Arabidopsis thaliana," Plant, Cell & Environment 2011, vol. 34, no. 5, pp. 811–820.
53. Zaixing Jiang, Mingqiang Wang, Hao Cheng, Jun Li, Aslan Husnu, Haibao Lv, Yongtao Yao, Lu Shao, Yudong Huang, Mingdong Dong. Facile Preparation of TiO_2 Nanoclusters on Graphene Templates for Photodegradation of Organic Compounds. Journal of Materials Science & Technology 2015, 31(8): 840-844.