

REVIEW GREEN NANOPARTICLES IN CROP PLANTS DISEASE CONTROL

MUHAMMAD HANIF^{*1}, SHEHWAR¹, SAMAR BASHIR¹, ZUBAIRIA ASHRAF¹, RIZWAN AMANAT¹, ATTA UL MUSTAFA ZAIN¹, SHAUKAT ALI² AND SAMINA SARWAR³

¹Department of Botany, GC University, Lahore, Pakistan, ²Department of Zoology, GC University, Lahore, Pakistan, ³Department of Botany, LCW University, Lahore, Pakistan

*Corresponding author's email: dr.mhanif@gcu.edu.pk

Abstract

The primary objective of any scientific development is the enhancement of human well-being. There is a dire need for novel strategies for the achievement of sustainable development by using an eco-friendly approach. Green nanotechnology has been a step toward sustainable development in the 21st century. By utilizing processes of green chemistry and green engineering, green nanotechnology offers a cost-effective and environment-friendly approach. Green nanoparticles especially plant-mediated ones have brought a revolution in almost all fields of human beings. Recently, much attention has been given to employing plant-mediated green nanoparticles in crop plant disease control. Every year, 20 to 40% of food crops are lost due to different diseases and pests attack which is a huge loss to the burgeoning human population thereby leading to food scarcity. Using chemical control techniques results in pest resistance thus further worsening the condition. Therefore, much research is being conducted for use of plant-based green nanoparticles in controlling food crop destruction. This review focuses on the use of plant-mediated green nanoparticles in controlling different crop plant diseases.

Keywords: Green Nanotechnology, Plant-mediated Nanoparticles, Green Nanoparticles, Crop Plants Disease, Disease Management

Nanotechnology

Nanotechnology, a major technology of the 21st century, has fostered a great deal of excitement among scientists. Owing to their size and properties, nanoparticles have gained much popularity in various biological and technological fields. Nanotechnology is an interdisciplinary research area involving chemistry, engineering, biology and medicine and has great potential for designing excellent procedures and products for the sustainable development of the environment and human mankind (Cai et al. 2008). Nanotechnology deals with materials of various types at the nano-scale level. Nanoparticles (nano-scale particles = NSPs) are atomic or molecular aggregates having at least one dimension between 1 and 100 nm (Ball, 2002; Roco, 2003). These particles can modify their physical and chemical properties in contrast to the bulk material (Nel et al., 2006). NPs comprise three layers i.e. (a) the Surface layer, which can be made functional with a variety of small molecules like metal ions (b) the Shell layer, a chemically different material from the core in all aspects, and (c) the Core, the central portion of the nanoparticle that is the NP itself (Shin et al., 2016). In contrast to general materials, nanoparticles comprising the same components have a lot of different characters because of their small size, surface or interface, etc. Nanoparticles have bridged the gap between bulk

material and atomic or molecular structure. Depending upon their morphology, size, and physicochemical properties nanoparticles are divided into four broad categories i.e. Carbon-based NPs, Metal NPs, Semiconductor NPs and Polymeric NPs.

Approaches to nanoparticles synthesis

Several techniques are used for nanoparticle synthesis, all of which are categorized under two broad categories i.e., bottom-up approach and top-down approach. Both these approaches are further divided into different sub-classes based on their reactions, working and protocols. Top-down synthesis uses a destructive approach for nanoparticle synthesis (Mukherjee et al., 2001). It involves the breakdown of larger molecules into smaller ones and then converting them into suitable nanoparticles. Grinding, milling, physical vapor deposition and other decomposition processes are used in a top-down approach. An example of a top-down approach is the synthesis of coconut shell nanoparticles via milling. The bottom-up synthesis also known as the building-up approach involves the synthesis of nanoparticles from simpler substances (Thakkar et al., 2010). Examples of this approach are sedimentation and reduction techniques. Sol-gel, green synthesis and biochemical synthesis of nanoparticles are included in the bottom-up approach. Recently, the micro-

emulsion technique has been established to produce nanoparticles (Eslamian and Shekariz, 2009). Once nanoparticles are synthesized, they are characterized using different techniques. For molecular characterization polarized optical microscopy, SEM and TEM are the most popular techniques used. SEM works on the electron scanning principle that provides all information about NPs at the nanoscale. TEM is based upon the electron transmittance principle that can provide information from low to higher magnification. Structural characterization is of prime importance as it involves the detailed study of the composition and nature of bonding materials. Raman, XRD, EDS, IR, XPS, BET and Zeita are the commonly used techniques for the structural analysis of nanoparticles. Among these XRD is the most important characterization technique for determining the structural properties of nanoparticles. It provides detailed information about particle crystallinity and also gives a rough idea about the size of the particle.

Green Nanotechnology

Recently, the green synthesis of nanoparticles has gained great attention owing to their eco-friendly nature and cost-effectiveness. A dramatic rise in the demand for green nanoparticles has been observed due to the high costs and toxic nature of physical and chemical techniques employed for nanoparticle synthesis. Green synthesis of nanoparticles follows a bottom-up approach and involves oxidation and reduction reactions. It does not require external experimental conditions like high energy and pressure which leads to saving energy. The biological synthesis of nanoparticles using plants, bacterial strains and fungi, etc. epitomizes the green synthesis of nanoparticles. In this synthesis, the reaction takes place in unicellular and multicellular organisms (Prashant et al., 2008).

Plants, the chemical factories of nature, are cost-effective and require little maintenance. They have shown great potential for detoxification and accumulation of heavy metals that can help in overcoming the problem of environmental pollutants. Even traces of these pollutants are toxic. Plant-assisted synthesis of nanoparticles is advantageous due to different reasons. Firstly, it is a simple process that does not require elaborate maintenance. Another advantage of plant-based nanoparticles is that the kinetics of the route employed in this method is amply higher than in other biosynthetic approaches (Nalawade et al., 2012). Due to the presence of phytochemicals in different plant parts especially in

leaves, they are being used for the green synthesis of nanoparticles. These phytochemicals are capable of reducing metal salts into metal nanoparticles. Moreover, plant-mediated biosynthesis of nanoparticles is a rather easier and simple process for the production of nanoparticles on large scale in contrast to bacterial production of NPs. Bacteria-mediated nanoparticle synthesis involves the preservation and identification of microbial cultures which is not only costly but also requires complex actions. Stable nanoparticles are produced via plant-mediated synthesis.

Method for synthesis of plant-mediated nanoparticles

The method for the synthesis of plants mediated nanoparticles is quite simple. The plant biomass used for this purpose can either be in form of extract or powder form (Thakkar et al., 2010). For nanoparticle synthesis, the plant extract is mixed with the desired metal salt solution. The salt solution used is half the quantity of plant extract used. The pH of the mixture is maintained and it is kept overnight at room temperature. Within a short period, nanoparticles are synthesized. The change in color of the solution is the first indicator of nanoparticle synthesis. Later on, this solution is centrifuged so that the nanoparticles settle down. After decanting the supernatant the nanoparticles can be seen at the base of Eppendorf. The properties of nanoparticles are then analyzed using SEM. Their antimicrobial and antifungal activity can also be determined. These nanoparticles can be refrigerated for future use.

A broad variety of metal and non-metal nanoparticles have been produced by using different plants. These nanoparticles possess unique properties and have many applications in different fields of human interest (Marchiol, 2012). For example, silver nanoparticles have been the subject of interest and research for researchers because of their diverse applications in various fields. Silver nanoparticles have been greatly used in the health industry, storage of food, textile coatings and also as an agent for the control of environmental pollution. Due to their antimicrobial activities, these are being used in the medicines and cosmetics industry. As silver nanoparticles also possess anti-cancerous properties thereby it is believed that in the future these nanoparticles could be employed in the treatment of cancer (Narayanan and Sakthivel, 2010). Other nanoparticles too have such applications and are the subject of research. Thus plant-mediated nanoparticle synthesis provides a cheap source and an eco-friendly

approach for the production of these highly useful particles (Dupont et al., 2002).

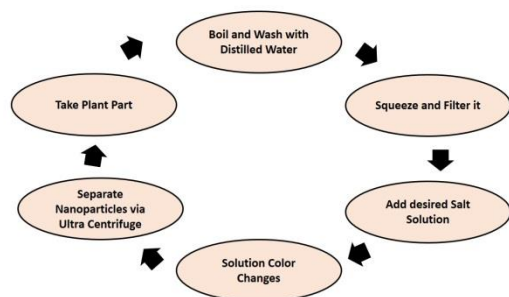


Fig.1 Synthesis of nanoparticles using plant extract

Use of plant-mediated nanoparticles in crops plant disease control

One of the defining challenges of the contemporary world is to keep up with the growing demand for food in the face of climate change and varying growing conditions. Annually 20-40% of food crops are lost due to different diseases and pests attack (Flood, 2010). The loss of staple crops adversely impacts food security and nutrition. Moreover, the threat of plant diseases and pests attack is increased by worsening climatic conditions. Due to these reasons, many types of research are being conducted to utilize plants mediated green nanoparticles in controlling crop plant disease. Several types of research have been carried out for disease management in different crops belonging to the family Poaceae.

Wheat is among the most important staple crop. In 2020 China, India and Russia, the major producers of wheat alone produced around 760 million tons of wheat (Curtis et al., 2002). In Pakistan too, wheat is the main staple crop being cultivated. It is the most consumed crop here. Infection by any pathogen leads to huge crop damage and economic loss. To combat these losses, much work is being done on plant-mediated green nanoparticles. Recently, green silver nanoparticles were produced by using leaf extract of *Moringa oleifera* to combat wheat stripe rust disease caused by *Puccinia striiformis* (Sabir et al., 2022). Leaf extract acted as a stabilizer and reduction agent. Characterization of Ag nanoparticles was done by different techniques. Zeta analysis showed the size of nanoparticles to be 4-30nm. The resonance band of NPs was found to be 400-450nm which was determined by UV-visible spectroscopy. The crystalline nature of nanoparticles was confirmed by

X-ray diffraction. The presence of metallic silver nanoparticles was determined by the EDX detector. The infrared analysis confirmed the presence of phenols in the plant extracts. Different concentrations of silver nanoparticles were applied on the leaves of wheat plants inoculated with *Puccinia striiformis* to check their activity against stripe rust disease. Silver nanoparticles at the concentration of 75ppm were found to be effective against wheat stripe disease in wheat plants. This research provided the basis for the novel synthesis of AgNPs which can be used in controlling wheat stripe disease of wheat which destroys around 71% of 9.1 million hectares of wheat growing in Pakistan every year (Bahri et al., 2011).

In another research biogenesis of titanium oxide nanoparticles (TiO₂ NPs) was carried out by using *Moringa oleifera* Lam. aqueous leaf extract. SEM, XRD, EDX, and UV-visible spectrophotometry were used for studying the properties of nanoparticles (Mishra et al., 2014). These nanoparticles were applied on the leaves of wheat plants infected with the fungus *Bipolaris sorokiniana* which causes spot blotch disease. 40mg/L concentration of TiO₂ nanoparticles was found effective in reducing spot blotch disease occurrence in wheat plants. Spot blotch disease is responsible for the loss of almost 20% yield of the wheat crop in Pakistan. So by using a foliar spray of titanium oxide nanoparticles on wheat crops, the damage occurring by spot blotch disease can be reduced significantly.

Another pathogen *Rhizoctonia solani* causes serious plant diseases by attacking the roots and lower portion of stems of herbaceous plants. This soil-borne pathogen inflicts serious damage to many economically important crops. Annually around 20% of wheat crops are lost worldwide due to this pathogen. To control infection by *R. solani* in wheat seedlings, research had been conducted in which silicon dioxide nanoparticles were used (Abdelrhim et al., 2021). These SiO₂ nanoparticles were synthesized using saffron stigmas extract. 100 µg mL⁻¹ concentration of SiO₂ nanoparticles was found to be effective against the mycelial growth of *R. solani*. These nanoparticles activate the multilayered defense system that protects the plants against the fungus. Thus this research showed that SiO₂ NPs could be considered an eco-friendly approach for the protection of wheat plants against this root rot disease-causing fungus.

Rice is one of the most popular commodities around the globe. However, it is susceptible to

mycotoxin contamination in pre-and post-harvest conditions (Majumder and Banik, 2019). Besides wheat and maize, rice is the most important staple crop. Around 15% of rice production is lost in developing countries due to diseases by fungal pathogens. Recently, research has been conducted to use green synthesized silver nanoparticles to combat diseases caused by *Aspergillus flavus* in rice crops (Sultana et al., 2021). For this process, an aqueous extract of *Moringa oleifera* leaves was used. SEM, X-ray analysis, and UV-vis spectrophotometry were used for the characterization of silver nanoparticles. Results showed that a 50gm/L concentration of AgNPs effectively controlled the proliferation of *A. flavus*. Thus silver nanoparticles can act as a useful means for controlling this pathogen by eco-friendly methodology.

Leaf blight caused by *Xanthomonas oryzae* is a deadly bacterial disease that causes great destruction to rice crops. The crop loss can be as high as 75% in severe epidemics. Globally millions of hectares of rice crops are infected by this pathogen annually. The use of antibacterial chemicals to control the disease has increased the toxicity in the environment. As nanotechnology promises to introduce products that are environment friendly thereby research has been carried out to use nanoparticles in controlling bacterial blight disease of rice. In one such research chitosan nanoparticles (CSNPs) were prepared using dried green tomato aqueous extract (Abdallah et al., 2020). UV-vis spectroscopy in the range of 300 to 550nm was used for the confirmation of nanoparticle synthesis. TEM, SEM, and X-ray diffraction were used to study the properties of chitosan nanoparticles. Results showed that CSNPs cause cell death thereby suppressing *Xanthomonas oryzae* infection in rice crops.

To control bacterial blight disease caused by *X. oryzae* copper oxide nanoparticles are prepared using *Annona squamosa* aqueous seed extract (Singh et al., 2021). Apart from having significant resistance against various gram +ve and gram -ve bacteria, plant-mediated copper oxide nanoparticles also have high antibacterial activity against rice pathogen *Xanthomonas oryzae*. Thus this research showed that copper oxide nanoparticles are an effective means of controlling plant pathogens. In another research, pure and Ag-doped tin oxide nanoparticles were prepared using fruit extract of *Averrhoa bilimbi* (Sunny and Kumar, 2021). The activity of this pathogen was observed against leaf blight disease caused by *Xanthomonas oryzae*. Results showed that the Ag-

doped tin oxide nanoparticles broke the cell wall of the pathogen followed by protein leakage which indicated the cleavage of pathogen DNA. Hence these nanoparticles proved to be eco-friendly alternatives to chemical antibacterial agents for controlling leaf blight disease of rice.

Bacterial leaf blight disease of rice crops can also be controlled by using silver nanoparticles prepared from leaf extract of rice cultivar Taichung native-1. In this research different parameters were optimized for nanoparticle synthesis. Results showed high antibacterial activity of green synthesized silver nanoparticles against phytopathogen *Xanthomonas oryzae* pv. *oryzae* (Xoo), the causative agent of leaf blight of rice (Namburi et al., 2021). In another experiment conducted to combat this disease silicon dioxide nanospheres were being prepared. These nanospheres were loaded with silver nanoparticles (SiO₂-Ag). Rice husk was used as a base material for the synthesis of these nanoparticles. Results indicated that these nanoparticles inhibited the replication of *Xanthomonas oryzae* DNA. This research proved these nanoparticles to be effective against leaf blight disease of rice (Cui et al., 2016).

Sheath blight is another harmful disease that causes severe damage to rice crops. In China alone, 15 to 20 million ha of rice crops are adversely affected by disease annually causing a loss of around six million metric tons which equals 1% of total rice production globally (Xie et al., 2008). Keeping in view such a huge loss continuous, research is being carried out to find eco-friendly means to combat this disease. In one such research silver nanoparticles were prepared using rice leaf extract (Kora et al., 2020). Different characterization techniques were used for the in-depth study of these nanoparticles. When applied to rice crops these nanoparticles showed high antifungal activity against *Rhizoctonia solani*, the causative agent of sheath blight disease of rice crops. The concentration of 20 µg/mL showed complete mycelial growth inhibition of the fungus. Thus these silver nanoparticles can be utilized in the management and control of various fungal diseases.

Acidovorax oryzae is a rice crop pathogen that causes bacterial brown stripe disease. This strain causes serious damage to the rice crop. Bacterial brown stripe disease is widespread in China majorly due to the use of contaminated seeds for cultivation. Bactericides are commonly used to control the attack by this pathogen. However, due to increased bacterial resistance and environmental pollution, there is a need

for developing novel prevention strategies. So to combat attacks by this pathogen AgNPs have been synthesized in Chinese universities by using extract of *Phyllanthus emblica* fresh fruit (Masum et al., 2019). The resonance peak at 430nm confirmed the production of silver nanoparticles. 20 µg/ml concentration of silver nanoparticles proved to be effective in controlling *Acidovorax oryzae* strain attack on rice crops.

With the increase in human population, the demand for crops is also increasing rapidly. To fulfill the global crop requirement approximately 2.4×10^9 t/year of agricultural production is required. Maize, known as *Zea mays* is the queen of cereals. It is a staple crop with an average production of 1099.61 million metric tons per year. *Harpophora maydis* causes late wilt disease in maize that results in up to 80% crop loss. Several types of research are being conducted to develop innovative procedures for controlling this disease. In one such research silicon nanoparticles are being made using *Nerium oleander* plant leaf powder. Results showed that 20 and 40.2nm silicon nanoparticles effectively reduced the occurrence of late wilt disease in maize crops (Nouredine et al., 2022).

Since phytopathogens cause severe crop losses continuous efforts are being made to devise new products for controlling these pathogens in an eco-friendly manner. As silver nanoparticles show high antimicrobial activity, these were synthesized to control the antifungal activity of pathogens against the sugarcane crop. AgNPs were prepared using a sugarcane husk together with bacteria and fungi. Characterization was done using SEM and UV-Vis DRS. The presence of other compounds was determined using FTIR analysis. Antifungal activity was determined against *Colletotricum falcatum* and *Fusarium moniliforme*. Sugarcane husk-based nanoparticles showed maximum inhibition against both these fungal pathogens which can be used at the commercial level (Aguilar et al., 2018).

In another research, silver nanoparticles have been prepared using an aqueous extract of fresh mature pine cones. The focus of this research was to study the impact of pine cone-mediated nanoparticles on various agricultural pathogens. Characterization of nanoparticles was done using various techniques such as UV-Vis absorption spectroscopy, SEM-EDS, TEM, FTIR, and X-ray diffraction analysis. These nanoparticles showed high antibacterial activity against *Bacillus megaterium*, *Pseudomonas syringae*, *Burkholderia glumae*, *Xanthomonas oryzae*, and *Bacillus thuringiensis* (Velmurugan et al.,

2013). All these pathogens cause serious losses to various crops. Thus this research has high significance.

Conclusion

Green nanotechnology has revolutionized the field of agriculture by providing a safe, cheap, and eco-friendly alternative to conventional methods. Plant-mediated green nanoparticles have a unique significance field of nanotechnology. These nanoparticles greatly reduce the toxicity of crops resulting from using chemical means for combating pathogens attacks. This review focuses on in-depth research of green nanoparticles that will help researchers in understanding and develop novel green nanoparticles.

References

- Abdallah, Y., Liu, M., Ogunyemi, S. O., Ahmed, T., Fouad, H., Abdelazez, A., Yan, C., Yang, Y., Chen, J., & Li, B. (2020). Bioinspired Green Synthesis of Chitosan and Zinc Oxide Nanoparticles with Strong Antibacterial Activity against Rice Pathogen *Xanthomonas oryzae* pv. *oryzae*. *Molecules* (Basel, Switzerland), 25(20), 4795.
- Abdelrhim, A. S., Mazrou, Y. S., Nehela, Y., Atallah, O. O., El-Ashmony, R. M., & Dawood, M. F. (2021). Silicon Dioxide Nanoparticles Induce Innate Immune Responses and Activate Antioxidant Machinery in Wheat Against *Rhizoctonia solani*. *Plants*, 10(12), 2758.
- Aguilar, N.M., Arteaga-Cardona, F., Estévez, J.O., Silva-González, N.R., Benítez-Serrano, J.C., Salazar-Kuri, U. (2018). Controlled biosynthesis of silver nanoparticles using sugar industry waste, and its antimicrobial activity, *Journal of Environmental Chemical Engineering*, 6(5), 6275-6281.
- Bahri, B., Shah, S.J.A., Hussain, S., Leconte, M., Enjalbert, J., & Vallavieille-Pope, C. (2011). Genetic diversity of wheat yellow rust population in Pakistan and its relationship with host resistance. *Plant Pathology*, 60, 649 - 660.
- Ball, P. (2002). Natural strategies for the molecular engineer, *Nanotechnology*, 13: 15-28.
- Cai W, Chen X. (2008). Multimodality imaging of tumor angiogenesis. *J Nucl Med.*, 49:113S-28S
- Cui, J., Liang, Y., Yang, D., Yingliang Liu. (2016). Facile fabrication of rice husk based silicon dioxide nanospheres loaded with silver nanoparticles as a rice antibacterial agent. *Sci Rep* 6, 21423.
- Curtis, B.C., Rajaram, S., Macpherson, H. G. (2002). Bread wheat: Improvement and production. FAO, Rome.
- Dupont, J., Fonseca, G. S., Umpierre, A. P. (2002). Transition-metal nanoparticles in imidazolium ionic liquids: recyclable catalysts for biphasic hydrogenation reactions. *J Am Chem Soc*, 124:4228-9

- Eslamian, M., Shekarri, M. (2009). Recent advances in nanoparticle preparation by spray and micro-emulsion methods. *Recent Pat Nanotechnol*, 3(2):99-115
- Flood, J. (2010). The importance of plant health to food security. *Food Sec*, 2, 215–231.
- Kora, A. J., Mounika, J., & Jagadeeshwar, R. (2020). Rice leaf extract synthesized silver nanoparticles: An in vitro fungicidal evaluation against *Rhizoctonia solani*, the causative agent of sheath blight disease in rice. *Fungal Biology*, 124(7), 671-681.
- Majumder S, Banik P. (2019). Geographical variation of arsenic distribution in paddy soil, rice and rice-based products: A meta-analytic approach and implications to human health. *J Environ Manage*. 1;233:184-199.
- Marchiol, L. (2012). Synthesis of metal nanoparticles in living plants. *Ital J Agron*, 7:274–82.
- Masum, M., Islam, M., Siddiqua, M., Ali, K. A., Zhang, Y., Abdallah, Y., & Li, B. (2019). Biogenic synthesis of silver nanoparticles using *Phyllanthus emblica* fruit extract and its inhibitory action against the pathogen *Acidovorax oryzae* strain RS-2 of rice bacterial brown stripe. *Frontiers in microbiology*, 10, 820.
- Mishra, S., Singh, B. R., Singh, A., Keswani, C., Naqvi, A. H., & Singh, H. B. (2014). Biofabricated silver nanoparticles act as a strong fungicide against *Bipolaris sorokiniana* causing spot blotch disease in wheat. *Plos one*, 9(5), 97881.
- Mukherjee, P., Ahmad, A., Mandal, D. (2001). Fungus-mediated synthesis of silver nanoparticles and their immobilization in the mycelial matrix: a novel biological approach to nanoparticle synthesis. *Nano Letters*, 1(10): 515–519.
- Nalawade, P., Mukherjee, T., Kapoor, S. (2012). High-yield synthesis of multisized gold nanoparticles: Characterization and catalytic reactions. *Colloid Surf. A Physicochem. Eng. Asp*, 396, 336–340.
- Namburi KR, Kora AJ, Chetukuri A, Kota VSMK. 2021. Biogenic silver nanoparticles as an antibacterial agent against bacterial leaf blight causing rice phytopathogen *Xanthomonas oryzae* pv. *oryzae*. *Bioprocess Biosyst Eng*. 44(9):1975-1988.
- Narayanan, K. B., & Sakthivel, N. (2010). Phytosynthesis of gold nanoparticles using leaf extract of *Coleus amboinicus* Lour. *Mater. Charact*. 61, 1232–1238.
- Nel, A., Xia, T., Madler, L., Li, N. (2006). Toxic potential of materials at the nano level. *Science*, 311: 622 – 627.
- Noureddine, M., El Khomri, M., Ablouh, E. H., Bouich, A., Lacherai, A., Jada, A., Lima, E., & Sher, F. (2022). Biosynthesis of SiO₂ nanoparticles using extract of *Nerium oleander* leaves for the removal of tetracycline antibiotic. *Chemosphere*. 10.1016
- Prashant, M., Nisha, R., Sudesh, Y. (2008). Biosynthesis of nanoparticles: Technological concepts and future applications. *Journal of Nanoparticle Research*, 10, 507-517.
- Roco, M. C. (2003). Broader societal issue of nanotechnology, *Nanoparticles Research* 5: 181-189.
- Sabir, S., Arshad, M., Ilyas, N., Naz, F., Amjad, M., Shoaib, M., Zahid, N. and Chaudhari, S. K. (2022). Protective role of foliar application of green-synthesized silver nanoparticles against wheat stripe rust disease caused by *Puccinia striiformis*. *Green Processing and Synthesis*, 11(1), 29-43.
- Shin, W. K., Cho, J., Kannan, A.G., Lee, Y. S., Kim, D.W. (2016). Cross-linked composite gel polymer electrolyte using mesoporous methacrylate-functionalized SiO₂ nanoparticles for lithium-ion polymer batteries *Sci. Rep*, 6 p. 26332,
- Singh, P., Singh, K. R., Singh, J., Das, S. N., & Singh, R. P. (2021). Tunable electrochemistry and efficient antibacterial activity of plant-mediated copper oxide nanoparticles synthesized by *Annona squamosa* seed extract for agricultural utility. *RSC Advances*, 11(29), 18050-18060.
- Sultana, T., Javed, B., & Raja, N. I. (2021). Silver nanoparticles elicited physiological, biochemical, and antioxidant modifications in rice plants to control *Aspergillus flavus*. *Green Processing and Synthesis*, 10(1), 314-324.
- Sunny, Nisha & Kumar, Venkat. (2021). Anti- blight effect of green synthesized pure and Ag-doped tin oxide nanoparticles from *Averrhoa bilimbi* fruit extract towards *Xanthomonas oryzae*-the leaf blight pathogen of rice. *Inorganic Chemistry Communications*. 133. 108866. 10.1016/j.inoche.2021.108866.
- Thakkar, K.N., Mhatre, S.S., Parikh, R.Y. (2010). Biological synthesis of metallic nanoparticles. *Nanomedicine: Nanotechnology, Biology and Medicine*, 6(2):257–262.
- Velmurugan, P., Lee, S.M., Iydroose, M., Lee, K.J., Oh, B.T. (2013). Pine cone-mediated green synthesis of silver nanoparticles and their antibacterial activity against agricultural pathogens. *Appl Microbiol Biotechnol*. 97(1):361-8.
- Xie, X. W., M. R. Xu, J. P. Zang, Y. Sun, L. H. Zhu, J. L. Xu, Y. L. Zhou, and Z. K. Li. 2008. Genetic Background and Environmental Effects on QTLs for Sheath Blight Resistance Revealed by Reciprocal Introgression Lines in Rice. *Acta Agronomica Sinica* 34:1885–1893.

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