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Redgram Resurgence –A Perspective of Nanotechnological Approach

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ABSTRACT

Nanotechnology, with its unique ability to manipulate materials at the nanoscale, has emerged as a promising tool for revolutionizing agriculture. In this review, we delve into the application of nanotechnology in redgram (*Cajanus cajan* L.), commonly known as pigeonpea, which is an essential leguminous crop with global significance. It has been explored for the utilization of nanomaterials for improving seed germination, vigor, crop productivity, disease management, nutrient delivery, and storability in redgram. Through a systematic analysis of recent research papers, we highlighted the potential of nanotechnology to address key challenges in redgram production while providing sustainable solutions for modern agriculture.

Keywords Nanotechnology, Redgram, Seed quality, Seed yield, Nutrient delivery.

INTRODUCTION

Agriculture is facing unprecedented challenges in the 21st Century, including the need to feed a growing global population while minimizing environmental impact and adapting to changing climatic conditions. In this context, nanotechnology has emerged as a transformative field with the potential to address critical issues in modern agriculture. By harnessing the unique properties of materials at the nanoscale, nanotechnology offers innovative solutions to enhance crop production, improve disease resistance, and optimize nutrient management (Fraceto *et al.* 2016).

One crop of particular importance in the global agricultural landscape is redgram (*Cajanus cajan* L.), commonly known as pigeonpea. Redgram, a legume crop high in protein, is grown around the world in tropical and subtropical climates. In Latin America, Asia, and Africa, it is an essential grain legume crop. Globally, redgram is grown in an area of 63.57 lakh hectares with a production of 54.75 lakh tonnes and productivity of 861.25 kg/ha (FAOSTAT 2021). India ranks first in redgram production globally with 43.4 lakh tonnes cultivated in an area of 49.8 lakh hectares with a productivity of 871 kg/hectare during 2021-22 (agricoop.nic.in). To fulfill

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domestic demand, however, around 1-2 million tons of pulses are imported each year. Like many agricultural commodities, redgram faces multifaceted challenges that hinder its sustainable production. The crop is susceptible to various biotic and abiotic stresses, including pests, diseases, and unfavorable soil conditions. Inefficiencies in nutrient uptake and utilization further limit yield potential. Additionally, post-harvest losses due to inadequate storage facilities and pest infestations remain a significant concern. Consequently, more intense actions are required to boost the nation's pulse production and productivity.

The introduction of nanotechnology into agriculture has ushered in a new era of possibilities. It empowers farmers and researchers with tools to precisely manipulate matter at the nanoscale (Chhipa 2019) enabling tailored solutions for crop improvement and resource management. In the case of redgram cultivation, nanotechnology promises to enhance seed germination and vigour, optimize crop productivity, enable precise disease management, improve nutrient delivery, and extend storability, thereby preventing storage losses considerably. This review aims to explore the burgeoning field of nanotechnology and its myriad applications in the context of redgram cultivation. By examining recent developments and research findings, we seek to elucidate the potential of nanotechnology to revolutionize redgram production and provide sustainable solutions for modern agriculture (Kopittke *et al*. 2019).

Nano-formulations for controlled delivery of bioactive compounds

Nano-formulations, especially nanoparticles, have gained significant attention as carriers for the controlled delivery of bioactive compounds in various agricultural applications, including crop protection and enhancement of plant growth. These nano-formulations can be designed to deliver nutrients, pesticides, or other bioactive compounds in a controlled and targeted manner, thereby improving the efficiency of these compounds and reducing potential environmental impacts. Encapsulation of these compounds in nanocarriers ensures controlled release and prolonged activity of bioactive chemicals.

The utilization of nano-insecticides represents a cutting-edge approach to agricultural pest management. These nanoscale formulations have shown promise in enhancing seed quality through their unique properties and precise targeting mechanisms. An investigation by Raghu *et al.* (2017) looked at how redgram seed quality was affected by nano insecticide. These treatments include Malathion, Fenvalerate, Emamectine Benzoate,Thiodicarb, Sweet flag, and Neem Seed Kernel (NSK) nanopowder which were synthesized using a high energy planetary ball mill. Both macro and nano insecticides produced from these treatments were studied. Different nano insecticides were applied to the redgram seedlings at lower concentrations (10 to 90% less than recommended). Notably, seeds treated with nano malathion (50% less), Fenvalerate (60% less), Thiodicarb (10% less), Emamectine Benzoate (30% less), Sweet flag (70% less), and NSK powder (40% less) exhibited significantly higher seed germination, reduced abnormal seedlings, longer shoot and root lengths, greater seedling dry weights, and higher seedling vigour indices compared to untreated seeds and macro insecticides. This study emphasizes the significant (0.1%) enhancement in seed quality attributes due to nano-based pesticides.

The role of nanoparticles in shaping seedling traits has gained substantial attention in recent years, owing to their potential to revolutionize modern agriculture. This burgeoning field has been substantiated by studies such as the investigation conducted by Raju and Rai (2017) on the impact of various nanoparticle treatments on redgram seedling characteristics. These treatments comprised encasing the seed polymer with Zn and Fe nanoparticles (NPs) @ 10 and 25 ppm as well as $ZnSO_4$ and $FeSO_4$ @ 100 and 500 ppm. Additionally, variable hydropriming times (between 6 and 12 hrs) were taken into account. The most significant outcomes were from seed polymer coating with Fe NPs at a 25 ppm concentration. Higher seed germination, speed of germination, root length, shoot length, overall length, dry weight, were obtained due to NPs. Furthermore, it outperformed bulk forms and control treatments in terms of the proportion of abnormal seedlings produced. Nevertheless, hydropriming had a positive influence on the quality of redgram seeds, although the choice of priming method was found to be significant. Consequently, based on these results, it was concluded that the use of Fe and Zn NPs at 25 ppm could enhance the quality of redgram seeds.

In recent times, the limited water solubility of active ingredients in conventional pesticides and fertilizers has reduced their effectiveness on crops. To combat this issue and address the growing concerns of environmental pollution and toxicity from chemical fertilizers, many eco-friendly nano-biofertilizers and nano pesticides are developed. CuNPs promote the growth and development of plants by releasing copper ions (Cu^{2+}) that are easily absorbed by the roots and transported throughout the plant. These copper ions play a crucial role in various metabolic processes, including photosynthesis, as they are a key component of chlorophyll's plastocyanin pigment. CuNPs activate several metabolic components like Cu transporters, Cu chaperones, and P-type ATPases, leading to enhanced plant growth and development. In a specific study conducted by Shende *et al.* (2017), the application of CuNPs at a concentration of 20 ppm significantly improved the plant height, root length, fresh and dry weights of seedlings, and performance index of redgram seedlings.

Nanoparticle concentrations and their effects on germination vary from one plant to another. Accordingly, Pavani *et al.* (2020) demonstrated that ZnONPs (5, 10, 15, 20, and 25 mg/100 ml) significantly inhibited *Cajanus cajan* seed germination, shoot and root growth, number of leaves, and fresh and dry weight of plants when exposed to higher concentrations (20, 25 mg/100 ml ZnONPs), while translocation of ZnONPs into the seed was verified by TEM image. In contrast, higher levels had more protein, carbohydrates, chlorophyll, ascorbic acid, H_2O_2, and glutathione reductase activity. However, red gram seeds and leaves showed a reduction in catalase activity when exposed to greater concentrations of ZnONPs. This shows unequivocally that antioxidant activity and seedling growth inhibition are highly correlated with nanoparticle concentration. It is possible that the harmful effects of ZnONPs on plants are caused by the ROS that are produced during NP absorption. Since redgram is most often used in the human diet, NPs can enter the human body and interact with cells, causing unanticipated outcomes. Therefore, in-depth research is required to ascertain whether ZnONPs have beneficial or harmful effects on redgram plants.

Zinc (Zn) is recognized as a vital micronutrient essential for the growth of both plants and animals. In plants, it serves multiple roles, acting as a cofactor, regulatory factor, and metal component within enzymatic systems. The study aimed by Tulasi *et al.* (2023) was to synthesize Zinc oxide (ZnO) nanoparticles (NPs) eco-friendly using the aqueous leaf extract of *Schrebera swietenioides.* These synthesized NPs were subsequently employed to enhance seed germination and promote plant growth in redgram. The process involved utilizing Zinc acetate as the metal source, with the metal being reduced using the aqueous leaf extract of *S. swietenioides* as a green reducing agent and the resulted NPs had a hexagonal structure with a spherical shape and irregular surfaces, averaging 68nm in size with a metal composition of 73.70%. It was found that the mean germination time for NPs-treated seeds was significantly shorter and germination percentage for NPs-treated seeds was notably higher compared to control and Zinc acetate-treated seeds. Additionally, enzyme activities related to growth, such as amylases, protease, and catalase, were significantly higher in redgram seeds treated with ZnONPs compared to the other groups.

In research exploring the potential advantages of SiO_2 nanoparticles on agricultural systems, redgram seeds treated with SiO_2 nanoparticles in powder form together with polymer coating showed noticeable improvements across a range of seed quality traits. The seeds of redgram showed a significant improvement in terms of germination rate, seedling length, mean seedling dry weight, and seedling vigour indices (I and II). These results highlight the strong beneficial effect of S_iO_2 nanoparticle treatment on the quality of redgram seeds, potentially providing useful information for enhancing redgram cultivation and yield (Gowda *et al.* 2023).

Nanoparticles for nutrient delivery and increasing yields

For crops to thrive as best they can, nutrients must be delivered effectively. Innovative solutions offered by nanotechnology include nano-fertilizers, which release nutrients gradually and improve the uptake of nutrients by redgram plants. The ability to stimulate overall plant development through nanoencapsulation of growth-promoting chemicals has been demonstrated using *Aloe barbadensis* (Aloe-Vera) leaves having components like lignin, hemicellulose, and pectins, which can act as reducing agents for metal ions synthesis of MgO and ZnO and as bio-templates to avoid agglomeration of particles (Rani *et al.* 2020). Its leaf extract act as a capping and reducing agent that affected the growth of the roots, shoots, fresh and dry biomass, and the germination of the seeds of *Cajanus cajan* (red gram) and *Vigna radiata* (mung bean). In comparison to control seeds treated with water, the results showed a significantly higher rate of germination for seeds treated with MgO and ZnONPs. To further support the potential of these synthesized NPs for increasing seed germination, the amount of chlorophyll was assessed. This study showed a more eco-friendly and economical way to make inorganic nanoparticles and witnessed their potential as eco-friendly agrochemicals, especially for promoting seed germination in redgram and other crops seeds.

Foliar spraying provides the advantages of low application rates, homogeneous dispersion of fertilizer components, and rapid reaction to applied nutrients. Foliar application of certain nutrients in nano-form is regarded as a superior strategy to enhance the efficiency of fertilizer usage and raise crop yields, even if there is still some debate over the advantages and proper execution of this technique. The use of nano-sized fertilizer combinations in agriculture has gained popularity recently as a way to improve nutrient usage efficiency and resolve long-standing issues brought on by the extensive use of traditional fertilizers. In order to compare the feasibility of nano micronutrient fertilizer to conventional fertilizers on the production and economics of redgram, little attempts have been performed. The results showed that foliar application of conventional multi-micronutrients, specifically Grade-I, along with the advised dose of fertilizer at flower initiation and pod-bearing stages, consistently outperformed both nano multi-micronutrients and soil applications, yielding higher grains and more favorable benefit-to-cost ratios. This is despite the fact that foliar spraying has benefits like low application rates and quick nutrient response. Although better nutrient utilization efficiency is a potential benefit of nano-sized fertilizers, their higher input costs now make them less economically feasible than their traditional equivalents. This study emphasizes the necessity for some further investigation and cost-cutting initiatives in the use of nano fertilizers in agriculture (Kailas *et al*. 2017).

In a recent study focused on enhancing redgram seed quality, Surabhi *et al.* (2018) explored the application of different nanoparticles and their bulk forms as seed treatments. The findings highlighted the significant improvements achieved through these treatments. Notably, the use of Silica nanoparticles (SiO_2) at a concentration of 250 mg emerged as the most effective treatment, resulting in a remarkable 98% germination rate, 95% field emergence, an increased mean seedling length, a high seedling vigour index, and a low electrical conductivity. Following closely behind was the application of Zinc oxide nanoparticles (ZnO) at 500 mg, which also exhibited favorable results. Silver nanoparticles (Ag) at 250 mg also demonstrated improved seed quality attributes. In contrast, the untreated control group showed significantly lower performance in all aspects, underscoring the potential of nanoparticle-based seed treatments to enhance the quality and performance of redgram crops. These findings present a promising avenue for future agricultural practices seeking to optimize seed treatment protocols and improve crop yields.

The effects of various concentrations of green Zinc oxide, green Silicon dioxide, chemical Zinc oxide, chemical Silicon dioxide, and Spinosad on redgram growth and yield were studied by Sowjanya *et al.* (2023). Among these, the application of green Zinc oxide at a concentration of 1250 ppm resulted in an increase in plant height, nodules per plant, pod length, the number of seeds per pod, pods per plant, seed yield per plant, and hundred seed weight. Furthermore, the seeds from this treatment had high seed germination rates, better seedling development, enhanced dehydrogenase activity, and lower electrical conductivity of seed leachates. These findings highlight the effectiveness of treating seeds with green Zinc oxide at 1250 ppm to enhance both seed yield and quality parameters in redgram.

Nanotechnology for seed storage

Seed storage is a critical component of seed production programs because the quality of stored seeds directly impacts crop yield and performance in the field. As seeds age, they tend to lose their ability to germinate and grow into healthy plants. This decline in seed quality can lead to poor crop stand and reduced field performance which necessitates optimum seed storage. Nanoparticles (NPs) have unique properties like increased surface area results in higher catalytic activity and reactivity, making NPs potentially beneficial in various applications, including seed storage. Nanocoatings and packaging materials provide barrier properties, preventing moisture and gas exchange that contribute to seed deterioration. Supporting this statement, Korishettar *et al.* (2017) investigated how coating redgram seeds with Zn and Fe NPs, as opposed to their bulk forms, affects the seeds' ability to be stored effectively. The results of the experiment showed that the coating of seeds with Zn NPs at a concentration of 750 ppm had the most positive impact on various seed parameters like seed germination, seedling growth (measured in terms of length and dry weight), field emergence, seedling vigour index, and the activities of certain enzymes (α-amylase and dehydrogenase) at the end of 10 months of storage period. Additionally, the study found that the nanoparticle treatment did not affect the seed moisture content or insect infestation levels. It demonstrates the promising application of nano technology in the field of seed science, highlighting the potential of using zinc and iron nanoparticles to enhance the storage potential, germination, and overall performance of red gram seeds. This could have significant implications for improving crop yields and food production.

The inclusion of nanotechnology in optimizing the storage potential of redgram holds the promise of revolutionizing food security. A compelling example of this potential is the recent laboratory experiment exploring the impact of nanoparticles on redgram seed quality and storage potential (Surabhi *et al.* 2021). Notably, seeds treated with SiO_2 nanoparticles at a concentration of 250 mg exhibited superior performance in terms of germination rate, seedling growth, field emergence, dehydrogenase activity, electrical conductivity, and seed moisture content over a storage period of 0 to 10 months. These findings suggest the potential of nanotechnology in improving seed quality and prolonging the storability of redgram seeds. Interestingly, ZnO nanoparticles at 500 mg also yielded comparable results, indicating that different nanoparticles and concentrations can achieve similar enhancements. This research holds promise for enhancing agricultural practices by harnessing nanotechnology to boost crop yields and preserve seed quality.

Nanoparticles as anti-microbial agents

The susceptibility of redgram to various pathogens poses a challenge to its cultivation. Nanotechnology-based approaches, including the development of nanopesticides and nanosensors, enable precise disease management. Nanomaterials with antimicrobial properties can selectively target pathogens while minimizing environmental impact. Nanosensors aid in real-time disease detection, allowing for timely interventions.

Nanoscale research is seen to have the potential to transform agricultural and food systems. Nanoparticles have shown great promise as "magic bullets" loaded with herbicides, fungicides, nutrients, and fertilizers that target specific plant tissues and release their charge to the desired part of the plant to produce the desired results. Nanoparticles have been tested as antifungal agents against pathogenic fungi. Numerous nanomaterials, including those made of copper (Cu), zinc (Zn), titanium (Ti), gold (Au), alginate, and silver (Ag), have been produced to fight infections. Exploring novel antimicrobial resources, such as plants in light of the rising problem of multidrug-resistant diseases is important. Taking note of the antioxidant properties of redgram leaves, which are rich in flavonoids and stilbenes, can help in developing powerful antimicrobials against infections. Nagati *et al.* (2012) synthesized silver nanoparticles from *Cajanus cajan* leaf extracts and tested their effectiveness as antibacterial agents against different bacterial strains. These green leaves produced silver nanoparticles demonstrated strong dose-dependent antibacterial action against the test pathogens, including Gram-negative *Escherichia coli* and Gram-positive *Staphylococcus* *aureus*. Further, it was observed that in both cases, bacterial growth decreased as the concentration of green leaves produced nanoparticles get higher and their efficacy was also verified by a Zone of inhibition experiment.

Redgram nanoparticles used for human health management

The redgram (*Cajanus cajan*) leaf material has various therapeutic benefits, including antioxidant (Wu *et al.* 2009), antihelminthic (Siddhartha *et al.* 2009), hepatoprotective (Ahsan *et al.* 2009), glycemic (Jaiswal *et al.* 2008), neuroactive (Nicholson *et al.* 2010), hypocholesterolemic (*Luo et al.* 2008), and antibacterial activity (Zu *et al.* 2010). The seed extract also exhibits antisickling properties (Ekeke and Shode 1990). It was anticipated that gold nanoparticles made from the seed coat of *C. cajan* would have better therapeutic qualities and the phytochemical molecule would function as a capping agent with anticancer characteristics. The active ingredient in the seed coat was identified as 3-butoxy-2-hydroxypropyl 2- (2, 4 - dihydroxyphenyl) acetate, a monodisperse (spherical), very stable gold nanoparticles with diameters ranging from 9 to 41 nm. Liver cancer cells were used to study anticancer activity, and MTT, Annexin-V/PI Double-Staining Assay, Cell Cycle, Comet Assay, and Flow Cytometric Analysis for Apoptosis were used to assess cytotoxic mechanism. This study created a new opportunity for the functionalization of gold nanoparticles for apoptosis research in liver cancer cells (Ashok Kumar *et al*. 2014).

CONCLUSION

The aforesaid comprehensive review sheds light on the transformative potential of nanotechnology in redgram or pigeonpea (*Cajanus cajan* L.) crop production. As a pivotal leguminous crop with global significance, redgram faces a range of challenges that hinder its sustainable production and contribution to food security. The integration of nanotechnology into redgram cultivation offers a multitude of innovative solutions that address these challenges across various aspects of crop production. From enhanced seed germination and vigour to optimized crop productivity, precise disease management, improved nutrient delivery, extended seed storability, and even potential applications in human health management, nanotechnology's impact on redgram husbandry is multifaceted and promising. However, as with any emerging field, careful consideration of factors such as nanoparticle concentrations, environmental impacts, and cost-effectiveness is paramount. This review emphasizes the necessity of ongoing research and development in the field of nanotechnology in redgram agriculture. Nevertheless, collaborative efforts between scientists, agronomists, and policy makers would be vital in harnessing the full potential of nanotechnology to revolutionize the redgram cultivation and contribute to sustainable, resilient, and productive agricultural systems.

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