

INTEGRATION OF NANOTECHNOLOGY AND INDIGENOUS AFRICAN AGRICULTURAL KNOWLEDGE: A REVIEW



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ABSTRACT

There is a pressing need to improve agricultural methods and apply cutting-edge technologies to boost food production and ensure food security in Africa. For decades, farmers have relied on commercially available pesticides that are both environmentally harmful and expensive. On the other hand, nanotechnology is an emerging technology with numerous promising uses, among which is the prevention and treatment of plant diseases. Its application has allowed for more precise and efficient pesticide distribution to plants but there have been increasing concerns about toxicity and general acceptance. This review article examines the infusion of Indigenous agricultural knowledge into nanotechnology for pesticide production in Africa. This study employs a systematic review to identify relevant published articles from electronic databases like PubMed, Directory of Open Access Journals (DOAJ), and African Journals Online (AJOL) after which a total of 46 articles were selected from 373 articles which were identified at the initial stage. The study shows that the African agricultural system, governed by Indigenous Agricultural Knowledge, which is the result of human efforts to optimise crop yields via careful planning, experimentation, and the transmission of tried-and-true techniques from generation to generation has proven to be an economical, eco-friendly, and healthful strategy for addressing issues like weed control and insect and disease prevention in agriculture. The findings of this review suggest that incorporating Indigenous Agricultural Knowledge with nanotechnology via green methods can solve these problems.

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INTRODUCTION

Pesticides play a crucial role in contemporary agriculture because of their ability to ward against pests and diseases (Hashimi et al., 2020). Most commercially available pesticides are chemical formulations, and their use has been standard in traditional pest control for decades (Samada & Tambunan, 2020). However, using these pesticides relies on blanket spraying, which exposes non-targets and pollutes the surrounding area (A. Sharma et al., 2020). Other potential drawbacks are the development of resistance to these pesticides over time (Abdollahdokht et al., 2022) and the short duration of action which necessitates their frequent reapplication, causing more environmental harm and higher costs for farmers. This necessitates research into potential solutions to improve pesticide application while reducing environmental impacts. Recently, nanotechnology has gained special attention for its applications in solving many environmental problems. Additionally, using nanopesticides selectively reduces the overall amount of pesticides needed, which benefits the environment and reduces the likelihood of pesticide residues in human food and water supplies (Bratovic et al., 2021). By increasing the duration of exposure and reducing the number of treatments needed, controlled release increases the effectiveness of pesticides (Chaud et al., 2021). To reduce the number of treatments and the overall ecological impact of pesticide use, nanopesticides can aid in promoting sustainable agricultural practices (R. Kumar et al., 2022).

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Despite the need and potential of nanotechnology in combating food insecurity in Africa, its development and application are fraught with challenges because of the increasing concern for the potential toxicity of nanomaterials and their effects on human health and the environment over time. The development of nanotechnology for agricultural applications in Africa is still at an early stage and is progressing quite slowly, as noted by Jellason et al. (2021). As a result, very little research has been conducted in this field in Africa, especially in the area of incorporating nanotechnology and indigenous agricultural technology. Achieving the dual goals of food security and environmental protection thus becomes very pertinent.

The objective of this study is to explore how Africa's agricultural sector can be advanced to promote environmentally sustainable practices toward achieving food security. To achieve this, the article begins by outlining the current state of pesticide usage on agricultural land across the continent. It then examines the diversity of nanoscale system through a literature review. The discussion also considers several research works and that have shown the potential to integrate indigenous agricultural knowledge with nanotechnology for sustainable environment and agricultural transformation. This review study concludes with a recommendation for more research to be carried out to establish the cost implications and feasibility for small holder farmers in Africa.

LITERATURE REVIEW

Diversity of Nanoscale System

Nanoparticles

Nanoparticles (NPs), which range in size from 1 to 100 nanometers, have attracted significant attention from a wide range of scientific and professional communities due to their intriguing properties. Their high surface-to-volume ratio and remarkable size-dependent features make them useful and versatile across many fields. In agriculture, nanoparticles hold tremendous potential to revolutionise crop protection and yield. Fewer agrochemicals are utilised with a more precise distribution approach, protecting people and the environment from harm (V. Sharma et al., 2022). Silver nanoparticles, which have antibacterial properties and can be used to treat plant infections (Vanti et al., 2020), and iron oxide nanoparticles, which can be utilised for remediation of the environment or as nanofertilizers (S. Khan et al., 2023) are only two examples. Carbon-based nanoparticles like graphene and carbon nanotubes are perfect for developing novel sensors, biosensors, and intelligent agriculture systems due to their exceptional mechanical strength and conductivity (Malik et al., 2023). As a result, they may be engineered to respond to specific stimuli or to transport bioactive chemicals, nanoparticles are finding growing use in controlled-release systems and precision agriculture (Thi et al., 2019). Figure 2 illustrates how nanoparticles are used to deliver nano pesticides in plant root meristem.

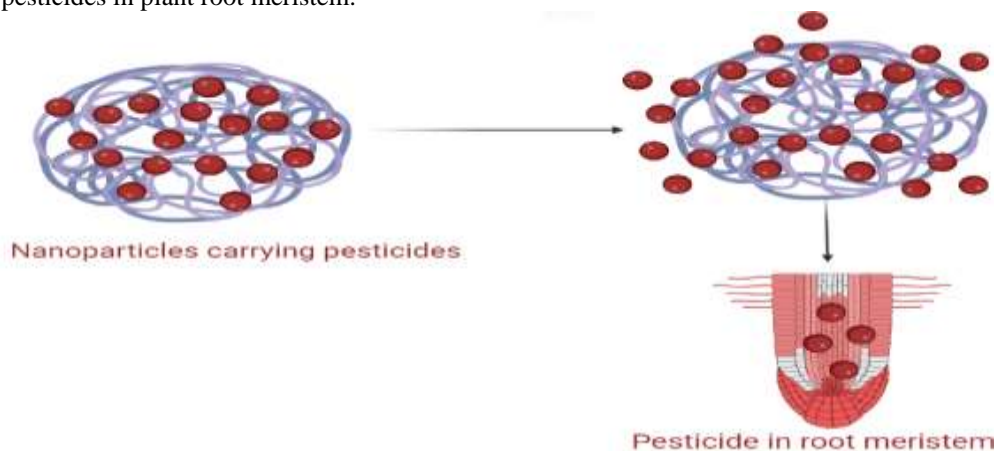


Figure 1. Nanoparticles as carriers for pesticide molecules. Generated by BioRender.com and published based on their academic license term.

Nanogels

In several fields, including biomedicine, environmental science, and agriculture, nanogels have proven to be versatile and promising materials (Lima et al., 2020). These three-dimensional networks are made of cross-linked polymer chains that are highly hydrated and capable of transporting a wide variety of bioactive substances (Maddiboyina et al., 2022; Yang et al., 2024).

Considering its potential to increase crop yield and sustainability, nanogels have attracted a lot of interest in the agricultural sector (Arora et al., 2022). Nanogels' potential to act as controlled-release delivery systems for nutrients, fertilisers, and insecticides is one of its primary benefits (Del Prado-Audelo et al., 2022). Nanogels can encapsulate and protect active substances thanks to their porous structure, preventing the ingredients from being prematurely released or degraded (Shelar et al., 2023). As a result of this controlled-release mechanism, bioactive substances are released gradually and consistently, giving plants a steady and effective dose of nutrients or pesticides (Del Prado-Audelo et al., 2022). Nanogels assist in reducing waste, and environmental pollution, and increase crop health and production by facilitating the efficient and targeted administration of agrochemicals.

Nanocapsules

The core-shell structure of these nanoparticles allows for the regulated release of insecticides. The pesticide is housed within the nanocapsule's core, while the shell serves as a barrier. This encapsulation prevents the pesticide from degrading or evaporating before it reaches its intended location (Kannan et al., 2022). Nanocapsules' controlled release qualities allow for the pesticide to be exposed to pests for a longer period, increasing its effectiveness while decreasing the amount of pesticide required (Ning et al., 2022).

The capacity of nanocapsules to concentrate their contents in certain plant organs is a major benefit. They can travel through plant tissues and access high-density pest populations in places like feeding sites and stomata because of their diminutive size (Shelar et al., 2023) where they can do the most damage. Using this method of tailored delivery encourages more eco-friendly pest control methods by cutting down on unnecessary pesticide use and exposure to non-target organisms (Singh et al., 2022). Nanocapsules improve the pesticide's stability and bioavailability, enabling a continuous and regulated release that boosts the pesticide's efficacy (Li et al., 2021).

Nanofibres

The creation of nanopesticides for efficient plant protection has seen the emergence of nanofibers as a viable technology. Due to their high surface area and adaptability, these ultrafine fibers have significant benefits for the delivery of pesticides (Subhan et al., 2021). The nanofiber matrix provides a barrier against degradation and volatilization, and this makes the pesticide to be more stable and last longer (Shanguan et al., 2022). This method of controlled release keeps the pesticide in the environment for an extended period, increasing its effectiveness while reducing the amount of pesticide used. Targeted delivery is a major advantage of nanofibers in nanopesticides (Okey-Onyesolu et al., 2021).

Significance of nanotechnology to pesticide delivery

Non-target organisms are less likely to be harmed by nanopesticides than they would be by conventional pesticides (Deka et al., 2021); modifying polymers used in pest control in even small ways can improve their biocompatibility, biodegradability, and the controlled administration of active ingredients (AI).

Recent studies have shown that nanopesticides can lessen the harmful effects of chemical-based pesticides, provide pest control that is more tailored to its target, and aid in the development of smart nano-systems that may mitigate issues like environmental imbalances and their adverse impact on food security and crop yields (Asif et al., 2021). They solve environmental issues including excessive nutrient levels in water bodies and the buildup of non-biodegradable components in the food chain by limiting the release of active ingredients, and they have an extended shelf life. There is still a need to improve the methods to see substantial gains in agricultural productivity.

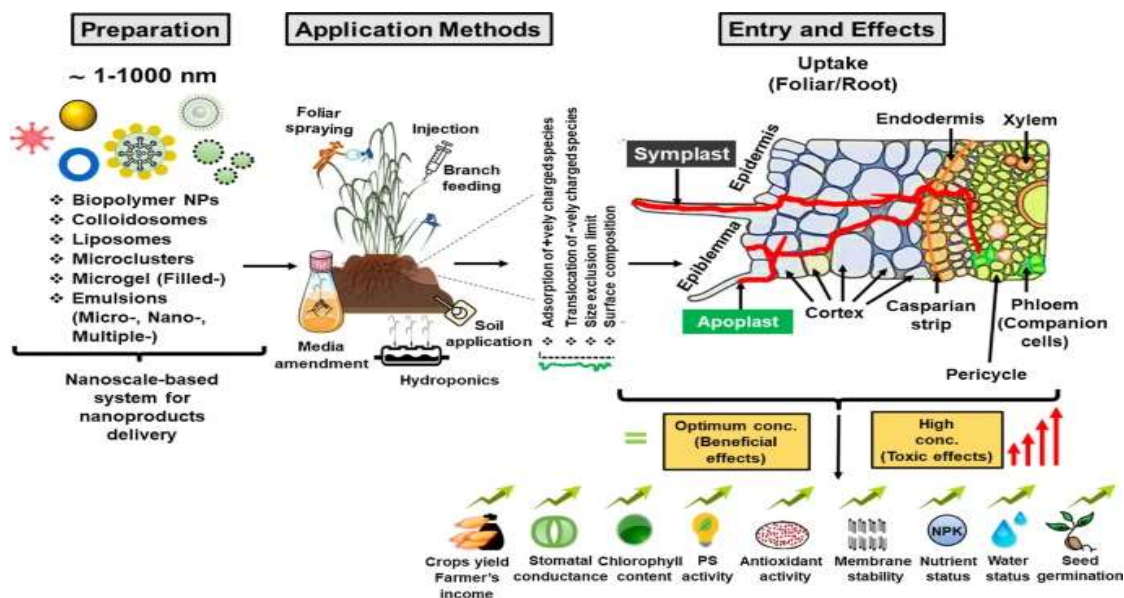


Figure 2. Overview of nanotechnology application in plants and their interactions with plants.

Source: A. Kumar et al. (2021)

Challenges of nanotechnology to pesticide delivery

Nanotoxicity

The delivery of pesticides utilizing nanotechnology may be affected by concerns over nanotoxicity. Nanotechnology has the potential to improve the delivery of pesticides to specific areas, but their potential toxicity must be carefully examined. Accumulation of NPs in plant tissues can have negative effects on plants and, by extension, human health. NPs can enter plant cells via endocytosis, interacting with organic compounds, ion channels, stomatal openings, and the bases of trichomes after being translocated into the plant system (Ali et al., 2021).

There is also the possibility of harm to non-target organisms and ecosystems from the nanoparticles used in pesticide delivery (Chaud et al., 2021). Nanoparticles' enhanced interactions with living organisms might have unanticipated harmful effects, such as oxidative stress, cellular damage, inflammation, and disruption of physiological systems (N. Sharma et al., 2024), due to their small size and increased surface area.

Assessing nanotoxicity in pesticide delivery also requires considering the environmental impacts and behavior of nanomaterials. Metallic NPs are the basis for many cutting-edge nano-agricultural products, including nanopesticides, nanoherbicides, and nanofertilizers. Soil NPs, including ZnO- and CuONPs, might have detrimental impacts on enzymatic activity and nutrient cycles of several valuable soil microbial communities like *Azotobacter*, *Sphingomonas*, and *Rhizobiales* upon accumulation (Rajput et al., 2020). Evaluating the impact of nanoparticles on ecosystems requires an understanding of the potential for nanoparticle release, transport, and change in environmental systems. Figure 3 shows the toxic effects of nanopesticides in plant cells.

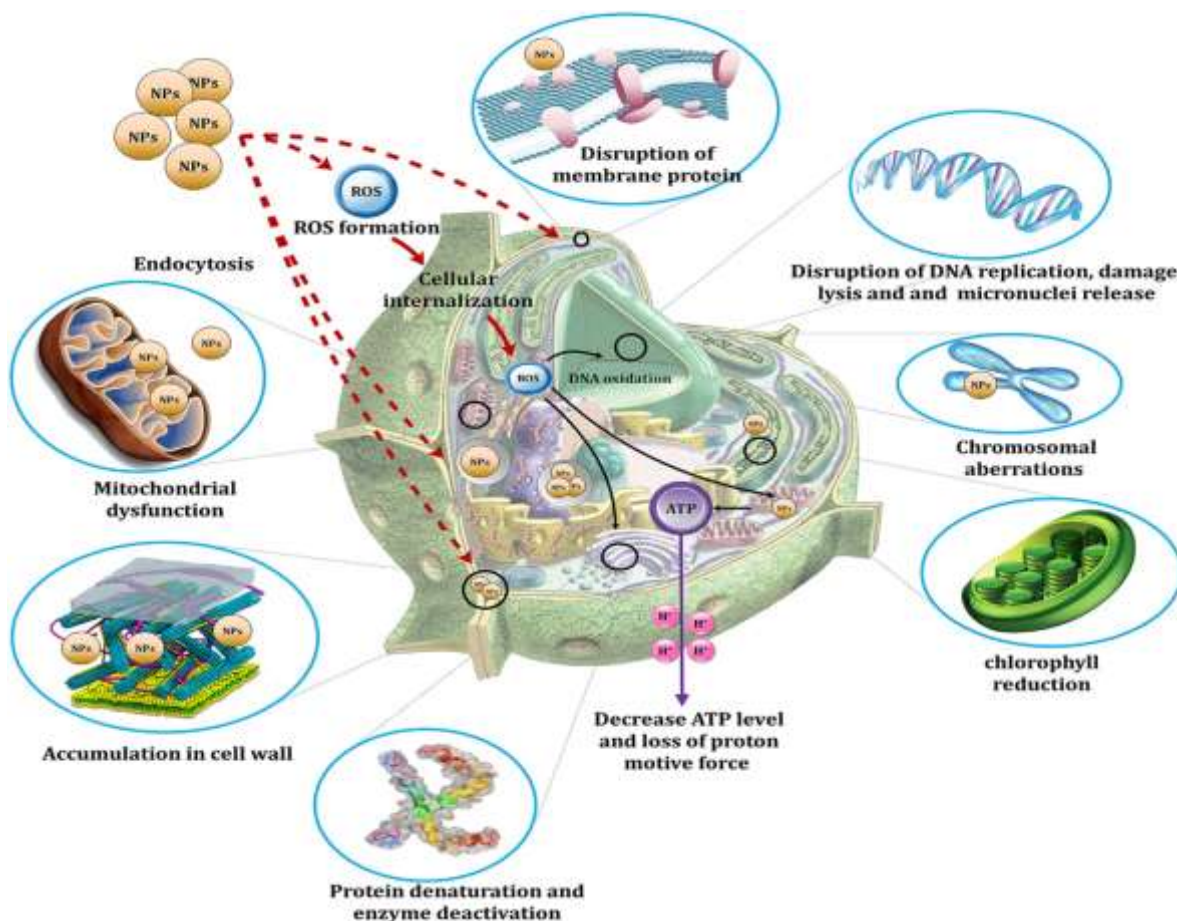


Figure 3. Toxicity of nanopesticides in plant cells.

Source: Ali et al. (2021)

Uncertainties of Nanotechnology in Agriculture: Limitations of nanotechnology's broad applicability have been fairly assessed, although there are still questions about its use in agriculture. However, it does not appear that the existing risk assessment data in agriculture is sufficient for customers to make educated decisions. The regulatory structure is severely hampered by this lack of information which raises serious concerns about consumer and environmental safety (Mwaanga, 2018). These worries have prompted important inquiries like, "Do current toxicology testing protocols provide enough information?" Which indicator best characterizes the toxicity of NPs, especially those that enter the body through the digestive tract? Is there enough regulatory framework to safeguard NPs used in farming? (Grillo et al., 2021)

Regulation: It may be challenging to develop a regulatory framework for nanotechnology because of the size-related distinctions between nano-particles and their bulky counterparts. Governments need to adopt nano-specific regulations and formulate a standard definition to encourage knowledge sharing, trade in products containing nanoparticles, and risk mitigation (Grillo et al., 2021). Figure 4 gives an overview of the Potential implications of nanopesticide production and its applications

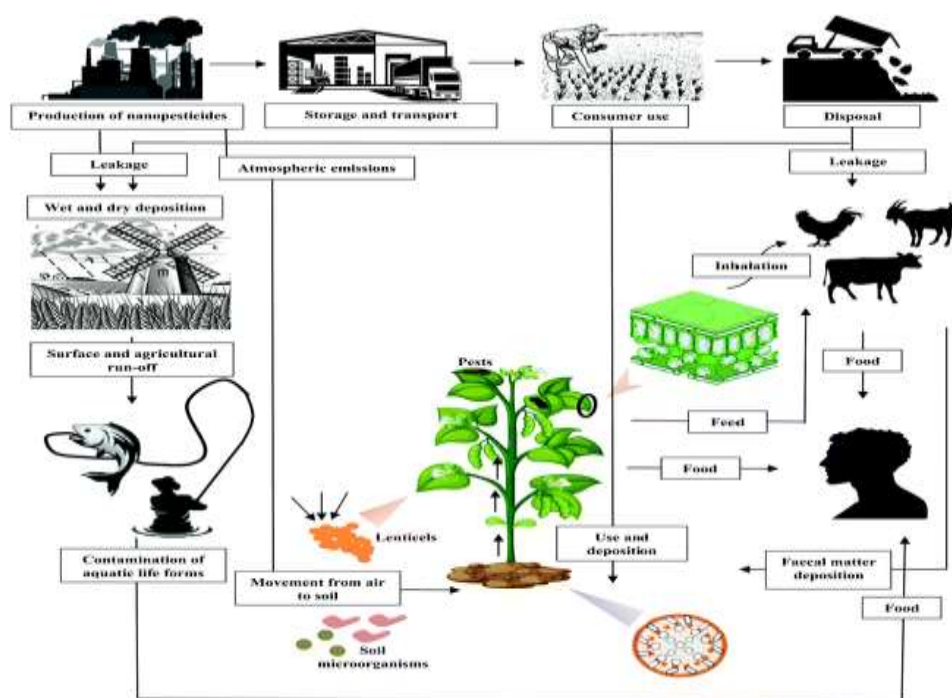


Figure 4. Potential implications of nanopesticide production and applications.
Source: Shekhar et al. (2021)

MATERIALS AND METHODS

A systematic literature review was conducted to identify relevant published articles between 2016 - 2024 on indigenous agricultural knowledge and nanotechnology. Keywords such as ‘nanotechnology’, ‘indigenous agricultural knowledge’, ‘toxicity’, ‘effect of pesticide toxicity’, ‘agricultural advancement in Africa’, and ‘challenges of nanotechnology’ were explored on several electronic databases like PubMed, Web of Science, Directory of Open Access Journals (DOAJ), and African Journals Online (AJOL). Only peer-reviewed journals, books, and reports were considered to ensure the credibility of the information. A total of 373 articles were identified in the first stage of review but only 46 articles were selected to be a good match for the review based on the objective of the study. The review is limited by the availability of full-text full-text articles.

DISCUSSIONS

IAK and nanotechnology for pesticide delivery: the way forward for agricultural advancement in Africa

Researchers have identified that combining IAK with scientific approaches has improved several facets of agriculture (Limpo et al., 2022; Al-Shabeeb et al., 2022; Ghidan et al., 2017). Due to their affordability, biodegradability, and comparable levels of control, plant-based alternatives have gained increasing attention as a safer and more sustainable option as opposed to synthetic products (Souto et al., 2021).

The use of NPs to improve the efficiency and safety of chemical applications to plants and combining it with IAK is a topic we investigate further.

The IAK of using plants to combat pests has been integrated into nanotechnology research by several researchers to synthesize NPs for pesticide formulation. These are innovations that could benefit the agricultural system in Africa. The synthesis of AgNPs from coriander was studied by M.Z.H. Khan et al. (2018). The coriander leaf extract was used in this study with an aqueous solution of AgNO_3 to synthesize AgNPs with silver ions being reduced into nanoparticles in this study. Tippayawat et al. (2016) used aloe vera extract to synthesize AgNPs. In this study, they employed a hydrothermal process used to produce uniformly small spheres of nanoparticles. Furthermore, Zinc oxide nanoparticles have been synthesized from *Vachellia nilotica* leaf extract (Gupta et al., 2024). Gunasekaran et al. (2023) synthesized Cerium Oxide (CeO_2), another significant NP from turmeric rhizomes.

Producing nanoparticles through green methods holds great promise for improving plant development while reducing the risk of phytotoxicity. It has been shown that producing nanoparticles via green methods is not only safe, but also environmentally friendly, cost-effective, and free of harmful chemicals (Garg et al., 2023). Ghidan et al. (2017) proposed the synthesis of MgHNPs using neem leaf extract which is traditionally used to control aphids. The concentration of MgHNP has been shown to have a significant effect on aphid mortality, suggesting their potential utility as an aphicide. However, more research in screenhouses and field settings is required to corroborate these findings (Ghidan et al., 2017). Judging by this, African farming and food systems could benefit greatly from the incorporation of IAK and the use of nanoparticles as it would not only dispel health and environmental concerns but also contribute to achieving food security in Africa.

CONCLUSIONS

The study aimed at exploring how Africa's agricultural sector can be advanced to promote environmentally sustainable practices toward achieving food security. The result of this study revealed that incorporating nanotechnology and IAK holds great promise for improving plant development, environmental preservation, and public health. This paper uniquely contributes to scientific knowledge in Africa especially in the area of incorporating nanotechnology and indigenous agricultural technology because there is very little research in this area. The case studies used were limited to Thailand and India which were the readily available research that had been carried out in this area of research as at the time of the writing of this review. These research works revealed that incorporating nanotechnology and IAK holds great promise for improving plant development, environmental preservation, and public health. This review study concludes with a recommendation for more research to be carried out to establish the cost implications and feasibility for small holder farmers in Africa. Additionally, it is recommended that the government provide funds for more research in this field toward food security and a sustainable environment.

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Conflicts of Interest: The authors declare no conflict of interest.

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