Smart Nanomaterials Technology

Azamal Husen *Editor*

Nanobiosensors for Agricultural and Other Related Sectors

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Contents

Gold Nanomaterials and Composites Based Nanosensors for Agricultural Sectors

Aisha Kamal, Ayeesha Khatoon, Nida Sultan, and Sazia Siddiqui

Abstract Gold nanomaterials and composite-based nanosensors have surfaced as pivotal tools of transformation in agricultural sectors, offering advanced solutions for pathogen detection, nutrient monitoring, and abiotic stress management. The nanosensors exploit the special properties inherent in gold nanomaterials, such as high surface-to-volume ratios, exceptional conductivity, and biocompatibility, to provide enhanced sensitivity and selectivity in detecting various agricultural analytes. They enable real-time, on-site monitoring of contaminants, pathogens, and nutrient levels, addressing critical challenges in sustainable agriculture and food security. Recent developments highlight their potential in identifying heavy metals, pesticides, and plant stress markers with unprecedented precision through techniques such as surface plasmon resonance (SPR), electrochemical sensing, and surface-enhanced Raman scattering (SERS). However, despite these advancements, several challenges remain, including high production costs, environmental concerns, and the need for integration with existing agricultural systems. Ensuring the stability and durability of nanosensors in harsh field conditions, along with the development of eco-friendly synthesis methods, is crucial for their practical application. Moreover, addressing regulatory and consumer acceptance issues is essential for the widespread adoption of these technologies. Future research should focus on enhancing cost-effectiveness, scalability, and field validation to bridge the gap between laboratory prototypes and real-world applications. By overcoming these challenges, gold nanomaterials and composite-based nanosensors can play a pivotal role in revolutionizing modern agriculture, contributing to increased productivity, resource efficiency, and environmental sustainability.

Keywords Gold nanoparticles · Gold nanomaterial based composites · Plant protection · Graphene · Au-NMs

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1 Introduction

Agriculture is a cornerstone of human society, providing food, raw materials, and livelihoods to billions worldwide. However, with the rapid increase in global population and the intensification of environmental challenges, the agricultural sector faces significant pressure to enhance productivity, optimize resource utilization, and ensure environmental sustainability. The adoption of cutting-edge technologies, such as nanosensors, represents a promising avenue for addressing these challenges by enabling precise, real-time monitoring and management of various agricultural parameters [1]. Among the different types of nanomaterials, gold-based nanomaterials and their composites have emerged as particularly effective candidates for developing high-performance nanosensors, due to their unique properties and versatility in diverse sensing applications.

Gold nanomaterials, known for their exceptional optical, electrochemical, and catalytic properties, are increasingly being employed in the agricultural sector [2]. Their tunable surface plasmon resonance, high biocompatibility, and excellent stability make them ideal for detecting a wide range of agricultural analytes, including soil nutrients, water pollutants, pathogens, and pesticides [3, 4]. Gold-based nanocomposites further enhance the functionality of these materials by combining them with polymers, carbon-based materials, and other metal oxides, thereby improving their sensitivity, selectivity, and stability under challenging environmental conditions [5, 6]

The applications of gold nanomaterials in agriculture are vast [7, 8]. From soil and water quality monitoring to real-time detection of plant health and pathogen exposure, gold-based nanosensors have the potential to revolutionize the way agricultural processes are managed. For example, gold nanosensors can detect heavy metal contaminants in soil at trace levels, ensuring that crops grow in safe, non-toxic conditions [9]. Additionally, they offer solutions for rapid, in-field detection of nutrient deficiencies and pest infestations, allowing farmers to make informed decisions that promote crop health and yield [10–12]. Despite the promise of gold nanomaterials in agriculture, several challenges remain. These include the high cost of production, potential environmental impacts, and issues related to scalability and regulatory approval [13, 14] Overcoming these obstacles will be essential for the widespread adoption of gold-based nanosensors and their integration into smart farming systems that leverage big data and Internet of Things (IoT) technologies.

This chapter provides an in-depth exploration of gold nanomaterials and composites-based nanosensors in agricultural applications. It examines their unique properties, synthesis methods, sensing mechanisms, and specific applications across different aspects of agriculture. The chapter also addresses the advantages, limitations, and future prospects of these nanosensors, emphasizing their transformative potential in modernizing agriculture to address the needs of a rising population and changing climate.