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Nanosensor for Abiotic Stress in Crop

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INTRODUCTION

Abiotic stress is caused by non-living environmental factors such as drought, salinity, extreme temperatures, flooding, heavy metals, and pollutants, which negatively affect plant growth and development. These stresses can reduce crop yield by more than 60% and may even lead to plant death in severe cases. To monitor such stresses, conventional techniques like gas chromatography, high-performance liquid chromatography, and mass spectrometry are used. Although these methods are highly accurate, they are expensive, time-consuming, require skilled personnel, and do not provide real-time results. Therefore, there is a need for simple, fast, and cost-effective methods for detecting agricultural stress. Nanotechnology has improved modern diagnostics by developing advanced tools like biosensors and biophotonic systems, which enable fast detection of pesticides, pathogens, toxins, and heavy metals. Nanosensors are small, efficient devices that can detect specific molecules or environmental changes at very low levels. They are easy to use, cost-effective, provide real-time results, and do not require trained personnel.

Abiotic Stresses in Crops

Abiotic stress is an environmental condition that affects plant growth, productivity, and quality. It includes factors like drought, temperature, flooding, salinity, and heavy metals. Among these, drought is one of the most harmful stresses in agriculture. Plants respond to drought by producing abscisic acid (ABA), changing gene expression, closing stomata to reduce water loss, and maintaining internal balance.

Understanding these responses and improving drought tolerance in crops are important for ensuring food production and sustainable water use. Soil salinity is a major problem that reduces land use and crop production. It occurs when high levels of salts, mainly NaCl, accumulate in the soil, causing osmotic stress that limits water uptake and ion toxicity due to excess Na^+ and Cl^-.

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This disrupts nutrient balance, reduces photosynthesis, and increases harmful reactive oxygen species, leading to damage in plants. It also affects the uptake of essential nutrients like K^+, Ca^{2+}, and NO_3^-. Plants respond by producing protective compounds, activating antioxidant systems, and changing gene expression. However, severe salinity stress can cause growth inhibition, leaf damage, and yield losses of up to 50%. Temperature stress affects crop growth and productivity and includes both high and low temperature conditions. High temperature stress damages plant growth when temperatures remain too high for long periods. Low temperature stress includes cold stress (0–15°C) and freezing stress (below 0°C), where ice formation can severely damage or kill plants. Both extremes reduce crop yield. In response, plants produce heat shock proteins (HSPs), which help protect and stabilize other proteins, allowing plants to tolerate high temperatures better. Heavy metal stress is a major problem that affects plant productivity due to the accumulation of toxic metals in soil and plants. Elements such as Zn, Cu, Mn, Ni, As, Pb, Cd, and Hg can disturb soil properties and harm plant growth. These metals cause morphological changes and metabolic disorders, leading to reduced crop yield.

Nanosensors

Nanosensors are tiny devices (1–100 nm) made from nanoscale materials, which makes them highly sensitive and selective. They can detect heavy metals, gases, biomolecules, microorganisms, and environmental factors like pH and temperature. Due to their small size, they enable fast and real-time detection, making them useful in agriculture, environment, and healthcare. A typical nanosensor works through three main steps. First, sample preparation involves treating the sample (such as soil, water, or plant material) to remove impurities and make the target substance easy to detect. Second, recognition occurs when the sensor specifically identifies the target molecule or analyte, such as a chemical, biomolecule, or microorganism. Finally, signal transduction converts this recognition event into a measurable signal (such as electrical or optical), which can be analyzed to determine the presence or amount of the target. Nanosensors work on the principle of specific interaction between the target substance (analyte) and a recognition element present on the sensor surface. When the analyte binds to the sensor, it causes small physical or chemical changes such as electrical, optical, or mechanical changes. These changes are then converted into measurable signals by a transducer, allowing accurate and real-time detection of the target substance.

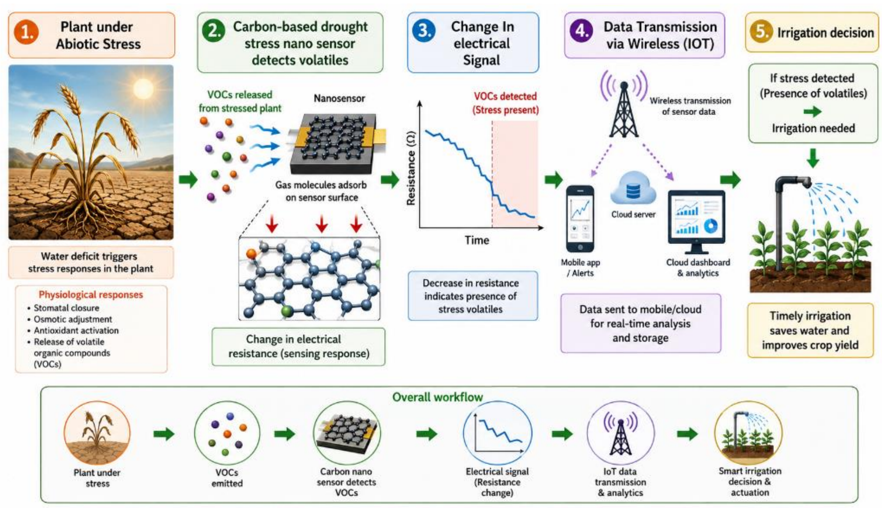

Figure 1. Mechanism how nanosensor works under Abiotic Stress

Types of nanosensor

Nanomaterials include different types such as nanoparticles, nanotubes, nanowires, nanocomposites, and quantum dots, each used for specific applications. Nanoparticles are very small particles, while nanotubes are tube-shaped structures at the nanoscale. Based on their working mechanism, nanosensors are classified into physical, chemical, and biological types. Physical nanosensors detect changes in physical properties like temperature, pressure, or light, and include piezoelectric sensors (which detect mechanical changes) and optical sensors (which respond to light). Chemical nanosensors identify substances such as gases, pesticides, or heavy metals through chemical reactions. Biological nanosensors use biological components like enzymes, antibodies, or DNA to detect biomolecules or microorganisms such as bacteria and viruses.

Applications

1. Irrigation friendly sensor to manage drought in crop

Nanosensor is a gas-based sensor used to detect β-caryophyllene, a volatile organic compound released by plants under stress. It is made of nanomaterial reduced graphene oxide (rGO) and metal oxide (ZnO). This sensor works mainly for detecting drought stress and has a detection limit of 27 ppb. It is non-invasive and allows real-time monitoring. The working mechanism is simple when a plant is under drought stress, it releases β-caryophyllene gas, which is detected by a chemiresistive sensor made of rGO/ZnO. rGO is highly sensitive to gases, while ZnO increases the surface area and enables fast electron transfer. When the gas is adsorbed onto the nanomaterial surface, oxygen ions capture electrons, leading to a change in electrical resistance. This change indicates that the plant is under stress. This technology is very useful in agriculture because it helps farmers detect stress before any visible damage appears. With early detection, farmers can provide water at the right time, save crops, and avoid losses. It also supports smart farming by enabling real-time monitoring without harming the plant. For common people, this means better crop production, less water wastage, lower farming costs, and improved food availability. Overall, nanosensors are a simple, fast, and effective way to manage abiotic stress and make agriculture more sustainable.

2. Eco- friendly temperature based nanosensor with wireless module (RFID/IoT)

This nanosensor is temperature-based and integrated with a wireless module (RFID/IoT). RFID (Radio Frequency Identification) is used for data transmission. The RFID tag (sensor) is attached to the leaf, and the RFID reader is the device that collects the data. IoT is used for data monitoring and analysis. The sensors send data to mobile phones, computers, or cloud systems. This nanosensor is used to detect leaf temperature and air temperature and works against temperature stress. It operates on a thermal sensing principle and is sensitive to small temperature differences (~0.1–0.5 °C). The working mechanism is simple, when a plant is under temperature stress, its leaf temperature becomes higher than the air temperature. This happens due to a decrease in transpiration, which makes the leaf warmer. When the leaf temperature is measured, a higher temperature difference indicates more stress. This leads to wireless data transmission, where the signal is converted into an electrical signal. Data analysis is then performed, and the temperature difference between the leaf and air is measured to detect stress. This technology is very helpful for farmers, as data is monitored in real time. Signals are sent through RFID (radio signals) and IoT systems. Due to early detection, crop losses can be reduced.

3. Drought Stress Monitoring in Wheat Using Wireless Sensors

This is a wireless sensor network (WSN)-based on environmental sensing system that detects physical parameters such

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as soil moisture, temperature, and humidity under drought stress in wheat plants. Its detection limit is based on threshold values of about 30–40%. If the value falls below this range, irrigation is turned ON. It works on a simple mechanism as sensors measure soil moisture, temperature, light, and humidity. A microcontroller collects and processes the sensor data, which is then transmitted wirelessly to a server or cloud. The decision-making mechanism detects drought stress and decides the required action. The automatic irrigation system then turns ON or OFF accordingly when drought stress is detected. This system is helpful for farmers in managing drought stress. It is a good application for smart irrigation systems, reducing water loss. It can also be useful for achieving sustainability and precision farming in the future. It improves wheat growth under drought conditions and is suitable for large-scale farming.

4. Nanosensor for Ethylene Detection in Fruit Ripening

This is a type of chemiresistive nanosensor used to detect ethylene gas, which is helpful in the ripening of plants. It works on a simple mechanism: ethylene gas released by plants interacts with the sensor surface, causing a change in electrical resistance. This change is measured and indicates the stress level or ripening stage. Its detection limit is as low as 0.5 ppm of ethylene. It is used for monitoring fruit ripening, detecting stress in plants, determining the optimal harvest time, and controlling storage conditions to reduce spoilage. Its advantages include early detection of stress and ripening, non-invasive operation, real-time monitoring, reduced post-harvest losses, improved storage management, and enhanced crop quality and shelf life.

CONCLUSION

Nanosensors act as early warning systems in crops by providing real-time, accurate, and non-destructive monitoring of plant stress. They help in detecting stress at an early stage, allowing timely management practices to reduce crop losses. By improving decision-making in irrigation and crop care, nanosensors make agriculture more efficient and resource-saving. Overall, their use supports sustainable farming, enhances productivity, and ensures better food security for the growing population.

