Rapid On-site Detection of Pesticide Residues in Agricultural Foods

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Pesticides are substances used to control pests, including insects, weeds, fungi, and other organisms that often harm crops. Pesticides are crucial in agriculture to protect crop plants and ensure food production. Chemical pesticides are synthetic substances manufactured specifically to kill or control pests. Chemical pesticides are most commonly used because of their effectiveness in managing various pests rapidly. These chemicals may include insecticides to combat from insects, herbicides to control weeds, and fungicides to prevent fungal diseases. In today's agricultural landscape, ensuring the safety and quality of the food we consume is paramount. Pesticides play a crucial role in protecting crops from pests and diseases, yet their residues on agricultural produce present potential health risks, if not effectively monitored. The need for rapid, on-site detection of pesticide residues in food has become increasingly imperative, fostering a demand for innovative technologies and methods to address this concern.

Impact of Pesticide Residue on Human Health and Environment

Pesticide residues have significant implications for both human health and the environment. Exposure to these residues, present in food, air, water, and soils, can lead to various health issues. Pesticides have been linked to chronic illnesses such as cancer, respiratory diseases, and neurological disorders. They can also impact reproductive health, causing birth defects, sterility, and infertility. The negative effects extend to non-target organisms, causing endocrine disruption and reproductive problems. Pesticide pollution has raised a serious concern for their presence in the gut microbiome and also adversely affects the nervous system.

Environmental consequences of pesticide pollution have led to the reduction of the biodiversity in soil. Pesticides also contaminate water sources and harm aquatic life. It was recently reported that pesticide depositions have led to significant environmental degradation. Soil respiration decreased by 35%, and around 90% of the water sources in agro-lands become polluted due to pesticide runoff. Pesticide pollution has even dire consequences for microbial life, disrupting soil ecosystems. Pesticides accumulate and magnify within aquatic and terrestrial food chains, endangering their integrity. Studies in Europe reveal a huge threat to the biodiversity posing a 70% decline in insect biomass and 50% in farmland bird populations, similar reductions in species richness have been noted globally. United Nation warns of global pollinator risk, particularly for bees and butterflies, for bees have been suffered injurious effects with notable decrease in their ecological contributions. Honey bee

populations are continuously declining posing adverse impact on pollination. Pesticide contamination risks to human health through the food chain.

Several epidemiological and molecular researches highlighted a close association between persistent pesticides exposure and increased risk of diseases such as neurodegenerative disorders, endocrine disruptors, respiratory complications, reproductive disorders, and birth defects. The consumption of such vegetables and fruits that are grown in pesticide contaminated soil and water used for long-term, accumulation increase the concentration of toxins inside the body organs and causes chronic diseases such as neurotoxicity, cancer, necrosis, asthma, reproductive disorder, cardiac disease, diabetes, etc..

## Importance of Pesticide Residue Detection for Food Safety

Pesticide residue detection is of paramount importance for ensuring food safety. The residues left on food after pesticide application has tremendous hazards to human health. Rapid on-site testing plays a vital role in identifying unacceptable levels of pesticide residues in agricultural products, thereby safeguarding consumers. Such detection methods, including mass spectrometry and intelligent analysis systems allow for efficient screening to prevent harmful residues from entering the food chain.

In the pursuit of effective pest control and increased crop yields, farmers usually use excessive amounts of pesticides, resulting in unacceptably high levels of pesticide residues in many agricultural products. These residues, if consumed, are highly toxic to humans and may lead to fatal illnesses and their accumulation in long term sometimes leading to cancer and many other chronic conditions. Conventional laboratory-based pesticide detection methods suffer the limitation of being time-consuming, dependency on skilled personnel and nevertheless expensive. Consequently, the demand for precise, swift, and on-site pesticide analysis is increasing, driven by concerns for food safety. As a result, the significance of on-site or point-of-care (POC) pesticide residue detection has grown considerably, addressing the urgent need for ensuring the safety of food supply.

An increase in annual rate of pesticide usage widespread, often surpassing recommended levels, combined with prolonged use, has raised alarming concerns due to potential ecological and food safety risks. Pesticide residues have permeated various mediums, encompassing soil, water, fruits, vegetables, and crops, triggering apprehensions about their impact on ecological systems and human health. This concern addressed by many countries has established monitoring programs. These programs include routine checks on locally sold food and agricultural products to evaluate pesticide residue levels. The aim is to ensure the safety of food by assessing the presence of pesticide residues and associated health risks.

Analytical methods for detection of pesticides in fruits and vegetables

The detection of pesticides in fruits and vegetables involves various analytical methods. Traditional techniques include gas chromatography, high-performance liquid chromatography (HPLC), and mass spectrometry. These methods offer accurate results but can be time-consuming and require trained personnel. More modern approaches employ automated systems for rapid detection at the site, enhancing efficiency. Advances in analytical methods have enabled the quantification of pesticide residues in different produce like grapes, tomatoes, apples, and more. Analytical quality control and method validation are essential aspects of pesticide residue analysis, ensuring reliable results and food safety. Several studies provide insights into the comprehensive array of techniques employed for pesticide detection in fruits and vegetables. Chromatographic methods that are commonly used in determination and separation of target pesticides and herbicides include gas chromatography and liquid chromatography. Mass spectrometry is used as an additional technique coupled with gas chromatography and liquid chromatography in order to enhance the detection performance.
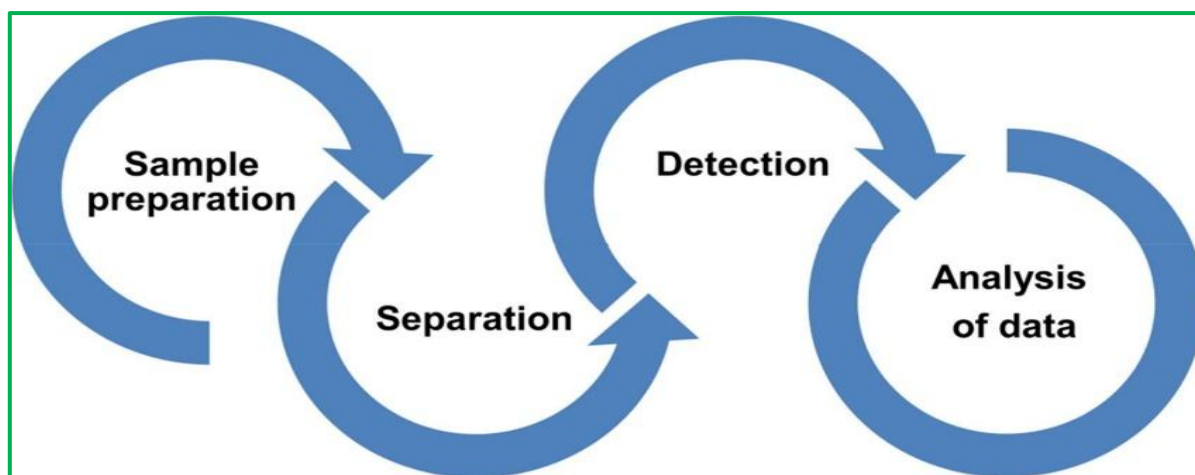
Steps involved in the determination of pesticides

Recently reported conventional analytical methods for monitoring pesticide residues include liquid chromatography, capillary electrophoresis, gas chromatography, thin-layer chromatography, micellar electrokinetic capillary chromatography, fluorescence microscopy, gas chromatography–mass spectrometry, quantitative real-time polymerase chain reaction, high-performance liquid chromatography, enzyme-linked immunosorbent assays (ELISA), and liquid chromatography–mass spectrometry (LC-MS). All these analytical methods possess a substantial degree of selectivity, sensitivity, and reliability. Furthermore, they are all characterized by a low limit of detection (LOD). However, these techniques are laborious and time-consuming; involving complicated solvent extraction and sample pretreatment procedures, and require sophisticated laboratory procedures and instrumentation, whereby they involve a high degree of difficulty while examining pesticide residues, thus requiring professionally trained technicians, expensive analysis, and time-consuming operational processes.

In contrast to the traditional pesticide-screening methods, modern innovative approaches involve integrating modified materials, functionalized nanoparticles, and engineered nanomaterials into the analysis of substrate matrices and target analysts. Despite the pros and *cons* of these traditional techniques, their use is gradually declining due to their unsuitability for on-site monitoring of pesticide residues. Consequently, there is a pressing need to design and create cost-effective, straightforward, efficient, and swift on-site sensing methods, along with portable tools. These advancements are crucial to accurately detect pesticides in fruits and vegetables on-site, promoting both food safety and public health objectives.

Rapid onsite detection of pesticide residues in agricultural foods

Importance of non-destructive quality evaluation techniques of fruits and vegetable

Non-destructive quality evaluation techniques are pivotal for pesticide detection in fruits and vegetables due to their significance in maintaining product integrity and safety. These techniques enable the assessment of pesticide residues without altering the produce's physical characteristics. Methods like Near-Infrared Spectroscopy (NIRS) have been applied to detect pesticide residues qualitatively and quantitatively, enhancing researcher capabilities. Such non-destructive approaches aid in ensuring food safety and quality by detecting contaminants without compromising the product's visual appearance, taste, and texture.

The importance of non-destructive techniques extends to quality assessment of fruits and vegetables themselves. These methods allow for rapid and accurate evaluation of attributes such as ripeness, freshness, and nutritional content, contributing to informed decision-making in the supply chain. Moreover, non-destructive evaluation minimizes waste, enhances consumer satisfaction, and supports sustainable agricultural practices by optimizing resource utilization. In the context of pesticide detection, non-destructive methods play a crucial role in safeguarding public health and maintaining the overall quality and safety of food products.

Some common non-destructive evaluation methods include:

1. **Spectroscopy:** This technique involves analyzing the interaction between matter and electromagnetic radiation to determine properties like chemical composition, ripeness, and nutritional content. Near-infrared spectroscopy (NIRS) and hyperspectral imaging are examples used for non-destructive analysis.

2. **Imaging Technologies:** Various imaging technologies, including digital cameras, infrared imaging, and computed tomography (CT), allow visual inspection and analysis of external and internal characteristics such as size, color, and defects without damaging the produce.

3. **Ultrasonic and acoustic methods:** These techniques use sound waves to evaluate the internal quality of fruits and vegetables, assessing factors like firmness, maturity, and structural integrity.

4. **Electrical Impedance or Conductivity:** The electrical properties of the produce such as impedance or conductivity can be measured. These methods determine moisture content which is crucial for assessing freshness and shelf life of the produce.

5. **Gas Sensors:** Gas sensors are employed to detect and quantify volatile compounds emitted by fruits and vegetables. This helps in determining ripeness, freshness, and detecting spoilage.

6. **X-ray and Magnetic Resonance Imaging (MRI):** These advanced techniques provide detailed internal information about the structure, composition, and defects within the produce without causing damage.

7. **Electronic Nose and Tongue:** These sensor arrays mimic human olfactory and gustatory senses, detecting odors and flavors to assess the quality and authenticity of fruits and vegetables.

Conclusion

These non-destructive techniques offer several advantages. They allow for rapid and accurate assessment, enabling timely decisions in harvesting, storage, and distribution. They also contribute to reducing waste by aiding in proper sorting, grading, and ensuring optimal post-harvest handling. Moreover, these methods promote food safety by detecting contaminants or defects without compromising the integrity of the produce.