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Research on the application of rapid detection technology in agricultural product safety

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ABSTRACT
The safety of agricultural products is at the core of ensuring people's livelihood and promoting high-quality agricultural development. This paper focuses on the testing needs for pesticide residues and heavy metal pollution in agricultural products, summarizing the application issues of rapid detection technologies in this field. To address technical challenges, unclear operational standards, and unsuitable environments, this paper suggests specific strategies to improve the use of rapid detection technologies in agricultural product safety by focusing on three areas: advancing technology research and development, streamlining operational procedures, and strengthening safety measures. These strategies aim to provide theoretical support and practical approaches for the prevention and control of agricultural product safety.

KEYWORDS
Agricultural product safety; Rapid detection technology; Application problems; Application strategies

1 Introduction

Agricultural product quality and safety are crucial to public health and social stability. As the industry scales up, traditional testing methods, due to their long cycles and high costs, struggle to meet the demands of real-time supervision. In response, rapid detection technology, with its convenience and efficiency, has become an essential tool for agricultural product safety control. However, problems in using the technology and the absence of standard procedures have limited its effectiveness, making it necessary to conduct thorough research to improve regulatory efficiency over time.

2 Basic overview

2.1 Rapid detection technology

Rapid detection technology mainly uses physical, chemical, or biological methods to quickly verify and measure safety indicators like pesticide residues, veterinary drug residues, heavy metals, and microorganisms in agricultural products. Its core feature lies in breaking the time and space constraints of traditional laboratory testing, compressing the testing cycle from "daily" to "minute-level to hour-level." Additionally, it extends testing scenarios from laboratories to fields, production workshops, and distribution markets by simplifying operational procedures and reducing equipment size and cost. Rapid detection technology mainly includes three types: the first is immunoassay technology that uses specific antigen-antibody binding to quickly verify for pesticide residues in 10 to 15 minutes; the second is biosensor technology, which detects very small amounts of veterinary drug residues using immobilized enzymes, microbial cells, or nucleic acid probes; the third is portable spectroscopy technology, which scans materials quickly by looking at their molecular characteristics. These technologies, leveraging their advantages of "on-site, lightweight, and intelligent," have become the "frontline sentinels" in agricultural product quality and safety supervision, particularly suitable for initial risk screening and process control at the front end of the supply chain.

2.2 The value of agricultural product quality and safety demand

In the new era context, the demand for agricultural product quality and safety is not only a baseline requirement to ensure public health but also a core driving force for industrial upgrading and maintaining social stability. From the perspective of people's livelihood, China's consumption structure of agricultural products has shifted from "quantity safety" to "quality safety." The pesticide residue rate in fresh food agricultural products has exceeded 5% for three consecutive years, directly threatening consumer health. Establishing a rapid testing system covering the entire chain is a critical barrier to prevent risks from "farm to table." From an industry perspective, quality and safety are the foundation for the branding and internationalization of agricultural products. Markets such as the EU and the US set stringent inspection

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thresholds for imported agricultural products. Enhancing rapid testing capabilities can help Chinese agricultural products break through trade barriers.

3 Application of rapid detection technology in agricultural product safety

3.1 Technical bottleneck constraints

Firstly, the ability to resist interference in complex matrix samples is insufficient. In terms of detection sensitivity, the immunochromatographic test strip has inadequate resistance to interference from complex matrix samples, with some pesticide residue detection limits (LOD) still exceeding national standards. Regarding specificity, enzyme-linked immunosorbent assay (ELISA) can result in false positives due to antibody cross-reactivity at a rate of 12% to 15%. In a provincial agricultural product inspection in 2023, differences in antibody preparation processes led to a misjudgment rate of 8% for procymidone in leeks, resulting in 12 batches of qualified products being incorrectly deemed non-compliant. Secondly, the capability for multi-residue synchronous detection is insufficient. Current mainstream rapid testing technologies primarily target single pollutants, whereas actual contamination in agricultural products often presents a complex profile. Traditional methods require multiple tests, which are time-consuming and labor-intensive. Due to the limitations of portable spectrometers in spectral resolution, their accuracy in distinguishing structurally similar pollutants is only 75% to 80%, lower than the over 95% achieved by laboratory mass spectrometry. The inherent limitations of these technical principles make it difficult for rapid testing to fully replace traditional methods in "precise identification," especially in the initial screening of high-risk agricultural products, where there is a potential for amplified risks.

3.2 Lack of operation specifications

The standardization of testing operations directly affects the reliability of results. From a device perspective, rapid detectors from different manufacturers show significant differences in sample pre-treatment processes, calibration methods, and result interpretation standards. A comparison of 150 grassroots testing devices conducted by the Ministry of Agriculture and Rural Affairs in 2022 revealed that the maximum difference in dichlorvos detection results among the same batch of green vegetables reached 20%, leading to data distortion. Insufficient professional skills among personnel also exacerbate testing errors; less than 40% of personnel at county-level and lower regulatory agencies have professional testing qualifications. Some testers rely on experience rather than instrument quantification when interpreting colloidal gold strips, resulting in a misjudgment rate of up to 25% at critical values.

3.3 Adaptation to environmental limitations

Temperature and humidity sensitivity is a common issue: when the humidity exceeds 80% or the temperature drops below 5℃, the chromatographic rate of the nitrocellulose membrane changes, leading to abnormal color development on the test line. A cold chain logistics company experienced an error rate of 18% due to low temperatures in their winter transportation tests; the stability of the optical path system in portable near-infrared spectrometers decreases at high temperatures, with wavelength drift exceeding 0.5nm, causing the deviation in fruit sugar content detection to expand to ±5%. Complex matrix interference further limits the applicability of the technology. Fats and proteins in livestock and poultry products can clog the recognition sites of biosensors, leading to signal attenuation in veterinary drug residue detection. The pH value and organic matter content of soil significantly affect rapid heavy metal detection instruments; in acidic soils (pH <5.0), the detection error for cadmium increases by 2 to 3 times compared to standard conditions. Insufficient environmental adaptability greatly reduces the effectiveness of rapid detection technologies in extreme climate regions and special farming and breeding scenarios, making it difficult to meet the regulatory needs across the entire chain and all scenarios.

4 Application strategies of rapid detection technology in agricultural product safety

4.1 Strengthen technology research and development: break through the bottleneck of trace detection and matrix interference

4.1.1 Nanomaterials drive the performance of trace detection to leap forward

Surface functionalization of nanomaterials has provided a revolutionary solution for trace detection. After antibody-directed conjugation, the plasmon resonance effect of gold nanoparticles reduces the detection limit of clenbuterol on immunochromatographic test strips from 5 ng/mL to 0.3 ng/mL, achieving one-tenth of the national standard requirement and meeting the on-site screening needs for β-receptor agonists in livestock and poultry products. Two-dimensional MXene materials, with their ultra-high specific surface area and electronic conductivity, demonstrate excellent performance in heavy metal detection, lowering the detection limit for cadmium and lead to 0.1 μg/L, which is ten times higher than traditional electrochemical methods, making them suitable for real-time monitoring of environmental samples such as soil and irrigation water. More advanced quantum dot fluorescence labeling technology, through tunable fluorescence wavelengths, enables simultaneous detection of multiple residues. A single quantum dot can be conjugated with more than three antibodies, increasing the throughput of multi-residue detection for organophosphorus and carbamate pesticides in vegetables by three times, reducing the detection time per sample to 15 minutes.

4.1.2 Bionics technology solves the problem of specific detection

Regarding the antibody cross-reactivity issue in traditional immunotechnologies, molecular imprinting polymers (MIP) and CRISPR-Cas systems have brought about breakthrough progress. MIP accurately distinguishes between imidacloprid and its structural analogs with a 98% accuracy rate, surpassing ELISA technology and effectively addressing the misidentification of neonicotinoid pesticides. The CRISPR-Cas12a system achieves gene-level precise identification of target pollutants by designing sgRNA sequences that target pesticide molecules. After identifying the target molecule, it triggers fluorescence signal amplification, enhancing detection specificity while simplifying the process to a two-step "add sample-reaction" method, reducing the time to just 30 minutes. In the field of matrix separation, microfluidic chips integrated with immunomagnetic bead technology can efficiently separate fat particles from veterinary drug residues in livestock meat samples within 5 minutes, improving sensor signal stability and resolving interference from high-fat matrices.

4.1.3 Intelligent algorithm enables complex data parsing

The integration of machine learning and spectroscopy significantly enhances the ability to identify complex matrices. By combining convolutional neural networks (CNNs) with Raman spectroscopy, specialized recognition models have been established for high-fiber samples such as spinach and celery. Through training on 100,000 spectral images, the accuracy of pesticide residue identification has been improved, effectively addressing the peak overlap issue in traditional spectroscopic techniques. In the field of mass spectrometry data analysis, an intelligent system based on gradient boosting tree (GBRT) algorithms can automatically identify 120 antibiotics and their metabolites in poultry and livestock meat, reducing the detection time to 40 minutes and lowering the false positive rate to below 5%, providing efficient technical tools for grassroots supervision.

These technological breakthroughs bring rapid testing close to the level of laboratory mass spectrometry in terms of qualitative and quantitative analysis of trace pollutants and precise identification of complex matrices. The cost of single-sample testing has been reduced from 50 yuan to less than 15 yuan, making it economically viable for large-scale application and promotion.

4.2 Optimize the operation process: build a standardized and intelligent management system

4.2.1 Construction of standardized operation specifications for the whole chain

The Ministry of Agriculture and Rural Affairs should lead the formulation of the "Technical Application Specifications for Rapid Detection of Agricultural Products," clarifying operational standards for three core stages: First, standardize key parameters such as particle size, solvent ratio, and oscillation time for 12 types of matrices, including leafy vegetables, poultry meat, and soil. Pilot data from a central province shows that after unifying the pre-treatment process, the repeatability error of test results has been reduced to 8%, significantly improving consistency at the grassroots level. The second step involves the establishment of a three-tier calibration system, which includes weekly calibration at the county level, quarterly validation at the city level, and an annual comparison at the provincial level. Portable spectrometers are required to calibrate their optical paths using standard solutions weekly, and municipal institutions conduct comprehensive performance validations, including linearity and precision, every quarter. In the pilot program in Guangdong, the wavelength drift of grassroots equipment was controlled within ±0.3nm, leading to an increase in the pass rate of test data. Third, developing a quantitative judgment mathematical model based on grayscale values, converting the color intensity of colloidal gold strips into concentration values, replacing traditional visual colorimetry methods, reducing the false positive rate of critical values to 5%, and increasing the compliance rate of test reports to 95%.

4.2.2 Integration and application of intelligent detection mobile platform

Relying on IoT, blockchain, and AI technologies to develop an "intelligent inspection mobile platform" for the full digital management of inspection processes:

First, by using built-in sensors in devices to collect 12 operational data points, such as calibration time, environmental temperature and humidity, and sample volume in real-time, the platform automatically triggers audio-visual alerts and locks the device when inspectors fail to calibrate according to standard procedures. After application at a wholesale market in Zhejiang, the rate of non-compliance dropped to 4%, significantly enhancing the standardization of inspection processes.

Second, setting 80% of national standards as warning thresholds, the platform automatically initiates a three-level response mechanism —primary warning, intermediate response, and advanced response—when detection values exceed limits. In Shandong's pilot program, the time from exceeding standards to initiating recalls was reduced to 6 hours, increasing risk-handling efficiency by 8 times.

4.3 Improve the guarantee mechanism: build a scenario adaptation and collaborative supervision network

4.3.1 Accurately formulate technical application guidelines for different scenarios

Develop an "one scenario, one solution" adaptation strategy for the environmental characteristics and matrix interference of different application scenarios:

(1) Cold chain logistics scenario: To address the impact of low temperatures and high humidity on immunochromatographic test strips, the guidelines require portable testing kits with temperature control and dehumidification functions. The test strips should be stored vertically to prevent moisture from affecting the membrane material, and a compensation model for color intensity at low temperatures must be established. After application by a dairy company, the misjudgment rate during winter transportation was reduced to 3%.

(2) Acid soil detection scenario: In view of the problem that the error of heavy metal detection increases when pH is less than 5.0, the guide proposes to adjust the pH of the leaching solution to 7.0±0.5 with EDTA-Na solution and establish the pH compensation equation for cadmium detection, which is built into the detector to control the error rate within ±3%.

(3) Detection of high-fat livestock and poultry products: In view of the problem of fat blocking sensor identification sites, the guide recommends the use of n-hexane defatting pretreatment combined with ultrasonic assisted extraction (power 200 W, time 10 minutes) so as to improve the recovery rate of clenbuterol and other veterinary drug residues.

4.3.2 Three-dimensional collaboration of the three-level detection network

Construct a tiered supervision network of "rapid testing at the grassroots level—confirmation by municipal laboratories —early warning by provincial platforms" to achieve "early detection, precise identification, and broad alerting."

First, rapid testing at the grassroots level involves deploying portable devices with IoT and blockchain capabilities in town regulatory stations and farmers' markets, which upload test data in real-time and automatically mark critical values. In Hubei's pilot program, the efficiency of testing data from grassroots equipment has improved, reducing the time for risk discovery to 30 minutes.

Second, confirmation at the municipal level involves equipping municipal quality inspection centers with high-precision instruments such as GC-MS and LC-MS/MS, which handle three main functions: confirming samples that exceed standards, developing regional characteristic matrix standards, and training grassroots personnel. For example, in 2023, the Guangdong municipal center trained 4,200 people, increasing the standardized operation rate of frontline testers to 92%. Third, early warning at the provincial level uses GIS technology to create safety heat maps, establish seasonal risk prediction models, and set specific warning thresholds for varieties, enabling precise regulation.

5 Conclusions

In the new era context, optimizing and applying rapid detection technology is key to solving the challenges of agricultural product quality and safety supervision.

In the future, by breaking through sensitivity bottlenecks through technological research and development, establishing a standardized system for operational procedures, and enhancing environmental adaptability in safeguard mechanisms, a comprehensive quality and safety prevention model can be formed: "precise testing—intelligent supervision—coordinated governance." Rapid detection will ultimately become the foundational data cornerstone of the big data platform for agricultural product quality and safety.

References

[1] Liu Bing. (2025). Exploration and Discussion on the Application of Rapid Detection Technology in the Testing of Fruit and Vegetable Agricultural Products. China Food Industry, (04),67-69.

[2] Sun Ai Yuan. (2024). Exploration and Discussion on the Application of Rapid Detection Technology in the Inspection of Fruit and Vegetable Agricultural Products. Food Industry at Home and Abroad, (23),47-49.

[3] Li Chunsheng, Zhang Weiran, Wu Danmiao, Chen Xingjuan. (2020). Problems encountered and solutions in rapid detection of agricultural products. Agricultural Technology and Equipment, (11),93-94.

[4] He Fengzhen. (2022). Application research of rapid detection technology in agricultural product testing. New Agriculture, (13),71-72.

[5] Guan Long, Wu's Nuan, Xu Ningning. (2024). Application of New Rapid Detection Technology in the Quality and Safety of Agricultural Products. Food Safety Guide, (36),137-139.