Scientific and Social Research, 2026, Volume 8, Issue 1
https://ojs.bbwpublisher.com/index.php/SSR
Online ISSN: 2981-9946
Print ISSN: 2661-4332

Research on the Application of Rapid Food Detection Technology in Cross-border Food Supervision

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Abstract: Food quality and safety are related to public health and life safety, and are the core issues of food supervision work. With the rapid development of the cross-border food industry, the complexity of the food supply chain has continuously increased. Traditional laboratory detection methods are difficult to meet the needs of real-time and rapid supervision due to limitations such as long time consumption and cumbersome processes. With its characteristics of speed, convenience, and efficiency, rapid food detection technology plays an increasingly important role in cross-border food supervision and has become a key technical support for ensuring food safety. Based on this, this paper focuses on introducing the application practice of rapid food detection technology in cross-border food supervision, and analyzes its application paths in cross-border food supervision from four aspects: raising attention, optimizing application processes, strengthening team building, and improving the institutional system, aiming to provide reference for the application of rapid food detection technology in cross-border food safety supervision.

Keywords: Food; Rapid detection technology; Cross-border; Food supervision

Online publication: January 30, 2026

1. Application status of rapid food detection technology in the food supervision industry

1.1. Application characteristics of rapid food detection technology

Rapid food detection technology shows significant speed advantages in practical applications, capable of completing the analysis and judgment of harmful substances or key indicators in food samples in a short time [1]. Traditional laboratory detection usually takes hours or even days for sample pretreatment, instrumental analysis, and result confirmation, while rapid detection technology compresses the entire detection cycle to a few minutes to tens of minutes through integrated reagents, portable equipment, and real-time reading systems.

The operation process of this technology is highly convenient. Most rapid detection methods are designed as modular processes, which can be independently completed on-site by front-line supervisors without complex professional training. For example, immunochromatographic test strips, color card kits, and handheld spectrometers all support simple steps of "sampling — adding reagents — observing results", and some equipment is also equipped with intelligent terminal connection functions to realize automatic data collection and transmission [2].

Economically, the cost of rapid food detection technology is significantly lower than that of traditional physical and chemical analysis methods [3]. This is mainly reflected in low equipment investment, controllable consumable prices, and low labor demand. The purchase cost of conventional high-performance liquid chromatography or mass spectrometry instruments is high, maintenance is complex, and professional and technical personnel are required to be on duty for a long time. In contrast, the portable devices relied on by rapid detection have a low unit price, strong reusability, and supporting reagents are mostly supplied in mass production, further reducing the cost of a single detection.

These characteristics together form the practical foundation of rapid food detection technology in cross-border supervision scenarios. The improvement of detection speed responds to the strict requirements of international trade for timeliness, the simplicity of operation ensures the implementability of the technology in various environments, and the low-cost structure provides economic feasibility for continuous and regular monitoring. The combination of the three makes rapid detection not only an effective tool for risk preliminary screening but also creates conditions for establishing a dynamic response mechanism, promoting the development of cross-border food safety governance towards efficiency, precision, and sustainability [4].

1.2. Application scenarios of rapid food detection technology

In the source control stage, rapid detection technology is widely used in initial links such as agricultural product planting, livestock and poultry breeding, and aquatic product fishing. On-site screening of pesticide residues, veterinary drug residues, heavy metal pollution, and prohibited additives that may exist in soil, water sources, feed, and animals and plants through portable detection equipment can effectively identify potential risk factors [5]. In export-oriented agricultural production bases, rapid detection methods have realized the whole-process data tracking from the field to before export declaration, improving the authenticity and traceability of source data.

After entering the production and processing link, rapid food detection technology is mainly used for raw material acceptance, processing process control, and finished product factory inspection. In cross-border food production enterprises, raw materials come from different countries or regions with complex components and inconsistent standards. Rapid detection methods can complete the screening of microbial pollution, toxin content, allergenic substances, and illegal additives in a short time to ensure that products meet the quality and safety regulations of the importing country. At the same time, some automated rapid detection systems have been integrated into production lines to realize online dynamic monitoring, further improving the precision and coverage of supervision [6].

In the circulation and sales stage, rapid food detection technology has become an important tool to cope with the complexity of cross-border logistics and market diversity. Since cross-border food usually undergoes long-distance transportation, multi-node warehousing, and cross-border distribution, it is vulnerable to temperature fluctuations, packaging damage, and cross-contamination. Therefore, rapid detection methods are widely used in

port inspection, bonded warehouse sampling inspection, and retail terminal supervision. With the help of mobile rapid detection vehicles and handheld Raman spectrometers, customs supervision departments can complete the preliminary determination of adulterated components, genetically modified components, or excessive preservatives in imported food within a few minutes, greatly shortening the customs clearance time. The rapid response capability at this stage not only enhances consumer confidence but also improves the risk prevention and control level of the entire cross-border food supply chain.

1.3. Common rapid food detection technologies

Molecular biology rapid detection methods occupy an important position in rapid food detection, and are widely used in cross-border food supervision due to their advantages of high sensitivity, strong specificity, and short cycle [7]. Among them, polymerase chain reaction (PCR) technology is the core means, which realizes the accurate identification of pathogens by amplifying specific DNA fragments of target microorganisms. Quantitative real-time PCR further improves the visualization and quantitative capabilities of detection, and can complete the detection of common foodborne pathogens such as *Salmonella*, *Listeria monocytogenes*, and *Escherichia coli* O157:H7 within a few hours, which is suitable for on-site screening of imported meat products, dairy products, and aquatic products. Combined with specific primer and probe design, this technology can effectively distinguish live bacteria from dead bacteria, reduce false positive results, and improve the scientificity of regulatory decisions.

Loop-mediated isothermal amplification (LAMP) technology, as an emerging molecular detection method, achieves efficient amplification without complex temperature cycling equipment, making it particularly suitable for on-site rapid detection at ports [8]. The reaction process is carried out at a constant temperature, usually 60–65 ℃, for 30–60 minutes to complete the detection. Combined with visually observable color changes or turbidity to judge results, it significantly reduces the dependence on professional instruments. LAMP has been successfully applied to the simultaneous screening of pesticide residue-associated microbial contamination in cross-border fruits and vegetables, as well as the rapid identification of Vibrio parahaemolyticus in frozen seafood, with good on-site applicability.

Gene chip technology realizes the simultaneous detection of multiple pathogens through high-throughput parallel analysis of multiple target gene sequences. When facing a type of imported food with complex sources and diverse batches, this technology can screen dozens of potential pathogenic microorganisms at one time, improving the coverage and efficiency of supervision. Although the current equipment cost is relatively high, with the development of microfluidic and integrated platforms, portable gene chip detection systems have gradually entered the practical stage, providing stronger technical support for border inspection institutions [9].

2. Application strategies of rapid food detection technology in cross-border food supervision

2.1. Attach importance to food supervision and increase support for rapid food detection technology

Relevant national departments should formulate and issue special policy documents for rapid food detection technology, establish the legality and authority of rapid detection technology from the top-level design, and clarify its legal status and technical standards in the import and export inspection and quarantine process. By incorporating rapid detection technology into the formal supervision process and endowing it with the same effectiveness as traditional laboratory detection or the legal function as a pre-screening tool, the law enforcement

basis and technical credibility are enhanced. Policy guidance should also reflect the incentive orientation for technological innovation and industrial development, encouraging scientific research institutions, universities, and enterprises to jointly carry out key technological research, and promoting breakthroughs in key areas such as new sensing materials, portable instrumentation, and intelligent data analysis systems [10].

Financial investment is an important guarantee for technological implementation. The government needs to set up special funds to support the construction of rapid detection capabilities at border ports, bonded areas, and key import distribution centers. Funds can be used to purchase advanced rapid detection equipment with high sensitivity and multi-item joint inspection, update old facilities, and modernize detection capabilities [11]. Support the construction of regional rapid detection centers to form a technical network covering major import and export channels. Introduce a performance evaluation mechanism in the process of fund use to ensure that funds are used for specific purposes and improve the efficiency of fund use. Give preferential support to grass-roots supervision units in equipping basic rapid detection equipment to narrow the gap in supervision capabilities between regions. Through continuous capital injection and technological iteration, the rapid detection system can always maintain the ability to respond to emerging pollutants, illegal additives, and unknown risk factors, and effectively build a cross-border food safety defense line.

2.2. Optimize rapid detection processes and improve the application efficiency of cross-border rapid food detection

First, establishing an efficient and scientific rapid detection process helps shorten the detection cycle, improve customs clearance efficiency, and ensure the safety of imported food [12]. Based on the current characteristics and risk distribution of cross-border food circulation, relevant government supervision departments should organize professional and technical forces to formulate unified and operable rapid detection operation guidelines, clarifying the technical parameters and implementation specifications of each step. Through the issuance and promotion of standardized documents, break the result deviations caused by operational differences between regions and departments, and realize homogeneous and same-standard detection work at ports, logistics hubs, and border checkpoints, enhancing the mutual recognition and authority of detection data.

In the actual supervision process, avoid relying solely on a single detection method, and take rapid detection as one of the core tools to organically combine with other inspection modes. Conventional laboratory inspection has high accuracy and is suitable for confirmatory analysis; sampling inspection can reflect the quality status of the entire batch; while rapid detection highlights the advantages of “speed” and “convenience”, and is suitable for large-scale screening in the early stage of entry. Reasonably embed the three into the supervision chain to form a progressive inspection mechanism of “preliminary screening — classification — precise inspection”, which can not only improve the discovery probability of problematic food but also reduce the resource pressure caused by comprehensive inspection and submission. For example, during the customs clearance of imported fresh products, priority is given to on-site pesticide and veterinary drug residue detection using immunochromatographic test strips or portable Raman spectrometers, and suspected positive samples are transferred to laboratories for quantitative verification, so as to achieve precise risk interception [13].

Build a cross-border rapid food detection data sharing platform to realize real-time upload, automatic comparison, and early warning push of detection results, helping supervision departments dynamically grasp the food safety situation. Cooperate with electronic labels, blockchain traceability, and other technologies to ensure that the identity of detection objects is traceable, the process is monitorable, and the results are reviewable. At the

same time, promote the intelligent upgrading of detection equipment, develop multi-functional integrated portable devices, reduce the dependence on operators' experience, and further improve the stability and response speed of on-site detection. The continuous improvement of the process also needs to be regularly evaluated based on actual operation feedback, identify bottleneck links, and implement dynamic adjustments, ensuring that the rapid detection system always adapts to the development rhythm of cross-border trade and the changing trends of new security threats.

2.3. Strengthen the rapid detection team and cultivate high-quality cross-border rapid food detection talents

Strengthening the construction of the cross-border rapid food detection team is crucial to building a scientific and systematic talent training mechanism. Institutions of higher learning, vocational training institutions, and supervision departments can cooperate to offer professional courses targeting rapid food detection technology, strengthen the teaching of microbial detection, chemical residue analysis, molecular biology technology, and other contents, ensuring that talents have a solid professional foundation [14].

Establishing a scientific and reasonable assessment mechanism is important for maintaining team vitality. Set unified assessment standards to comprehensively evaluate rapid detection personnel from multiple dimensions, such as theoretical knowledge, practical operation, emergency response, and professional ethics. The assessment cycle is set to once every six months or a year, organized by an independent third-party institution or a higher-level supervision department to ensure an objective and fair evaluation process. The assessment results serve as an important basis for post appointment, professional title promotion, and salary adjustment, realizing the matching of ability and treatment. Commend and reward those with excellent results to stimulate their work enthusiasm; arrange supplementary training and re-examination for those who fail to meet the standards, and transfer them from key positions if necessary, forming a management mechanism of "able to be promoted and demoted." Through continuous talent training and strict ability evaluation, build a professional, standardized, and international cross-border rapid food detection technical team, providing solid human support for building a national food safety defense line.

2.4. Improve rapid detection systems and strengthen the supervision of rapid food detection technology

Establishing a scientific and perfect technical standard system for rapid food detection is the basic guarantee for the effectiveness of cross-border food supervision. Led by relevant supervision departments, joint scientific research institutions, detection units, and technical experts to formulate unified rapid detection technical specifications, covering detection equipment performance indicators, reagent use conditions, operation process steps, and result interpretation basis. For different types of food pollutants, such as pesticide residues, heavy metals, pathogenic microorganisms, and illegal additives, set corresponding detection limits and judgment thresholds to ensure the comparability and consistency of various rapid detection methods in practical applications [15].

Cross-border food supervision involves the connection of regulations and detection systems of multiple countries, requiring the promotion of coordination and mutual recognition of international rapid detection standards. Actively participate in relevant activities of international standardization organizations, learn from advanced experiences from the European Union, the United States, Japan, and other regions, and revise and improve local standards in combination with China's actual needs. Encourage domestic rapid detection technology

R&D units to participate in international proficiency testing projects to improve the credibility of detection results. Establish standardized rapid detection laboratories at border ports, equip certified instruments and consumables, strictly implement standard operating procedures, and ensure the transparency, traceability, and reviewability of the detection process of cross-border food at the entry link. Support the construction of an information management system to realize real-time upload, automatic analysis, and abnormal early warning of detection data, improving the speed and accuracy of regulatory decisions.

3. Conclusion

In summary, rapid food detection technology plays an irreplaceable role in cross-border food supervision, providing strong support for the rapid screening of problematic food and the timely prevention of food safety risks. With the continuous progress and improvement of such technologies, their application in cross-border food supervision will become more extensive and in-depth. In the future, all parties need to work together to further consolidate the food safety risk prevention and control system by optimizing personnel training, improving infrastructure, and enhancing the quality of rapid food detection products, building a solid food safety barrier, and providing support for ensuring food safety.

Funding

Tianshan Talents Cultivation Program of the Xinjiang Uygur Autonomous Region (Project No. 2024TSYCJ0062)

Disclosure statement

The authors declare no conflict of interest.

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