Research Progress on Food Safety Risk Early Warning Mechanism

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Abstract Food safety has always been a critical issue concerning people's livelihoods. The complexity and diversity of hazardous substances in food make systematical and scientifical identification of potential risk factors affecting food safety and accurate assessment and early warning for such risks one of the urgent problems for food safety inspection authorities. This paper explored food safety risk identification technologies, food safety risk monitoring technologies, and food safety risk early warning methods, aiming to provide theoretical support and research insights for improving food risk early warning systems.

Key words Food; Risk early warning; Detection technique
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In recent years, China has intensified its efforts to supervision and crackdown on illegal additives and excessive use and unauthorized scope of additives in food, aiming to provide essential safeguards for food safety and the maintenance of market economic order. However, some vendors still illegally add drugs to food for profit, endangering people's lives. Therefore, establishing a food safety risk early warning mechanism centered on risk identification, monitoring and early warning has become a key focus of current research.

Food Safety Risk Identification Technologies

Chemical sensor technology

Chemical sensor technology converts the concentration of chemical substances into measurable electrical signals, enabling the qualitative and quantitative detection of hazardous substances in food. ALIEV *et al.*[1] developed a multi-electrode chemical sensor system using electrodes made of various materials such as copper, nickel, and carbon fiber. The study applied molecular docking and density functional theory for modeling, and optimized the detection method combined with machine learning algorithms, successfully achieving efficient detection of antibiotic residues in complex matrices such as milk.

Fluorescent sensor technology

Fluorescent sensor technology converts chemical information from molecular interaction into fluorescent signals, enabling selective recognition of specific molecules or ions. Zarejousheghani *et al.*[2] developed a multi-target modified sensor based on molecularly imprinted polymers, successfully achieving simultaneous detection of 129 chemical pollutants in water samples. This method significantly reduces detection costs while offering long-term stability and operational simplicity, demonstrating strong potential for practical applications. Darwish *et al.*[3] combined fluorescent immunoassay with kinetic exclusion assay and integrated a fluorescent sensor to establish a detection method for copper ion residues in food. The results demonstrated that this method exhibits excellent performance characteristics in terms of sensitivity, selectivity, and accuracy.

Food Safety Risk Monitoring Technologies

Food risk monitoring technologies enable qualitative and quantitative analysis of hazardous factors in food. However, due to the complex matrix of food, substances such as fat, sugar, and salt can significantly interfere with detection, requiring sample pretreatment before instrumental analysis. Therefore, developing environmentally friendly, rapid, and convenient extraction technologies can improve the efficiency of food safety risk monitoring and assessment.

Gao *et al.*[4] combined electro-membrane extraction with liquid chromatography-mass spectrometry (LC-MS) to establish a detection method for adrenergic receptor agonists (such as ractopamine) in animal-derived foods. This method offers advantages including a wide linear range, high sensitivity, and satisfactory recovery rates. Thati *et al.*[5] developed a method using molecularly-imprinted dispersive micro-solid phase extraction coupled with high-performance liquid chromatography (HPLC) for determining aflatoxins in food. This method demonstrates high selectivity, simple operation, low cost, and stable detection results. Mortada *et al.*[6] combined Triton X-114 cloud point extraction with back-extraction technology for the detection of inorganic vanadium in food samples. The method effectively eliminates the adverse effects of surfactants on instruments and enables speciation analysis of inorganic vanadium in water samples as well as determination of total vanadium in various vegetables using inductively coupled

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plasma-optical emission spectrometry (ICP-OES).

Food Safety Risk Early Warning Technology

Food safety risk early warning technology serves as a crucial technical approach for the early identification and prediction of potential risk factors in food through systematic screening and warning model construction. This technology can not only promptly detect and warn of food safety hazards but also provide scientific basis for developing preventive measures, thereby effectively reducing food safety risks.

Non-targeted screening technology

The development of non-targeted screening technology has provided new research perspectives for food safety risk early warning. This technology enables simultaneous detection of multiple unknown compounds in samples, overcoming the limitations of traditional targeted analysis. However, due to the complexity of non-specific compounds, its practical application requires integration with various high-sensitivity analytical techniques to ensure the reliability and accuracy of detection results.

Multidimensional technology Traditional analytical techniques such as chromatography and spectroscopy have achieved significant improvements in detection sensitivity and analytical capability through continuous innovation and refinement. In particular, the development and advancement of novel technologies including multidimensional chromatography and three-dimensional fluorescence spectroscopy have provided more robust technical support for practical detection work.

Yu *et al.* [7] developed a multidimensional liquid chromatography-mass spectrometry method for proteomics analysis. This approach provides new research tools for proteomics studies and toxicological analysis, effectively revealing interaction mechanisms between hazardous substances and proteins, thereby offering important references for toxicological research on novel biological specimens. Song *et al.* [8] established an ion mobility-high resolution mass spectrometry method for detecting non-volatile migrants in food contact materials, significantly improving identification accuracy for such materials.

Instrumental hyphenation technology Instrumental hyphenation technology integrate the advantages of multiple analytical instruments, effectively addressing technical challenges in analyzing complex matrices such as food. These methods not only enhance the accuracy and reliability of detection but also expand the application scope of analytical approaches.

Ribeiro *et al.* [9] achieved speciation analysis of mercury and selenium in fish samples by coupling high-performance liquid chromatography with inductively coupled plasma mass spectrometry (HPLC-ICP-MS) and incorporating microwave-assisted enzymatic digestion pretreatment. The results obtained by this method showed good agreement with those from traditional speciation analysis, demonstrating high reliability. Pagliuca *et al.* [10] developed a rapid detection method for nut oil adulteration by combining ultra-high-performance liquid chromatography with photodiode array detection (UHPLC-PDA), high-resolution time-of-flight mass spectrometry (HR-TOF-MS), and high-performance thin-layer chromatography (HPTLC).

High-resolution mass spectrometry High-resolution mass spectrometry (HRMS) offers significant advantages in detecting trace and ultra-trace non-specific compounds due to its exceptional sensitivity and resolution. Currently, this technology is primarily applied in the compositional analysis of food and pharmaceuticals, demonstrating broad research potential in early warning systems for food and drug safety risks.

Xie *et al.* [11] developed a detection and screening method for 10 pesticide residues in five medicinal and edible agricultural products (ginseng, *Schisandra chinensis*, ginseng flower, *Ganoderma lucidum*, and *Ganoderma* spore powder) using high-resolution liquid chromatography-mass spectrometry (HR-LC/MS), providing crucial technical support for agricultural product safety monitoring and early warning. Liang[12] developed a liquid chromatography-high resolution mass spectrometry (LC-HRMS) method for detecting halogenated disinfection byproducts in tap water, achieving stable and reliable detection results. Turnipseed *et al.* [13] established an LC-HRMS method for detecting antibiotic residues in fruits, which can be applied not only for targeted analysis of specific antibiotics but also for non-targeted screening of chemical contaminants.

Establishment of early warning models based on chemometrics algorithms

In recent years, chemometrics algorithms have been increasingly applied in spectral analysis, significantly improving the accuracy and precision of experimental results. For example, Hu *et al.* [14] detected pesticide residues on fruit surfaces using functionalized gold nanomaterials combined with surface-enhanced Raman spectroscopy (SERS) and optimized the results with self-modeling mixture analysis, achieving high recovery rate. Cariappa *et al.* [15] effectively identified adulteration in virgin coconut oil using chemometrics and principal component analysis (PCA). Wang *et al.* [16] conducted qualitative and quantitative detection of four benzimidazole herbicides in food using SERS and established a partial least squares discriminant analysis (PLS-DA) model, providing a reliable statistical basis for rapid detection. Shah *et al.* [17] developed a solid-phase extraction method for enriching cadmium ions in food and water samples with surface modified iron oxide nanoparticles. This method stably enhances cadmium ion enrichment capacity while demonstrating good repeatability and reproducibility in detection.

Conclusions

In summary, this paper systematically reviewed risk identification technologies, risk monitoring technologies, and risk early-warning technologies in food safety risk warning mechanism from the perspective of analytical chemistry. Through in-depth analysis of the application status and development trends of these technologies, it aimed to provide scientific theoretical support and technical guidance for practical work in the field of food safety.

Currently, food safety issues remain severe, making continuous innovation and development in risk early-warning technologies crucial. In the future, with the advancement of science and technology, particularly the deep integration of analytical chemistry with related disciplines, food safety risk warning technologies will achieve further breakthroughs. It is anticipated that a more robust food safety warning system will be established through more precise and efficient risk identification and monitoring approaches, thereby effectively safeguarding public dietary safety and promoting social harmony and stability.

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