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High-Throughput Screening Methods for Detecting Antibiotic Residues in Food

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Introduction

The widespread use of antibiotics in animal husbandry, aquaculture, and agriculture has significantly contributed to food security and disease control. However, the unintended presence of antibiotic residues in food products—such as milk, meat, eggs, and fish—poses serious public health concerns. These residues, if consumed over time, may contribute to antibiotic resistance, hypersensitivity reactions, disruption of gut microbiota, and other toxic effects. Regulatory agencies worldwide have set Maximum Residue Limits (MRLs) for various antibiotics in food, prompting the need for efficient monitoring systems. Traditional analytical methods such as liquid chromatography and mass spectrometry are accurate and sensitive but are often time-consuming, costly, and labor-intensive. In response, High-Throughput Screening (HTS) techniques have emerged as a powerful solution, offering rapid, sensitive, and cost-effective ways to detect multiple antibiotic residues simultaneously in large sample sets. These HTS methods are now central to ensuring food safety, regulatory compliance, and public health protection [1].

Description

High-throughput screening methods for antibiotic residue detection are designed to analyze hundreds to thousands of samples within a short time frame, with minimal sample preparation and operator intervention. These technologies combine advances in immunoassays, biosensors, microfluidics, and molecular biology to provide rapid and multiplexed analysis. Among the most widely used HTS techniques are Enzyme-Linked Immunosorbent Assays (ELISA), Lateral Flow Immunoassays (LFIA), and Fluorescence Polarization Immunoassays (FPIA), each offering specific advantages in terms of sensitivity, throughput, and field applicability. ELISA remains the gold standard for many screening programs, capable of detecting low nanogram-per-milliliter concentrations of antibiotics across a variety of matrices. Commercial ELISA kits are available for detecting β-lactams, tetracyclines, sulfonamides, and aminoglycosides, among others, and can be semi-automated for higher efficiency.

Advancements in biosensor technologies have also revolutionized HTS applications for antibiotic detection. Optical, electrochemical, and piezoelectric biosensors integrated with microfluidic chips allow real-time, label-free analysis of multiple antibiotic targets. These biosensors often utilize aptamers or monoclonal antibodies as biorecognition elements and can be scaled up for parallel sample testing. Surface Plasmon Resonance (SPR) biosensors and Electrochemical Impedance Spectroscopy (EIS)-based systems offer exceptional sensitivity and are being integrated into portable platforms for on-site testing in food processing environments. Furthermore, nanotechnology has enhanced signal amplification and detection limits in biosensors, using materials such as gold nanoparticles, carbon nanotubes, and quantum dots to improve assay performance.

Molecular-based HTS methods are also gaining prominence. Techniques such as real-time PCR and Loop-Mediated Isothermal Amplification (LAMP) can detect genes encoding antibiotic resistance or biosynthetic pathways, indirectly indicating the presence of antibiotic residues. More recently, CRISPR-Cas-based diagnostics have emerged as ultra-sensitive and highly specific tools for residue detection. These methods can be integrated with lateral flow devices or fluorescence readers to yield results in under an hour, offering both speed and accuracy. Additionally, mass spectrometry-based HTS platforms using Matrix-Assisted Laser Desorption Ionization (MALDI-TOF) or Liquid Chromatography-Tandem Mass Spectrometry (LC-MS/MS) with automated sample handling are being developed for semi-targeted and untargeted screening of antibiotics in complex food matrices [2].

Conclusion

High-throughput screening methods have become indispensable tools in modern food safety monitoring, enabling rapid, accurate, and large-scale detection of antibiotic residues in food products. By leveraging innovations in immunoassays, biosensors, molecular diagnostics, and automated instrumentation, these techniques offer the sensitivity and specificity required to meet stringent regulatory standards while accommodating the fast-paced demands of the global food industry. The integration of HTS with AI, robotics, and miniaturized devices is set to further transform food safety protocols, allowing real-time surveillance and more proactive management of antibiotic contamination. As antibiotic resistance continues to threaten public health globally, robust and scalable HTS strategies will play a critical role in safeguarding the food chain and ensuring consumer protection.

Acknowledgement

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Conflict of Interest

None.

References

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