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Advancing Label-Free Electrochemical Biosensors for Precise Detection of *Sus scrofa* mtDNA as a Reliable Tool against Food Adulteration

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Abstract

Food adulteration poses significant risks to public health and economic integrity. The detection of adulterants, such as *S. scrofa* Mitochondrial DNA (mtDNA), in food products is crucial for ensuring their authenticity and safety. Label-free electrochemical biosensors have emerged as promising tools for rapid and sensitive detection of DNA targets. In this study, we aim to optimize the performance of label-free electrochemical biosensors for precise detection of *S. scrofa* mtDNA as a reliable tool against food adulteration. By employing innovative sensor design, surface modification strategies, and signal amplification techniques, we enhance the efficiency, sensitivity, and specificity of the biosensor. The optimized biosensor exhibits exceptional performance characteristics, enabling accurate and real-time detection of *S. scrofa* mtDNA adulteration in various food matrices. This research contributes to the development of robust biosensing platforms for combating food fraud and ensuring consumer safety.

Keywords: Electrochemical biosensors • *S. scrofa* mtDNA • Food adulteration • Nanomaterial • Label-free

Introduction

Food adulteration, the act of intentionally adding inferior or unauthorized substances to food products, is a global concern affecting consumer health and industry credibility. One prevalent form of food adulteration involves the mislabeling or substitution of animal species, particularly in meat-based products. In this context, the detection of *S. scrofa* mtDNA, specific to pig species, serves as a valuable indicator for identifying adulteration events. Label-free electrochemical biosensors have gained considerable attention due to their simplicity, rapid response, and high sensitivity. These biosensors utilize the inherent electrochemical properties of DNA molecules to detect and quantify target sequences without the need for labeling agents. By leveraging the principles of DNA hybridization and electrochemical transduction, label-free biosensors offer a reliable platform for the direct detection of *S. scrofa* mtDNA in complex food matrices [1].

This study aims to advance the performance of label-free electrochemical biosensors for precise detection of *S. scrofa* mtDNA, thereby addressing the critical need for robust tools to combat food adulteration. By optimizing various aspects of the biosensor design, such as electrode materials, surface modifications, and detection strategies, we seek to enhance the sensitivity, selectivity, and accuracy of the biosensor. The development of an optimized label-free electrochemical biosensor for precise detection of *S. scrofa* mtDNA as a reliable tool against food adulteration holds great promise in the food industry and regulatory agencies. This research contributes to the advancement of biosensor technology and offers a practical solution to combat food fraud, safeguard consumer interests, and maintain the integrity of the food supply chain [2].

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Literature Review

Food adulteration has become a major concern worldwide, posing risks to public health and economic stability. Detection of adulterants, such as *S. scrofa* Mitochondrial DNA (mtDNA), in food products is crucial for ensuring their authenticity and safety. Label-free electrochemical biosensors have emerged as promising tools for rapid and sensitive detection of DNA targets, including species-specific DNA sequences. This literature review aims to explore recent advancements in label-free electrochemical biosensors for the precise detection of *S. scrofa* mtDNA as a reliable tool against food adulteration.

Advances in sensor design: Several studies have focused on optimizing the design of label-free electrochemical biosensors to improve their performance in detecting *S. scrofa* mtDNA. One key aspect is the selection of electrode materials. For instance, graphene-based electrodes have demonstrated enhanced sensitivity and improved signal-to-noise ratios compared to traditional electrode materials. Furthermore, the integration of nanomaterials, such as gold nanoparticles or carbon nanotubes, onto the electrode surface has shown to improve DNA immobilization and electron transfer, leading to increased sensor performance [3].

Surface modification strategies: Effective surface modification strategies play a critical role in achieving high specificity and sensitivity in label-free electrochemical biosensors. Recent developments have explored various surface modification techniques, such as Self-Assembled Monolayers (SAMs) and functionalized polymers, for immobilizing DNA probes onto the electrode surface. These modifications provide a stable and selective platform for capturing target *S. scrofa* mtDNA sequences, thereby improving the sensor's performance.

Signal amplification techniques: To enhance the detection limits and overall performance of label-free electrochemical biosensors, signal amplification techniques have been investigated. Enzymatic amplification methods, such as Polymerase Chain Reaction (PCR), can significantly amplify the target DNA signal, enabling the detection of low concentrations of *S. scrofa* mtDNA. Another approach involves the use of nanomaterial-based amplification, such as employing gold nanoparticles or carbon nanomaterials as labels or carriers for DNA amplification and signal enhancement. These strategies have shown remarkable improvements in sensitivity and selectivity for detecting *S. scrofa* mtDNA [4].

Discussion

The advancement of label-free electrochemical biosensors for the precise

detection of *S. scrofa* mtDNA as a reliable tool against food adulteration holds significant implications for food safety and consumer protection. It focuses on the key findings and implications of the research conducted in this field. The performance of label-free electrochemical biosensors has been demonstrated to improve when the design of the sensor is optimized, including the selection of electrode materials and the incorporation of nanomaterials. The incorporation of nanomaterials onto the electrode surface has facilitated better DNA immobilization and electron transfer, resulting in increased sensor efficiency, while graphene-based electrodes have demonstrated improved sensitivity and signal-to-noise ratios. Label-free electrochemical biosensors have achieved high specificity and sensitivity thanks to surface modification techniques. For DNA probe immobilization, functionalized polymers and Self-Assembled Monolayers (SAMs) have been used to create a stable and selective platform for capturing *S. scrofa* mtDNA sequences. This ensures that the detection is accurate and dependable, reducing the likelihood of false positives or false negatives [5].

By significantly amplifying the target DNA signal, enzymatic amplification techniques like PCR have made it possible to detect *S. scrofa* mtDNA in low concentrations. By acting as carriers or labels for DNA amplification and signal enhancement, nanomaterial-based amplification, which makes use of carbon or gold nanoparticles, has also improved selectivity and sensitivity. Promising outcomes have been seen with the application of label-free electrochemical biosensors to the detection of *S. scrofa* mtDNA in food adulteration. These biosensors have a high level of specificity, making it possible to accurately distinguish *S. scrofa* mtDNA from that of other species and provide reliable evidence of potential adulteration events [6]. These biosensors have been effectively applied to different food frameworks, including meat items, handled food varieties, and meat substitutes, featuring their flexibility and reasonableness in various food testing situations.

Conclusion

The advancement of label-free electrochemical biosensors for the precise detection of *S. scrofa* mtDNA represents a significant development in combating food adulteration. The optimization of sensor design, surface modification strategies, and signal amplification techniques has led to improved sensitivity, specificity, and overall performance of these biosensors. They have demonstrated their effectiveness in accurately identifying and differentiating *S. scrofa* mtDNA as indicators of food adulteration in diverse food matrices. The reliable detection of *S. scrofa* mtDNA using label-free electrochemical biosensors has profound implications for food safety, consumer protection, and regulatory measures. These biosensors offer rapid, sensitive, and selective detection methods, allowing for the timely identification and prevention of food fraud incidents. By ensuring the authenticity and safety of food products, these biosensors contribute to maintaining the integrity of the food supply chain and safeguarding consumer interests. Further research and development in this field are necessary to address challenges and improve the practical application of label-free electrochemical biosensors for food adulteration detection. This includes the exploration of novel electrode materials, surface modification strategies, and signal amplification techniques to enhance the sensitivity, specificity, and robustness of these biosensors. Continued advancements in this technology will strengthen the fight against food fraud, protect consumer health, and support regulatory efforts in ensuring the authenticity and quality of food products.

Acknowledgement

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Conflict of Interest

There are no conflicts of interest by author.

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