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Electrical impedance tomography for meat marbling prediction

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ABSTRACT: Electrical Impedance Tomography (EIT) is a promising noninvasive technology for predicting meat quality traits, such as marbling in beef. Marbling, characterized by intramuscular fat, significantly influences beef quality by enhancing flavor, tenderness, and juiciness. This review evaluated the application of EIT in meat quality control, highlighting its ability to measure changes in conductivity to assess marbling and other quality attributes. Integrating EIT with machine-learning techniques further refines its predictive capabilities. Although EIT provides real-time, noninvasive assessments with lower costs, challenges like lower signal-to-noise ratios and complex algorithm requirements persist. Future directions include the integration of EIT with modern packaging systems and automation tools to enhance meat quality monitoring and industrial efficiency.

Keywords:
electrical impedance tomography, meat quality control, non-invasive imaging, marbling prediction

■ INTRODUCTION

Electrical Impedance Tomography (EIT) has shown promise in various fields, including the prediction of meat quality traits, such as marbling in beef. Meat marbling, intramuscular fat within muscle tissues, is a key determinant of beef quality, enhancing flavor, tenderness, and juiciness (Liu *et al*. 2022). Various assessment methods, such as biochemical analysis, moisture content determination, and real-time ultrasound, evaluate these traits and provide insights into muscle composition and carcass weight, which are crucial quality standards (Razanova 2023). Genetic advances have identified genes linked to marbling, aiding in understanding meat characteristics and consumer preferences (Dairoh *et al.* 2022). This mini review evaluates EIT's effectiveness in assessing marbling to enhance meat quality control.

■ PRINCIPLES OF ELECTRICAL IMPEDANCE TOMOGRAPHY

Electrical Impedance Tomography is a technology used in medical settings for real-time lung ventilation monitoring by measuring conductivity changes. Small alternating currents applied through thoracic electrodes enable detailed imaging of the conductivity distribution, which is crucial for adjusting ventilation and identifying volume changes (Bachmann *et al.* 2018). Essential to critical care, EIT enhances patient safety and care by continuously monitoring changes (Kaboutari *et al*. 2019). These were then used for meat imaging (Ulum *et al*. 2023).

■ APPLICATIONS IN MEAT MARBLING PREDICTION

Electrical Impedance Tomography, combined with Electrical Impedance Spectroscopy (EIS), aids in the assessment of meat quality traits, such as marbling. This technology evaluates meat freshness and composition by analyzing cell membrane integrity, offering rapid and precise quality checks for early detection (Huh *et al*. 2021). Integrating EIT with machine learning methods, such as k-nearest Neighbor and Fuzzy k-means algorithms, refines imaging capabilities and predicts beef intramuscular fat and other significant physicochemical traits (Darma & Takei 2021).

■ ADVANTAGES AND LIMITATIONS

Electrical Impedance Tomography is a non-invasive, cost-effective technology ideal for real-time monitoring of internal structures, such as lung ventilation without ionizing radiation, to enhance safety in critical care settings (Weiz 2023). It is also applied in industrial and material characterization processes. However, EIT challenges include a lower signal-to-noise ratio, which may degrade image quality, and the need for complex algorithms and additional hardware, which increases costs and operational complexity. In addition, its

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inferior temporal resolution can limit its effectiveness in tracking rapid physiological changes (Hope *et al*. 2019).

■ FUTURE DIRECTIONS IN EIT FOR MEAT QUALITY CONTROL

Electrical Impedance Tomography transforms meat quality control by offering noninvasive, precise assessments of traits such as marbling, tenderness, and freshness through advanced spectroscopic techniques and machine learning. This technology enables high-speed imaging, improving meat composition analyses' accuracy. EIT is also integrated with modern packaging systems, enhancing meat quality monitoring during transit using sustainably produced polymers and active compounds (Li *et al*. 2022). Future applications may include smart cutting tools and automation systems to boost real-time assessments and operational efficiency in the meat processing industry (Mason *et al*. 2022) and set new standards for product quality and safety.

■ IMPLICATIONS FOR THE MEAT PROCESSING INDUSTRY

Using Electrical Impedance Tomography in meat processing helps with quality control and meets food safety standards (Frerichs *et al*. 2016). EIT's technology is non-invasive and allows for real-time assessment of important quality factors like marbling, tenderness, and freshness. With the support of proteomics advancements, EIT helps improve processing methods for consistent quality (Paredi *et al*. 2012). Additionally, EIT can be combined with innovative packaging systems to ensure meat quality during transit and storage (Lvovsky *et al*. 2009). Integrating innovative tools and automation could improve efficiency and consistency (Tassin *et al*. 2009).

■ CONCLUSION AND RECOMMENDATIONS

Electrical Impedance Tomography has revolutionized meat quality control by noninvasively evaluating marbling, tenderness, and freshness in real time. Initially for medical use, EIT now enhances meat industry standards, improving quality and safety compliance.

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