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How are biosensors and Artificial Intelligence (AI) pioneering dynamic solutions for food quality control?

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1 INTRODUCTION: Intelligent Biosystems and Artificial Intelligence (AI) in Food Safety

🌍 **Global Food Iandsecurity – A Growing Crisis**

- **The 2023 Global Food Security Index (GFSI)** is alarmed to report a sharp decline, affecting nearly 1/3 of the world's population and marking a serious setback in the fight against hunger.

💡 **AI helps address food safety by enabling:**

- **Foodborne** pathogen early detection
- Avoidance of contaminations in the **supply chain**

🔬 **Technologies driving innovation**

- **Smart Sensors and Biosensors:** Detect hazardous agents in real-time
- **Internet of Things (IoT) and Blockchain:** Boost traceability and transparency
- **Machine Learning (ML) and Multimodal approaches**: Enable predictive models and fast diagnostics

📈 **AI Impact across food systems**

- **Higher effectiveness** in risk recognition
- **Minimizes testing expense** and **time required**
- **Assists regulatory decisions** by analyzing large volumes of data

2 METHODOLOGY

- **Systematic review:** analyzed the latest research and technological advances in the field of intelligent biosystems.
- **Data sources:** peer-reviewed journals, and real-word case technology examples.
- **Evaluation criteria:** focused on challenges (e.g. viability, effectivity, and sustainability).

3 TECHNOLOGICAL INTEGRATION

a) Sensor-based quality inspection
Electronic Noses (**E-noses**) emulate human smell to detect Volatile Organic Compounds (VOCs).
AI/ML models classify odors (fresh vs. spoiled).
Use case: E-noses are designed to detect the degree of freshness of meat or the ripeness of fruit (e.g. Ethylene gas detection).

🧠 ***AI Role:*** Pattern recognition, odor classification, freshness prediction.

b) Chemical interaction testing
Chemical reagents: Trigger noticeable alterations in the event of the presence of pathogens/adulterants (e.g. Benedict's reagent).
AI tools: Image processing, chemical signature classification.
Use case: Use color changes to detect spoiled milk or adulterated honey.

🧠 ***AI Role:*** Analyzing chemical reactions through vision models.

c) Real-time monitoring and predictive analysis
IoT sensors track real-time variables (e.g. T (ºC), and humidity (%)).
ML models forecast tendencies of spoilage or deterioration of quality.
Use case: Smart bakery ovens optimize bread quality; retail shelves detect expired products.

🧠 ***AI Role***: Time-series analysis, anomaly detection, environment optimization.

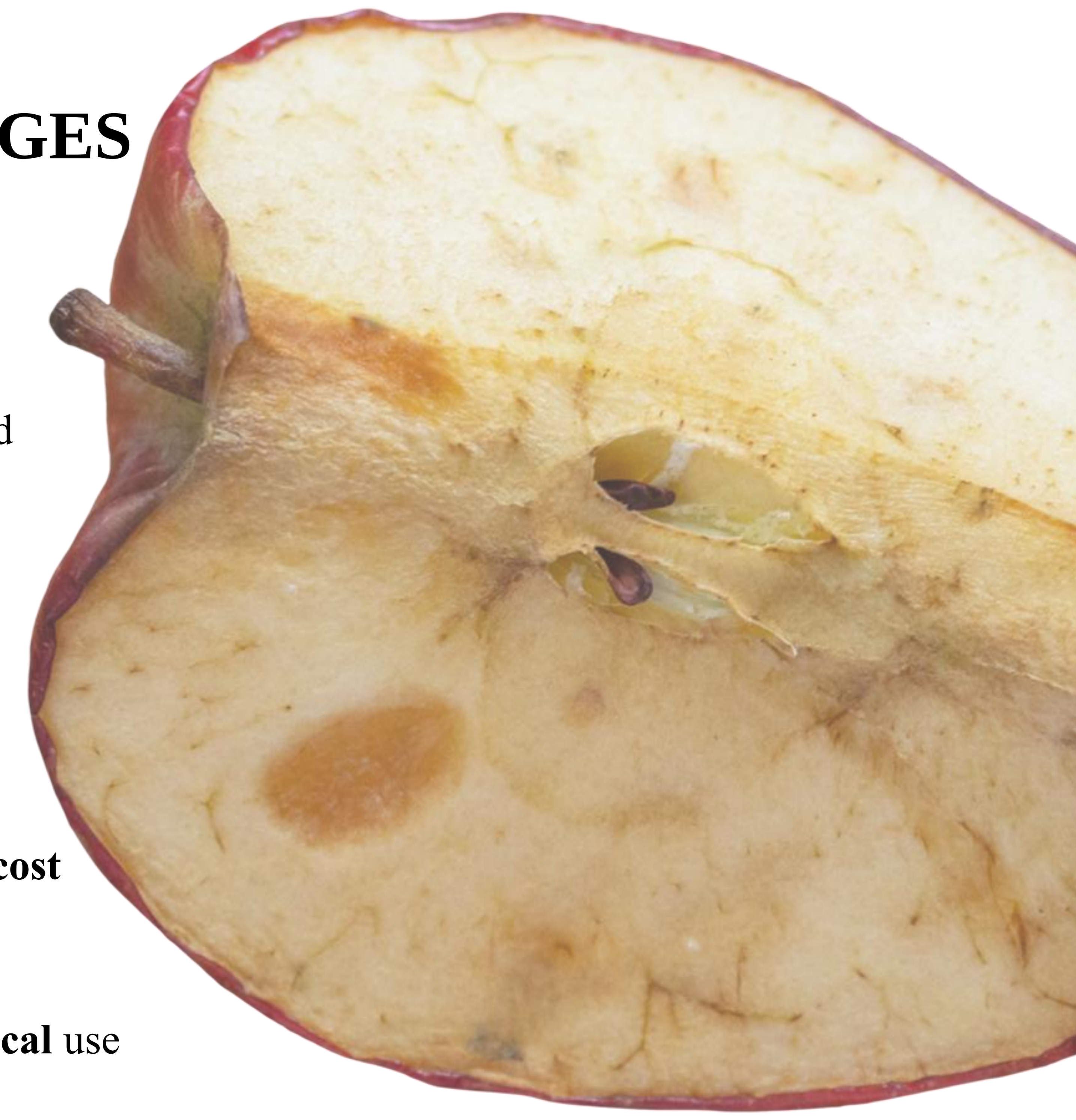
d) Generative AI for food quality control
Generative Adversarial Networks (GANs) emulate food degradation and spoilage scenarios (e.g. Synthetic photos of foodstuffs of different quality).
Augmented data augments training datasets for **Convolutional Neural Networks (CNNs)**
Use case: Train AI with synthetic images of spoiled vs. fresh items.

🧠 ***AI Role:*** Data augmentation, quality simulation, scenario generation.

e) Multimodal/Hybrid approaches
Visual + smell fusion: Link up camera and e-nose data for an extensive quality check.
Chemical + image integration: Visualize chemical reactions + texture analysis.
Use case: Fish freshness evaluation by visual and odor cues; agrochemicals presence by visual + chemical analysis.

🧠 ***AI Role:*** Multimodal fusion models, hybrid decision systems.

4 CHALLENGES AND LIMITA-TIONS



- **Data quality** and sharing model
- Scalability
- **Interpretability** sensor
- Calibration and **cost**
- **Regulatory**
- Compliance **ethical** use of AI

5 FINAL REMARKS AND FUTURE PERSPECTIVES

- **AI** and **intelligent biosystems** are renovating **food quality** and **safety.**
- **Smart** sensors and **e-noses** facilitate **rapid**, **f** contamination detection.
- **IoT + AI** backing **real-time** monitoring and **predictive** analytics.
- Industry leaders (Nestlé, IBM , bluwrap) are already using these tools.
- Benefits embrace better **traceability**, **less waste**, and solider consumer **trust.**
- **Key barriers:** data quality, price, scalability, guiding challenges, and ethics.
- The time to come lies in **connected**, and **data-driven** food systems.

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