Use of Artificial Intelligence and IoT for Seed Quality Testing

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Abstract— *The quality of seeds is a fundamental factor in ensuring agricultural productivity and food security. Traditional seed quality assessment methods, such as manual inspection and laboratory-based testing, are often time-consuming, labor-intensive and prone to human error. To overcome these limitations, modern agricultural technologies have increasingly integrated Artificial Intelligence (AI) and the Internet of Things (IoT) to enhance seed quality evaluation. AI-driven models, including deep learning and computer vision techniques, have demonstrated high accuracy in detecting seed defects, predicting germination potential and classifying seeds based on various parameters (Kundu et al., 2021). Additionally, IoT-based smart sensors enable real-time monitoring of critical environmental factors such as humidity, temperature and storage conditions, ensuring optimal seed preservation (Kler et al., 2023). The fusion of AI and IoT facilitates automated, high-throughput and non-destructive seed quality testing using hyperspectral imaging, near-infrared spectroscopy and cloud-based analytics. While these advancements offer numerous benefits, challenges such as high implementation costs, data security concerns and the need for technical expertise hinder widespread adoption. This review demonstrate that integrating IoT-driven sensing with advanced AI methods offers a scalable, objective solution for seed certification, with potential extensions to disease detection, phenotypic trait analysis, and adaptive sorting in commercial processing lines.*

Keywords— Seed quality, Artificial Intelligence (AI), Internet of Things (IoT) sensing, Deep learning, Smart sensors and Hyperspectral imaging.

I. INTRODUCTION

Seed quality is a fundamental determinant of agricultural productivity, influencing germination rates, crop uniformity, and overall yield. The growing global population, projected to reach 9.7 billion by 2050 (FAO, 2021), has intensified the demand for high-quality agricultural produce. Ensuring optimal crop yields starts with high-quality seeds, which directly influence germination rates, plant vigor and resistance to environmental stresses (ISTA, 2020). Traditional seed quality assessment methods, including manual inspection, germination tests and biochemical analyses, are widely used but often suffer from inefficiencies due to their labor-intensive nature and susceptibility to human error (McDonald, 1998). These limitations necessitate the adoption of advanced technologies that can enhance precision, efficiency and scalability in seed quality testing.

Recent advancements in Artificial Intelligence (AI) and the Internet of Things (IoT) have revolutionized the agricultural sector, offering innovative solutions for seed quality assessment. AI, particularly machine learning (ML) and deep learning (DL), enables the automated analysis of seed traits from digital images and sensor data, facilitating rapid and accurate classification, damage detection, and viability prediction (Zhou *et al.*, 2021). Convolutional Neural Networks (CNNs) have shown high accuracy in checking seed quality by analyzing features like size, shape, and color. They can also find small defects such as cracks or fungus that are hard to see with the human eye, making seed testing faster and more reliable (Zhou *et al.*, 2021; Sharma *et al.*, 2020). Additionally, IoT-enabled smart sensors facilitate real-time monitoring of seed storage conditions, including temperature, humidity, and moisture levels, ensuring optimal preservation and reducing post-harvest losses (Kler *et al.,* 2023). The integration of AI and IoT allows for automated, non-destructive and highly accurate seed quality assessment, addressing the limitations of conventional methods.

This review explores the latest advancements in the integration of Artificial Intelligence (AI) and the Internet of Things (IoT) for seed quality testing, emphasizing their applications, benefits, challenges, and future prospects within the context of agricultural innovation. By utilizing AI-driven techniques and IoT-enabled systems, the agricultural sector stands to significantly improve seed quality management, optimize crop yield, and ultimately contribute to global food security. These technologies offer promising solutions to enhance precision, sustainability, and efficiency in seed testing, paving the way for smarter and more resilient agricultural practices.

II. OBJECTIVE

- Enhance Accuracy of Seed Quality Assessment
- Automate and Speed Up the Testing Process
- Enable Real-Time Monitoring and Data Collection
- Improve Detection of Damaged or Non-Viable Seeds
- Ensure Consistency and Standardization in Testing
- Improve Seed Traceability and Quality Control

2.1 Traditional Methods of Seed Quality Testing:

Conventional seed quality assessment encompasses physical, physiological and biochemical evaluations:

- **Physical Inspection**: Manual examination of seed attributes like size, shape and color.
- **Germination Tests**: Assessing seed viability through controlled germination experiments.
- **Biochemical and Genetic Analyses**
- Advanced seed quality testing includes biochemical and molecular techniques to assess seed vigor, purity and resistance to diseases. These methods include:
- **Tetrazolium Test (TZ Test)**
- The tetrazolium test is a rapid biochemical method used to assess seed viability. Seeds are soaked in a tetrazolium chloride solution, which stains living tissues red. This test provides quick results but requires expert interpretation.
- **Enzyme Activity Tests**
- Seed vigor is often linked to enzyme activity. Tests measuring the activity of catalase, peroxidase and ehydrogenase enzymes help determine seed viability. Higher enzymatic activity generally indicates better metabolic function and vigor.
- **Molecular Marker Techniques**
- DNA-based techniques such as RAPD (Random Amplified Polymorphic DNA), SSR (Simple Sequence Repeat) and AFLP (Amplified Fragment Length Polymorphism) help assess genetic purity and seed authenticity. These methods are crucial for ensuring that seeds meet quality standards, particularly in hybrid seed production.

TABLE 1
COMPARISON OF TRADITIONAL VS. AI AND IOT-BASED SEED QUALITY TESTING

Method	Accuracy	Time Required	Cost	Automation
Manual Inspection	Moderate	High	Low	No
Germination Tests	High	High	Medium	No
AI-Based Image Processing	Very High	Low	High	Yes
IoT-Enabled Monitoring	High	Real-time	Medium	Yes

Traditional seed testing methods have limitations, including being time-consuming, labor-intensive, and prone to subjectivity. Some tests, like the tetrazolium test are destructive, making seeds unfit for planting. These challenges highlight the need for automated and real-time seed quality assessment technologies.

2.2 Artificial Intelligence in Seed Quality Testing:

Artificial Intelligence (AI) has significantly enhanced seed quality assessment by providing automated, accurate and high-throughput testing solutions. AI-powered models utilize machine learning (ML), deep learning and computer vision to analyze seed characteristics efficiently, reducing reliance on manual inspection. Here's a list of different techniques used in AI-driven seed quality assessment:

- **Image Processing and Machine Vision:** AI-based image analysis enables the identification of seed defects, classification based on size, shape and color and detection of impurities. Advanced deep learning techniques, such as Convolutional Neural Networks (CNNs) and You Only Look Once (YOLO) models, have shown high accuracy in seed classification (Kundu *et al.,* 2021).

  Example: Sachin Sonawane and Basant Kumar Mohanty (2021) n Improved Image Processing Scheme for Automatic Detection of Harvested Soybean Seeds. This research proposes an enhanced image processing method for the automatic detection of harvested soybean seeds. The scheme focuses on improving the accuracy of seed detection by analyzing topological features and object count, contributing to more efficient seed quality assessment.

- **Spectral Analysis:** AI-driven models process hyperspectral imaging, near-infrared (NIR) spectroscopy and X-ray imaging to assess seed composition, internal structure, moisture levels and viability (Shan *et al.,* 2022). These techniques offer a non-destructive approach, preserving seed integrity for further use.

  Example: Chu Zhang and colleagues applied hyperspectral imaging combined with chemometrics for variety classification of maize seeds, achieving high classification accuracy and safety inspection, highlighting its applications across various crops.

NIRS is commonly employed to assess moisture, oil, and protein content in seeds such as wheat, soybean, and maize, this method is a standard practice in seed quality assessment.

- **Predictive Modeling:** Machine learning algorithms analyze historical seed quality data, genetic information and environmental factors to predict germination rates, potential yield, and resistance to diseases. Support Vector Machines (SVMs), Random Forest and Artificial Neural Networks (ANNs) have been widely applied in seed viability and vigor prediction (Zhao *et al.,* 2021).

  Example: Singh *et al.* (2010) used Artificial Neural Networks (ANN) to predict wheat seed germination based on electrical conductivity and moisture content. The model provided a fast, non-destructive method for assessing seed viability, demonstrating ANN's effectiveness in seed quality testing.

- **Automated Sorting and Grading**: AI-integrated systems sort seeds based on quality parameters such as purity, weight and damage level, improving efficiency in seed processing plants (Liu *et al.,* 2022).
- **AI-Powered Seed Health Assessment**: Machine learning algorithms can detect fungal infections, insect damage and genetic mutations, ensuring that only disease-free, high-quality seeds are selected for cultivation (Singh *et al.,* 2023).

By integrating AI with **real-time data analytics and cloud computing**, seed testing becomes faster, more accurate and scalable, benefiting both small-scale farmers and large agribusinesses.

III. INTERNET OF THINGS IN SEED MONITORING AND QUALITY CONTROL

The Internet of Things (IoT) has emerged as a transformative technology in agriculture, offering real-time monitoring and data collection capabilities essential for maintaining seed quality. By integrating IoT devices with advanced analytics, farmers and agronomists can ensure optimal conditions for seed storage, germination and growth.

- **Environmental Monitoring**: IoT sensors are deployed to continuously monitor environmental parameters critical to seed quality, such as temperature, humidity and soil moisture. Maintaining these parameters within optimal ranges is vital for seed preservation and successful germination. For instance, Kler *et al.* (2023) developed an Arduino-based IoT framework that monitors air and soil moisture, enhancing sunflower seed yield by ensuring ideal growing conditions.
- **Automated Sorting Systems**: IoT-enabled devices, when integrated with Artificial Intelligence (AI) models, facilitate the automation of seed sorting and grading processes. These systems utilize sensors and imaging technologies to

assess seed attributes such as size, shape and color in real-time, classifying seeds based on predefined quality metrics. This automation not only increases efficiency but also reduces human error in seed quality assessment. Elmasry *et al.* (2019) highlighted the application of multispectral imaging combined with IoT for seed phenotyping and quality monitoring, demonstrating improved accuracy in seed sorting operations.

- **Data Analytics and Cloud Computing**: IoT devices generate vast amounts of data that, when analyzed through cloud-based platforms, provide actionable insights for improving seed quality and storage practices. Real-time data analytics enable the detection of environmental fluctuations that may adversely affect seed viability, allowing for prompt corrective actions. Moreover, historical data analysis aids in optimizing storage conditions and predicting germination success rates. Prakash *et al.* (2023) discussed the role of IoT and wireless communication in smart farming, emphasizing how data analytics and cloud computing enhance decision-making processes in seed quality management.

The integration of IoT in seed monitoring and quality control not only streamlines agricultural practices but also contributes to sustainable farming by minimizing resource wastage and ensuring high-quality seed production.

3.1 Integration of AI and IoT: A Synergistic Approach

The convergence of AI and IoT technologies offers a holistic approach to seed quality testing:

- **Enhanced Data Accuracy**: IoT devices provide continuous data streams, which AI models analyze to detect patterns and anomalies in seed quality.
- **Automation and Efficiency**: The integration reduces the need for manual intervention, streamlines operations, and accelerates decision-making processes.
- **Scalability**: AI and IoT systems can be scaled to accommodate large volumes of seeds, making them suitable for both small-scale and industrial applications.

IV. APPLICATIONS

Several studies have demonstrated the efficacy of AI and IoT in seed quality assessment:

- **Automated Seed Quality Testing**: Nagar *et al.* (2021) developed a computer vision-based system that employs Generative Adversarial Networks (GANs) and active learning to automate seed quality testing. Their approach includes a novel seed image acquisition setup capturing images from multiple angles, and an annotation tool leveraging Batch Active Learning to minimize manual labeling efforts. This system achieved an accuracy of 91.6% in assessing the physical purity of corn seeds.
- **Seed Classification Using UAV Imagery**: Margapuri *et al.* (2021) made a significant contribution to seed classification using synthetic data and advanced deep learning methods. Their study, which utilized low-altitude UAV imagery, seems to be a promising approach for large-scale seed monitoring in breeding environments. By incorporating domain randomization and combining several powerful CNN architectures (ResNet-100, VGG-16, and VGG-19), they achieved an impressive accuracy of 94.6%. The scalability of this method could indeed be crucial for improving seed certification and quality assessment processes. These case studies underscore the potential of integrating AI and IoT technologies to enhance the efficiency and accuracy of seed quality assessment processes.
- **Seed Yield Estimation via Ground Robot and Deep Learning**: Feng, J., Blair, S. W., *et al.* (2024). Robust soybean seed yield estimation using high-throughout ground robot video. A ground robot carrying fisheye cameras collects video across soybean plots. Frames are processed by P2PNet-Yield (a deep feature-extraction + regression architecture) to count seeds and predict plot yields. The system cut data-collection time by 32% and achieved an 83% genotype ranking accuracy.

V. CHALLENGES

Despite the promising advancements, several challenges persist in integrating AI and IoT into seed quality assessment:

- **High Initial Investment**: Implementing AI and IoT infrastructure requires substantial financial resources, which can be prohibitive, especially for smallholder farmers. The costs associated with acquiring advanced technologies, such as precision farming equipment and AI-powered systems, range from $20,000 to $100,000, posing significant barriers to adoption.

- **Data Management and Security**: The deployment of IoT devices in agriculture leads to the generation of vast amounts of data. Ensuring the privacy and security of this data is paramount, as breaches can compromise sensitive information about farming operations. Additionally, the lack of standardized data collection methods results in fragmented datasets, complicating the integration and analysis processes necessary for effective AI application.
- **Technical Expertise**: The effective utilization of AI and IoT technologies necessitates a workforce proficient in these advanced systems. Many farmers face challenges in hiring or training personnel with the requisite technical skills, leading to slower adoption rates and underutilization of the technologies potential benefits.

Addressing these challenges requires collaborative efforts among technology developers, policymakers and the agricultural community to create cost-effective solutions, establish robust data management frameworks and provide comprehensive training programs.

VI. FUTURE DIRECTIONS

The integration of AI and IoT for seed quality testing is expected to continue evolving with several promising advancements on the horizon:

6.1 Integration with Blockchain:

Block chain technology holds great potential for improving seed traceability. By incorporating block chain, seed quality data can be securely and transparently recorded at each stage of the supply chain. This ensures that the origin and quality of seeds are traceable, preventing fraud and increasing confidence in the testing process. Additionally, it allows stakeholders to access verified data, supporting decisions related to seed quality management (Al-Bassam *et al.*, 2022).

6.2 Edge Computing:

Edge computing enables real-time data processing closer to the source, such as in the field or storage areas. This reduces the need for data to travel to central servers, minimizing latency and ensuring faster, more responsive seed quality assessments. By deploying edge computing in AI and IoT systems, seed testing processes will become quicker and more efficient, making it possible to perform on-the-spot evaluations of seed quality (Singh & Mehta *et al.*, 2021).

6.3 Advanced Sensor Technologies:

IoT sensors are expected to become more sophisticated, with capabilities to detect a wider range of environmental and biological factors that influence seed quality. Future sensors may be able to detect chemical imbalances, microbial contamination, or even assess the genetic traits of seeds, providing a comprehensive understanding of their quality. Such advancements will lead to more precise and reliable testing methods, enhancing the overall seed evaluation process (Chakraborty *et al.*, 2021).

6.4 Global Collaboration:

Increased global collaboration between researchers, technology developers, and agricultural stakeholders will drive further innovation in AI and IoT applications. By sharing knowledge and resources, these collaborations will accelerate the development of more effective, adaptable, and accessible seed quality testing systems. The integration of local and global expertise will help address challenges like data quality, standardization, and affordability, ensuring that advancements in seed quality testing are accessible to farmers and industries worldwide (Choudhury *et al.*, 2022).

VII. CONCLUSION

The convergence of Artificial Intelligence (AI) and the Internet of Things (IoT) marks a transformative leap in digital technology, creating systems that are not only interconnected but also context-aware, autonomous, and adaptive. IoT provides the sensory infrastructure—an expansive network of sensors and devices generating vast amounts of real-time data. AI, in turn, acts as the cognitive engine, processing this data to extract insights, recognize patterns, and make intelligent decisions without human intervention.

This synergy empowers applications ranging from predictive maintenance in industrial IoT to personalized healthcare, precision agriculture, and autonomous systems in smart cities. Advanced AI models, particularly in machine learning and deep learning, elevate the potential of IoT by enabling real-time anomaly detection, demand forecasting, resource optimization, and autonomous control.

However, successful integration demands addressing critical challenges: data privacy and security, standardization, latency, computational limitations on edge devices, and the need for robust infrastructure. The evolution of edge AI, 5G connectivity, and federated learning is helping bridge these gaps, paving the way for scalable and secure intelligent systems.

In conclusion, the fusion of AI and IoT is not merely a technological enhancement—it's a foundational pillar for next-generation digital ecosystems. As this integration matures, it promises to redefine operational models, foster innovation, and accelerate the shift toward truly intelligent environments.

REFERENCES

[1] Al-Bassam, M., Rahman, S., & Sato, T. (2022). Blockchain for seed traceability: A secure solution for agricultural supply chains. *Computers and Electronics in Agriculture*, 189, 106421.

[2] Ather, D., Bin Abdul Hamid, A.B., Binti Yaakub, N.I and Kler, R. 2024. Enhancing Agricultural Productivity in Uzbekistan: Arduino-Based IoT Framework for Sunflower Seed Yield Improvement through Air and Soil Moisture Monitoring. *Journal of Cybersecurity & Information Management*.13(2):122-128.

[3] Chakraborty, S., Sharma, A., & Gupta, A. (2021). Advanced sensor technologies for enhanced seed quality assessment. Sensors, 21(12), 3942.

[4] Choudhury, S., Das, S., & Ghosh, S. (2022). Collaborative frameworks for enhancing AI and IoT adoption in agriculture. *Technology in Society*, 68, 101877

[5] ElMasry, G., Mandour, N., Al-Rejaie, S., Belin, E and Rousseau, D. 2019. Recent Applications of Multispectral Imaging in Seed Phenotyping and Quality Monitoring—An Overview. *Sensors*.19(5): 1090.

[6] FAO. 2021. The Future of Food and Agriculture – Trends and Challenges. *Food and Agriculture Organization of the United Nations*.

[7] Feng, J., Blair, S. W., Ayanlade, T., Balu, A., Ganapathysubramanian, B., Singh, A., Sarkar, S., & Singh, A. K. (2024). Robust soybean seed yield estimation using high-throughput ground robot videos. *Frontiers in Plant Science*, 16, e1554193.

[8] ISTA. 2020. International Rules for Seed Testing. *International Seed Testing Association*.

[9] Kundu, N., Rani, G and Dhaka, V.S. 2021. Seeds classification and quality testing using deep learning and YOLO v5. *In Proceedings of the International Conference on Data Science, Machine Learning and Artificial Intelligence*. 153-160.

[10] Liu, T., Huang, J and Wu, X. 2022. AI-driven automated sorting and grading system for seed processing. *Agricultural Engineering International: CIGR Journal*. 24(2): 45-58.

[11] Margapuri, V., Penumajji, N and Neilsen, M., 2021. Seed classification using synthetic image datasets generated from low-altitude UAV imagery. *In 2021 20th IEEE International conference on machine learning and applications (ICMLA)*. 116-121.

[12] McDonald, M.B. 1998. Seed Quality Assessment. *Seed Science Research.* 8(2): *265-275*.

[13] Nagar, S., Pani, P., Nair, R and Varma, G. 2021. December. Automated Seed Quality Testing System Using GAN and Active Learning. *In International Conference on Pattern Recognition and Machine Intelligence*. 509-519.

[14] Prakash, C., Singh, L. P., Lohan, S. K and Kumar, R. 2023. Advancements in Smart Farming: A Comprehensive Review of IoT, Wireless Communication, Sensors, and Hardware for Agricultural Automation. *Sensors and Actuators A: Physical*. 362, 114605.

[15] Sachin Sonawane and Basant Kumar Mohanty. 2021. An Improved Image Processing Scheme for Automatic Detection of Harvested Soybean Seeds *Journal of Food Measurement and Characterization.* 10.1007.

[16] Shan, R., Liu, Z and Chen, J. 2022. Application of hyperspectral imaging for non-destructive seed quality evaluation. *Journal of Agricultural Science & Technology*. 24(3): 15-28.

[17] Sharma, A., Kumar, A., & Singh, D. (2020). Deep learning-based classification of seed images for quality analysis. *Biosystems Engineering*, 197, 1–12.

[18] Singh, N., & Mehta, S. (2021). Edge computing for agricultural IoT applications: Enhancing real-time data processing. *Agricultural Systems*, 191, 103119

[19] Singh, R., Verma, P and Kaur, A. 2023. Detection of seed-borne diseases using artificial intelligence and machine learning. *Plant Pathology & AI Applications*. 12(4): 233-245.

[20] Zhau, Y., Wang, H and Guo, P. 2021. Machine learning approaches for seed germination prediction and quality assessment. *Computers and Electronics in Agriculture*. 183: 980-987.