AGRI MAGAZINE
(International E-Magazine for Agricultural Articles)
Volume: 03, Issue: 07 (July, 2026)
Available online at http://www.agrimagazine.in

Hyperspectral Imaging for Seed Quality Detection

*Dr. Vineeta Pandey
Assistant Professor, Faculty of Agricultural Sciences, GLA University, Mathura, India
*Corresponding Author's email: vineeta.pandey@gla.ac.in

Seed quality is a critical determinant of agricultural productivity, crop establishment, and food security. Conventional seed quality assessment techniques, including visual inspection, germination tests, biochemical assays, and destructive laboratory analyses, are often time-consuming, labour-intensive, and unsuitable for high-throughput screening. Hyperspectral imaging (HSI) has emerged as a powerful non-destructive sensing technology that integrates spectroscopy and digital imaging to simultaneously acquire spatial and spectral information from seeds. This review discusses the principles of hyperspectral imaging, instrumentation, image processing techniques, machine learning algorithms, and recent applications in seed quality detection. The article also highlights the advantages, limitations, and future prospects of HSI in precision agriculture and the seed industry.

Introduction

High-quality seeds are the foundation of sustainable agricultural production. Seed quality encompasses physical purity, genetic purity, physiological vigor, viability, moisture content, and health status. Traditional seed quality evaluation methods generally involve destructive laboratory testing, which limits their application in large-scale seed processing and breeding programmes. Recent advances in optical sensing technologies have enabled rapid, accurate, and non-invasive evaluation of seed quality. Among these technologies, hyperspectral imaging has gained considerable attention because it combines imaging and spectroscopy into a single analytical system. Unlike conventional RGB imaging, which captures only three colour bands, hyperspectral imaging records hundreds of narrow spectral bands, enabling detailed characterization of the chemical and physical properties of seeds.

Principle of Hyperspectral Imaging

Hyperspectral imaging combines digital imaging and spectroscopy by collecting information across numerous contiguous wavelength bands. Each pixel of the acquired image contains a complete reflectance spectrum, allowing identification of biochemical constituents within the seed. The collected dataset forms a three-dimensional structure called a **hyperspectral cube**, consisting of:

- X-axis: Spatial information
- Y-axis: Spatial information
- Z-axis: Spectral information

The spectral signatures obtained from different seed tissues help distinguish healthy seeds from damaged or infected ones.

Components of a Hyperspectral Imaging System

A typical HSI system consists of:

Illumination Source

Uniform illumination is essential for obtaining reliable spectral information. Common sources include:

- Tungsten-halogen lamps

- LED illumination
- Quartz lamps

Imaging Spectrograph

The spectrograph separates incoming reflected light into narrow wavelength bands.

Camera

Sensitive CCD or CMOS cameras capture spectral images over visible, near-infrared (NIR), or short-wave infrared (SWIR) regions.

Conveyor or Translation Stage

Automated movement enables continuous scanning of seed samples.

Computer and Software

Specialized software performs image acquisition, preprocessing, spectral analysis, feature extraction, and classification.

Spectral Regions Used in Seed Analysis

Spectral Region	Wavelength (nm)	Major Applications
Visible (VIS)	400–700	Colour, surface defects
Near Infrared (NIR)	700–1000	Moisture, protein, oil
Short Wave Infrared (SWIR)	1000–2500	Chemical composition

Different seed constituents absorb electromagnetic radiation differently, creating unique spectral fingerprints.

Image Acquisition Process

The general workflow includes:

1. Seed sample preparation
2. Calibration using white and dark references
3. Hyperspectral image acquisition
4. Image preprocessing
5. Feature extraction
6. Classification or prediction
7. Quality evaluation

Image Processing Techniques

Raw hyperspectral images require preprocessing before analysis.

Common preprocessing methods include:

- Noise removal
- Background subtraction
- Spectral normalization
- Savitzky–Golay smoothing
- Multiplicative Scatter Correction (MSC)
- Standard Normal Variate (SNV)

These techniques improve signal quality and reduce unwanted variability.

Feature Extraction Methods

Since hyperspectral datasets contain hundreds of wavelengths, dimensionality reduction is necessary.

Popular techniques include:

- Principal Component Analysis (PCA)
- Independent Component Analysis (ICA)
- Successive Projection Algorithm (SPA)
- Genetic Algorithm (GA)
- Partial Least Squares (PLS)

These methods identify informative wavelengths while reducing computational complexity.

Machine Learning in Hyperspectral Seed Analysis

Machine learning algorithms convert spectral information into meaningful predictions.

Common algorithms include:

Classification

- Support Vector Machine (SVM)
- Random Forest (RF)
- Decision Tree
- k-Nearest Neighbour (k-NN)
- Artificial Neural Networks (ANN)

Regression

- Partial Least Squares Regression (PLSR)
- Multiple Linear Regression (MLR)

Deep Learning

- Convolutional Neural Networks (CNN)
- Deep Neural Networks (DNN)
- Hybrid CNN-LSTM models

Deep learning enables automatic extraction of spectral and spatial features with high prediction accuracy.

Applications in Seed Quality Detection

Seed Viability

HSI can distinguish viable and non-viable seeds by detecting biochemical changes associated with ageing.

Seed Vigor

Spectral characteristics correlate with germination potential and seedling emergence.

Moisture Content

Near-infrared wavelengths accurately estimate moisture levels without destroying the seed.

Disease Detection

HSI detects fungal infections such as *Aspergillus*, *Fusarium*, and other seed-borne pathogens before visible symptoms appear.

Mechanical Damage

Internal cracks and embryo damage invisible to the human eye can be detected using spectral signatures.

Variety Identification

Different cultivars possess unique spectral fingerprints that facilitate rapid variety discrimination.

Genetic Purity

HSI assists in identifying off-types and maintaining seed certification standards.

Advantages of Hyperspectral Imaging

- Non-destructive analysis
- Rapid inspection
- Simultaneous spatial and spectral information
- High accuracy
- Chemical composition assessment
- Suitable for automation
- Reduced labour requirements
- High-throughput screening capability
- Environmentally friendly

Limitations

Despite its advantages, several challenges remain:

- High equipment cost
- Large data volume
- Complex image processing
- Requirement for advanced computational resources

- Need for skilled operators
- Limited portability in some systems

Recent Advances

Recent research focuses on:

- Portable hyperspectral imaging systems
- Drone-mounted hyperspectral sensors
- Artificial intelligence-assisted classification
- Cloud-based image analysis
- Edge computing for real-time processing
- Integration with robotic seed sorting systems

These developments are making HSI increasingly practical for commercial seed industries.

Future Perspectives

Future research should aim to:

- Reduce system cost
- Improve real-time processing speed
- Develop compact portable devices
- Standardize calibration protocols
- Integrate Internet of Things (IoT) platforms
- Combine HSI with Raman spectroscopy, thermal imaging, and X-ray imaging
- Develop robust deep learning models for multi-crop applications

The integration of HSI with artificial intelligence and precision agriculture technologies is expected to revolutionize seed quality management.

Conclusion

Hyperspectral imaging has emerged as one of the most promising non-destructive technologies for seed quality detection. By integrating imaging and spectroscopy, HSI enables comprehensive evaluation of physical, chemical, and biological seed characteristics. Combined with machine learning and deep learning techniques, hyperspectral imaging offers rapid, reliable, and automated assessment of seed viability, vigor, moisture content, disease infection, genetic purity, and variety identification. Although challenges such as high cost and computational complexity remain, continuous technological advancements are making HSI increasingly accessible. Its adoption is expected to play a significant role in modern seed testing laboratories, breeding programmes, and precision agriculture.

References

1. Mahlein, A. K. (2016). Plant disease detection by imaging sensors. *Annual Review of Phytopathology*, 54, 373–393.
2. Gowen, A. A., O'Donnell, C. P., Cullen, P. J., Downey, G., & Frias, J. M. (2007). Hyperspectral imaging—An emerging process analytical tool. *Trends in Food Science & Technology*, 18(12), 590–598.
3. Huang, M., Zhu, Q., Qin, J., & Lu, R. (2015). Hyperspectral imaging for seed quality and safety inspection. *Food Engineering Reviews*, 7(3), 214–228.
4. Cogdill, R. P., et al. (2004). Evaluation of maize seed quality using visible and near-infrared spectroscopy. *Applied Engineering in Agriculture*, 20(4), 475–483.
5. ElMasry, G., Sun, D. W., & Allen, P. (2012). Near-infrared hyperspectral imaging for food quality inspection. *Comprehensive Reviews in Food Science and Food Safety*, 11(2), 237–251.