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IMPROVING SEED QUALITY EVALUATION USING ARTIFICIAL INTELLIGENCE: DEVELOPMENTS AND USES IN CONTEMPORARY AGRICULTURE

Arpitha Karadi[1*], Sujatha Patta[2], Rao Polneni Jagan Mohan[3], Marco Brini[4], Vangala Navya[1], John William Carey Medithe[5] and Mandapelli Sharath Chandra[6]
[1]Department of Seed Science and Technology, Seed Research and Technology Centre, Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad, Telangana, India;
[2]Department of Genetics and Plant Breeding, Agricultural College, Jagtial, PJTAU, Telangana, India
[3]Department of Genetics and Plant Breeding, PJTAU, Rajendranagar, Hyderabad, Telangana, India
[4]Digital agriculture expert and author, Senior Director Smart Farming NADEC (KSA),Vice-Chair of the ITU Focus Group on "Artificial Intelligence (AI) and Internet of Things (IoT) for Digital Agriculture" (FG-AI4A), Riyadh, Saudi Arabia;
[5]Carey Joehln International Private Limited, Hyderabad; Telangana, India;
[6]AICRP on Integrated farming system, Professor Jayashankar Telangana Agricultural University, Rajendranagar, Hyderabad, Telangana, India
*Corresponding author E-mail: arpithakaradi18@gmail.com
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ABSTRACT

Artificial Intelligence is an accurate, efficient, and scalable method as it is transforming agricultural operations, including seed quality testing. Computer vision, machine learning, and deep learning algorithms are examples of AI-driven technologies that are augmenting or replacing traditional seed testing techniques, which are frequently laborious and tedious. Critical characteristics such as physical damage, germination rate, viability, and seed purity can all be precisely evaluated by these methods. Predictive analytics improves decision-making in seed processing and selection, while image-based AI models can detect and categorize seed flaws. AI also makes automation and real-time monitoring possible, which lowers operational expenses and human error. Therefore, increased crop yields, sustainable agricultural methods, and enhanced seed certification procedures are all anticipated when AI is incorporated into seed quality testing. This study examines the latest advancements, uses, and potential of artificial intelligence in the field of evaluating seed quality.
***Keywords*:** Artificial Intelligence, Seed Quality Testing, Machine Learning, Computer Vision, Agricultural Automation

Introduction

Physical purity test, sprouting test, thermal conductivity assessment, growth of seedlings test, rapid aging test, tetrazolium tests and cold test are applied to assess the caliber of seed lots. These procedures tend to be non-automated, tedious, costly, damaging, along with demand specific knowledge and expertise from the persons involved in conducting such tests. Therefore, in order to supply farmers with high vigor seeds prior to seeding, the seed industry needs to develop non-invasive, efficient screening techniques. AI based emerging technologies are in practice for the seed quality testing using Raman spectroscopy, InfraRed Thermography (IRT), X-ray visualization, hyperspectral photographic imaging (HSI) and multispectral analysis (MSI) etc. Each of these methods are employed based on the applicability.

AI and moisture estimation by Near Infrared (NIR) spectroscopy

Traditional infrared finding tools generally employ both emission and manifestation procedures as their identification tenets (Sun *et al.,* 2017). Principle of NIR Optical Detection consists that when rice kernel specimens are exposed to light, the wetness of the particles can be determined directly by the magnitude of the emitted light convey that is collected. Through its photosensitive components they capture this reflected light signal, and variations in its intensity provide a direct indication of the moistness of each cereal specimen (Isaksson *et al.,* 2003)

A quick-detection detector to determine the moisture level of rice grains (Lin *et al.,* 2019). Using a single-band Near-Infrared (NIR) measurement at 1450 nm. The system incorporates both hardware and software components, including an LED light source. This sensor holds considerable importance for monitoring rice grain quality throughout its production, transportation, and storage phases. The utilization of NIR technology at a specific wavelength enhances the accuracy of moisture content determination. The designed sensor is poised to aid in a crucial part at ensuring overall quality monitoring the rice grains at key stages of the supply chain, contributing to efficient management and maintenance of optimal storage conditions.

Precise and non-invasive measurement of maize seed moisture content is achieved through Vis/NIR and NIR imagery technology. Spectral images were acquired from both the developing egg and serve ends of 4 different maize varieties. The application of partially least squares regression (PLSR) with NIR data demonstrated superior performance compared to Vis/NIR spectra (Zhang and Guo, 2020). Rice moisture estimation utilizing electrostatic capacitance theory with an accuracy of 97.83% (Ponglangka, 2015).

AI in genetic purity testing

Genetic purity describes the genuiness of the variety which can be predicted by human intervention, but in case of inter class similarity the human decision may differ in classifying or judging the types. Historically, an agricultural variation is recognized by human aid by employing ODV test (Other Distinguishable Varieties test). The concept of seed quality encompasses various attributes, such as inherited pureness, well-being, survival, sprouting potential, and vitality (ISTA, 2019). By integrating CNN-extracted elements with hand-made characteristics, the reliable classification of 9 different types of seed significantly surpassed that achieved with hand-crafted features alone. This fusion approach demonstrates enhanced performance in seed variety classification. CNN-ANN architecture shows promise in accurately classifying corn varieties, with room for further enhancements (Javanmardi *et al.,* 2021).

Expensive high-quality rice (Chang-Li-Xiang) and cheap quality rice with low price (Li-Shui) were obtained and mixed with various proportions to obtain an adulterated rice sample. Visible, NIR (390-1050 nm) images were captured for 200 rice samples. ENVI software was utilized to process hyperspectral images for rice adulteration detection. A region of interest (ROI) was determined, and hyperspectral data was extracted using the averaged reflectance from the ROI pixels. Based on the entire spectral range, the support vector machine (SVM) emulate was built and it achieved 98% predictability and 93% a cross-valid accuracy. To enhance model performance and processing efficiency, conventional PCA which stands for principal component analysis (PCA) was employed to quiet down and extraction of features. Six characteristic wavelengths were identified, and an optimal number of principal components (PCs) was determined as 9. Simplified SVM models, based on these features, yielded promising results with 95% cross-validation and 96% prediction accuracy for characteristic wavelengths and 94% cross-validation and 98% prediction accuracy for optimal PCs. This indicates that rice adulteration can be successfully identified using hyperspectral scans (Sun *et al.,* 2014).

Discrimination of 5 different kinds of rice images with MSI of support vector machine. 250 seeds from five rice varieties (50 seeds each) were studied by Liu *et al.,* 2014. These seeds were categorized into a test set (40 grains from each kind) and a set of verification (10 grains from each of its kind). Employing spectral scrutiny with Videometer Lab equipment, images were acquired at nineteen spectral bands, ranging in sight to much shorter waves in near IR range (405-970 nm). Image segmentation involved background removal through analyzing Discriminants Canonically (CDA), subsequently straightforward threshold-based division of rice seed images. Extracting data on area, width/length, roundness, and color values, PCA (Principal Component Analysis) and the Least-Squared Vector Machines (LS-SVM) were employed for discrimination. The proposed model combining spectral and image features (Model-1) exhibited a discrimination accuracy of ninety percent discrimination accuracy at the test set and a precision of one hundred percent in the measurement set up. This innovative approach showcases the promise in mathematical analysis and multispectral photographic imagery to enable quick, efficient, non-destructive classification in rice seed varieties.

AI in predicting seed germination, dead seeds, seed quality, seed viability and seedling vigour

Conventional seed-viability testing methods are laborious and destructive. Multispectral NIR imaging offers a nondestructive and precise alternative for assessing soybean seed viability. This method replaces manual inspections with efficient and accurate discrimination based on near-infrared imaging, significantly reducing time and labor requirements. Instead of pixel-level analysis, grain- based method of image processing technique became utilized for categorizing whole seeds as either productive or infertile in hyperspectral images, streamlining the classification process for improved efficiency (Baek *et al.,* 2019).

Determining the capability over sprouting, germination speed, and vitality in the seedlings of *Jatropha curcas* L. seeds by integrating AI powered X-ray evaluation along with an algorithmic learning framework (de Medeiros *et al.,* 2020) (Figure 1). The Radiographic images from grains were automatically analyzed to extract the characteristics of form and structure of tissues. Subsequent physiological assessments had been conducted upon the radiation exam. Quality classes had been created based on individual seed descriptors, and LDA (Linear Discriminant Analysis) predicts had been used. The predictions on grain survival, growth rate, and robustness of seedling achieved median accuracies of Ninety-four, Eighty-three and Eighty-nine percentages respectively. The largescale CT visualization demonstrated the capability to separate individual *Jatropha curcas* kernels to distinct standard divisions efficiently, encompassing the strength of young developing plant, pace, and plant vitality. This proposed technique offers a quick and robust approach for seed classification, providing valuable insights for seed quality assessment.

Utilization of a computer-vision germination system, automated for continuous monitoring, was employed to observe seeds throughout imbibition and germination, facilitating the identification of distinct categories for each individual seed (ElMasry *et al.,* 2019). The study's findings highlighted the effectiveness of an imaging with multispectral technique, spanning radiation, obvious, and shortwave near IR regions, in discerning individual cowpea seeds into distinct classes. With its quick capture of photos and minimal prep work requirements, using this modern imaging approach, coupled with chemometric testing, proves to be a valuable tool for economical instantaneous fashion evaluating and separating practices. The design captures the biological and structural characteristics and essential organic date specifics involving seeds. The incorporation of algorithms to enhance images tailored for evaluation of seed grade, combined alongside in an ongoing reduction in computer hardware costs and increased computing power, enhances the attractiveness of developing computer-integrated systems for the automatic inspection of seed quality.

Evaluating the prompt investigation in maize seed durability by emloying brief raise in IR with HSI and chemo (Wakholi *et al.,* 2018). The 600 corn samples underwent either microwave heat treatment or served as overseeing put. HS photographic images were gathered with a shortwave infrared lens spanning a Thousand to 2500 nm in wavelengths. Various categorizing approaches, including partial least squares discriminant approach (PLS-DA), support vector machines (SVM) and discriminant evaluation with linearity (LDA) were evaluated with pre-processing procedures. The SVM model achieved the highest spectral classification accuracy at 100%, surpassing previous PLS-based methods by 5%. Additionally, the SVM model generated flawless classification images, indicating the potential of hyperspectral imaging for accurate corn viability classification. The present work represents a major step towards developing of a quick and non-invasive massive operations in separating tool with HSI in determining corn viability. Effective differentiation potential of wheat grains with spectroscopy ranging at of 400–1000 nm (VIS/NIR) (Zhang *et al.,* 2018). The pictures from X-rays were processed to evaluate the skeletal strength of grains, and a longevity forecasting technique based on integrity emerged. Additionally, CNNS (convolutional neural network) predictive algorithms for sustainability were created along with assessment. Both of the theories effectively differentiated between seeds that sprouted and those that didn't.

Nevertheless, the algorithm originated from CNN-based model exhibited superior in predicting seed development compared to emulate built around processing pictures. The CNN-based design achieved 86% precision in F1 score (92.11%) demonstrating success of the safe evaluation technique to measure tomato seed survival (Hong *et al.,* 2015).

Vibrational spectroscopy in the NIR region can effectively classify corn seeds based on viability traits. This non-destructive method utilizes starch and protein content to identify useful and infertile corn kernels. The technique provides a valuable tool for assessing seed quality in agriculture, aiding in optimal seed selection and ensuring successful crop cultivation (Ambrose *et al.,* 2016).

X-ray CT imaging was utilized to unveil the internal characteristics of seeds, accurately identifying empty, broken, or irregularly shaped endosperms with a remarkable 98% accuracy. This model enhances seed quality assessment for improved germination rates (Ahmed *et al.,* 2018).

The extent of seed being full, wounds/damages, the existence of concealed (obscured) sprouting, other flaws alongside anomalies of inner framework were determined using X-ray radiography for classification of cabbage seeds to judge their seed qualities (Musaev *et al.,* 2022) (Figure 2, 3). Digital photographs of a CT scans photographed with the PRDU-02 portable X-ray screening tool. The computerized inspection of these pictures were utilized for VideoTesT-Morphology 5.2 software. This investigation identified hidden flaws in cabbage, including uneven obscuring, pronounced firm division of embryonic regions, and seed angularity resulting in reduced viability. This automatic analysis verified that brightness is useful and form indicators in digital imagery of a CT scan, establishing their correlation with the sowing qualities of the grains studied.

Adoption of a dynamic AI i.e., a comprehensive approach in which standard and collaborative data mining technique was employed to determine the grade of soy seeds and young plants (Figure 4, 5) according to their biological interest and graphic attributes and simulations have been developed using cost-effective methodologies and freely available software which resulted in exhibiting remarkable performance, achieved an overall accuracy rate of Ninety-four per cent (de Medeiros *et al.,* 2020). Exactness of these simulators, derived from interactive and traditional machine learning, underscores their effectiveness in accurately classifying soybean seeds based on visual attributes and rapidly assessing soybean seedling vigor by employing accessible technologies for soybean seed and seedling classification is an efficient means to evaluate soybean seed quality and vigor.

Seed viability was predicted in castor seeds by using multispectral imaging (MSI) of Videometer Lab instrument (Olesen *et al.,* 2015). By sight, the following kinds of grains were noticed, yellow, grey and black colored (Figure 6, 7). All the planting shots had been taken at nineteen unique frequencies which fell between 375 to 970 nm. Tetrazolium Test was done for these samples and individual images were captured. Every seed visually categorized as yellow was confirmed to be non-viable in the tetrazolium test. Variability in longevity across grey and black grain types was noted. An approach for controlled categorization, employing normalized canonical discriminant analysis (nCDA) alteration within deceased and living seeds had been developed and put to trial with fresh seeds. The model achieved a 96% correct classification rate for predicting viable and dead seeds, highlighting the possibilities in using multifaceted perception gadgets via rating grades of grain. Multispectral imaging offers advantages over individual grain Ultraviolet (UV) or Infrared instruments by enabling measurement of numerous elements within obvious close to UV frequencies.

AI and seed health testing

Identification of wheat seeds with *Fusarium sp.* and black point disease-infected parts of the seed surface could successfully be distinguished from uninfected parts with the use of a multispectral imaging device at 405–970 nm wavelengths (Figure 8) (Vresak *et al.,* 2016). The methodology developed by Olesen *et al.,* (2011) was used as a reference for capture of multispectral images. All digital images were captured with a Videometer Lab instrument. Row A (Figure 8) performing traditional color (RGB) captured images of individual dry seeds captured before incubation; the following row B shows implementation of nCDA transformed images to distinguish infected and uninfected seed parts (dark blue coloring for uninfected parts, orange color for black point disease infection and light blue color for parts infected with *Fusarium* sp.) and in row C, RGB images are captured after seed incubation, which were used for confirmation of correct dividing of infected and uninfected parts by nCDA transformation. The highlight of separation was linked to detected infection on the seed parts that visually did not differ from uninfected ones (third and fifth column in Fig 5). Raman hyperspectral imaging is promising for identifying bacteria-infected watermelon seeds. Its efficacy suggests it could serve as a viable substitute for traditional detection methods, showcasing its potential as an alternative technology in seed quality assessment (Lee *et al.,* 2017). Rapid and precise detection of microorganisms by Infrared spectroscopy and Raman spectroscopy (Lu *et al.,* 2011).

A novel approach incorporating ML and spectral photography was introduced in classifying *Jatropha curcas* grain well-being (da Silva *et al.,* 2021). The seeds were artificially inoculated with various pathogenic fungi, including *L. theobromae*, *C. siamense,* and *C. truncatum*. Multifaceted shots have been taken at different time points during a 168-hour incubation period (Figure 9). The results demonstrated that MSI procedure, coupled with statistical frameworks, exhibited remarkable feasibility in distinguishing among various fungi in *J. curcas* grain just after 48 hours of incubation, achieving high accuracy levels exceeding 80%. The methodology utilized MRI in determining structural alterations in *J. curcas* grain diagnosed with distinct pathogens. The

MR imaging technique deployed on 168 hours incubated grain, successfully revealed distinct patterns of injury in endosperm end. This research highlights the efficacy of spectral imaging and Magnetic Resonance Imaging as valuable approaches for quick and precise identification of various fungi of *Jatropha curcas*. The amalgamation in advanced imaging technologies and machine learning holds significant promise for enhancing seed health assessment and contributing to the development of effective strategies for seed quality management in agriculture.

AI and Seed grading

Through advanced algorithms, a smart device was utilized, it optimized sorting based on various quality parameters and graded ensuring export grade quality cowpea (Audu and Aremu, 2021). Multispectral imaging (375-970 nm) effectively distinguishes sound white maize from 13 prevalent undesirable materials encountered in South African industry grading. This technology offers a practical solution for enhancing maize quality control, streamlining the grading process by accurately identifying and separating unwanted materials during industrial practices (Sendin *et al.,* 2018). Using Fourier transformation in near-infrared and Ramsey to categorize and asses the useful seeds of pepper (Seo *et al.,* 2016).

AI and Varietal Identification

iRSVPred marks a pioneering achievement as the first AI-powered web server designed for predicting 10 major basmati variety seeds solely through seed images. This innovative tool showcases the potential of artificial intelligence in streamlining and advancing seed variety identification based on visual data (Sharma *et al.,* 2020). A digital image analysis algorithm was devised for discerning six Basmati rice varieties in India, utilizing color, morphological, and textural features. Employing nine features from each category for discriminant analysis, a backpropagation neural network classifier identified unknown grain types. Additionally, an image processing technique determined the proportion of de-husked rice from Basmati deemed unadulterated, surpassing conventional methods in identifying broken grains and providing a comprehensive quality assessment (Gujjar and Siddappa, 2013). A hybrid CNN-SVM for classification of different rice varieties (Poudel and Devkota, 2022). Multifaceted photography to be a primary instrument in the field of science in accurately identifying and discriminating plant varieties based on genetic purity, offers significant applications in aid and enrollment of kinds of plants, ensuring integrity in agricultural genetic resources (Shrestha *et al.,* 2015). Utilizing image processing and artificial neural networks, a combined method effectively identifies 13 Iranian rice cultivars, streamlining the classification process with high accuracy (Abbaspour *et al.,* 2020). Seed images analysis using morphological characters for varietal identification (Sumathi and Balamurugan, 2013).

AI and chemical composition of seeds and predicting the seed quality

Maize seed quality evaluation achieved through gigantic, fast and safe surveillance revealed successful characterization of geographical patterns in substances. This innovative technique holds promise for efficient and extensive assessment of maize seed quality, offering a valuable tool for agricultural applications (Yang and Huang, 2018). Protein content estimation of corn seed using UV-rays luminescence spectroscopy (Egesel and Kahriman, 2012). Determination of quality parameters in maize grain by NIR VIS/NIR (Visible infrared and Near IR) spectra to figure out the physical and chemical features in grains and assess its quality (Natsuga and Kawamura, 2006).

Conclusion

Through the development of quick, precise, and non-invasive techniques for assessing seed qualities, artificial intelligence (AI) has greatly improved the process of improving seed quality. AI systems can more accurately evaluate criteria including seed viability, germination potential, purity, and health than conventional techniques by utilizing machine learning algorithms, image processing, and predictive analytics. These developments not only boost productivity and lower human error, but they also aid in improving the breeding and seed selection procedures, which eventually leads to increased crop yields and sustainable agriculture.

Future trends: AI improves post-harvest handling and sowing decisions by enabling real-time monitoring of seed storage and field conditions through the combination of Internet of Things (IoT) devices and satellite imagery. The complex models that can forecast seed performance in a range of climatic circumstances, supporting climate-resilient farming. Automation of seed sorting, grading, and packaging powered by AI will boost consistency and throughput in seed processing facilities. AI systems have the potential to improve production and resource efficiency by offering farmers tailored seed selection advice based on crop history, soil data, and weather forecasts. Blockchain and artificial intelligence (AI) can improve seed traceability and quality assurance, ensuring regulatory compliance and fostering trust in seed supply chains.

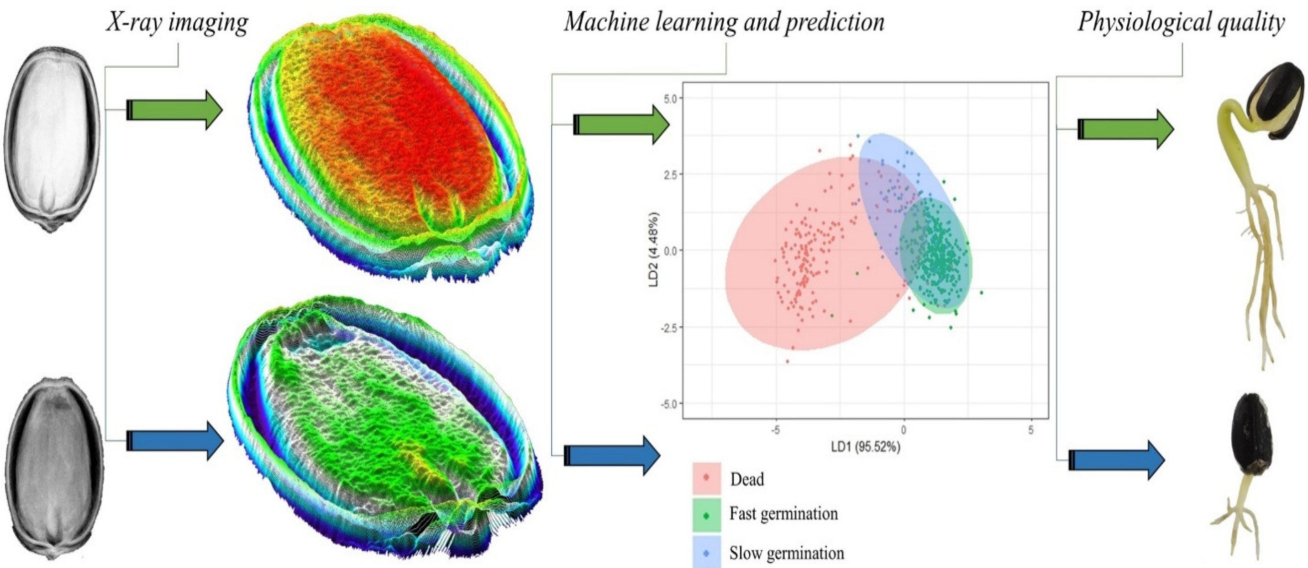

Fig. 1 : Graphical abstract with X-ray images, ML technique and the predictions related to the biological state of the grain (de Medeiros *et al*., 2020).

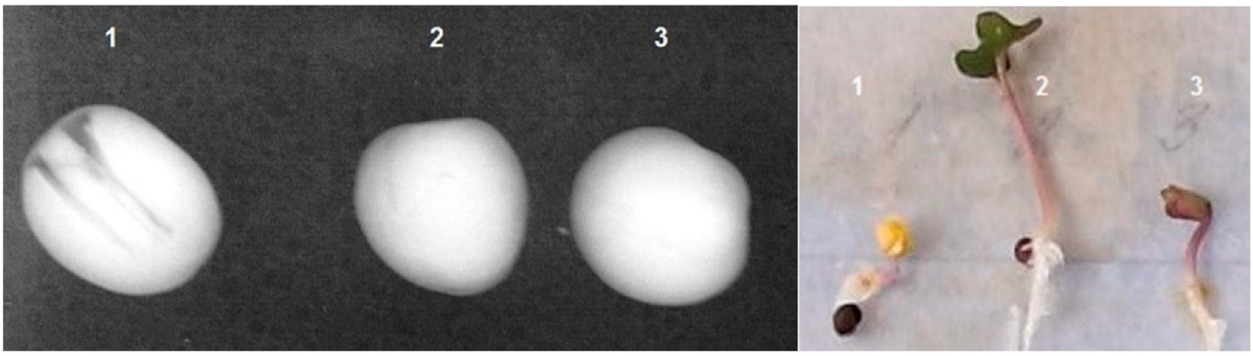

Fig. 2 : White cabbage -Imaging of seeds and seedlings with distinct divisions of embryonic Regions in seed No. 1 (Ahmed *et al*., 2018).

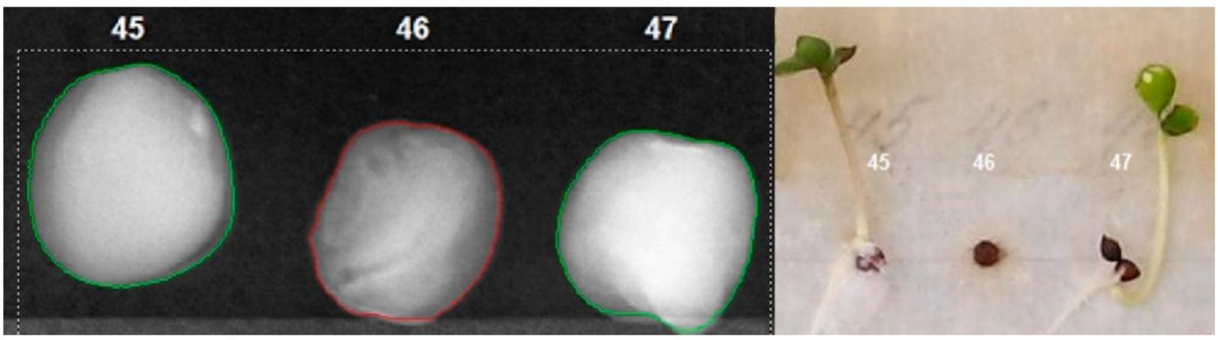

Fig. 3 : White cabbage - Digital radiograph of seeds seedlings displaying uneven obscuring trait (Ahmed *et al*., 2018).

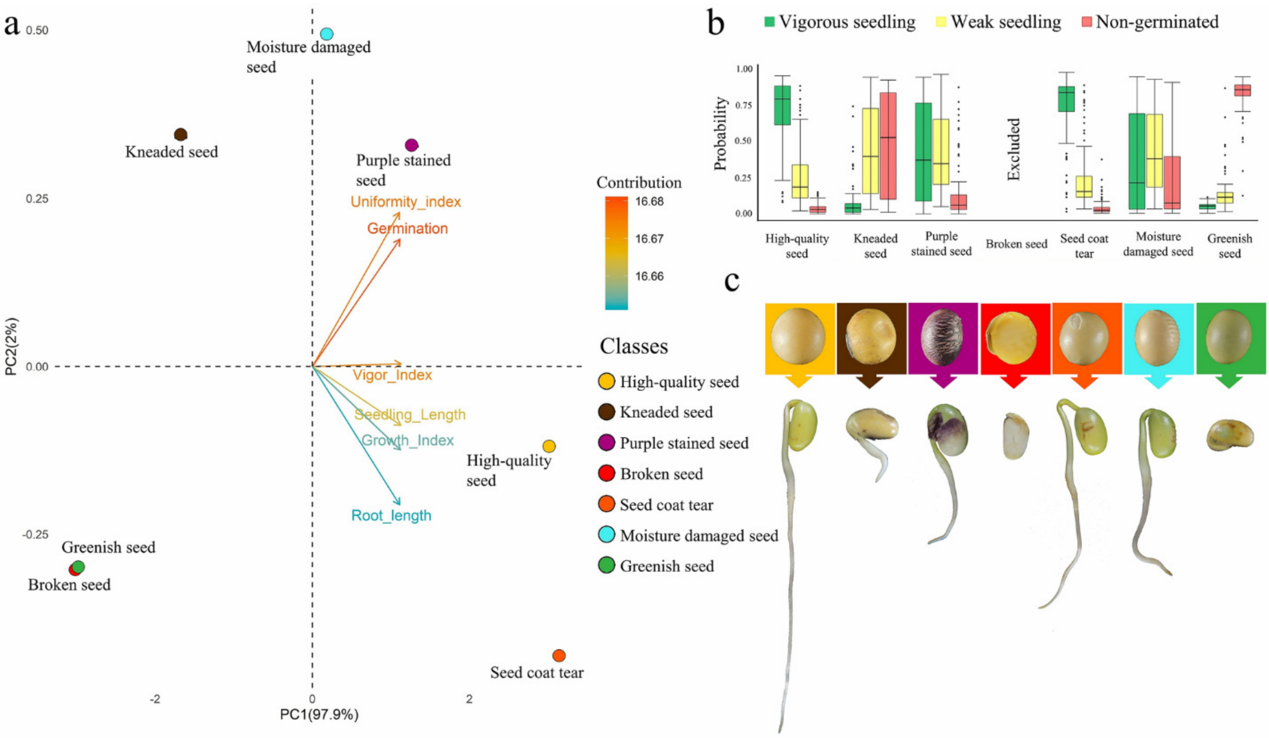

Fig. 4 : Link among the growth of plants and the outward look of the gain (a) Biplot chart demonstrating PCA and its crucial role in class scattering of grain quality metrics (b) potential of producing both sturdy and fragile sprouts based on its grade and, (c)- Feature of sprouts in every germinating group and their appearance after sprouting (de Medeiros et al., 2020).

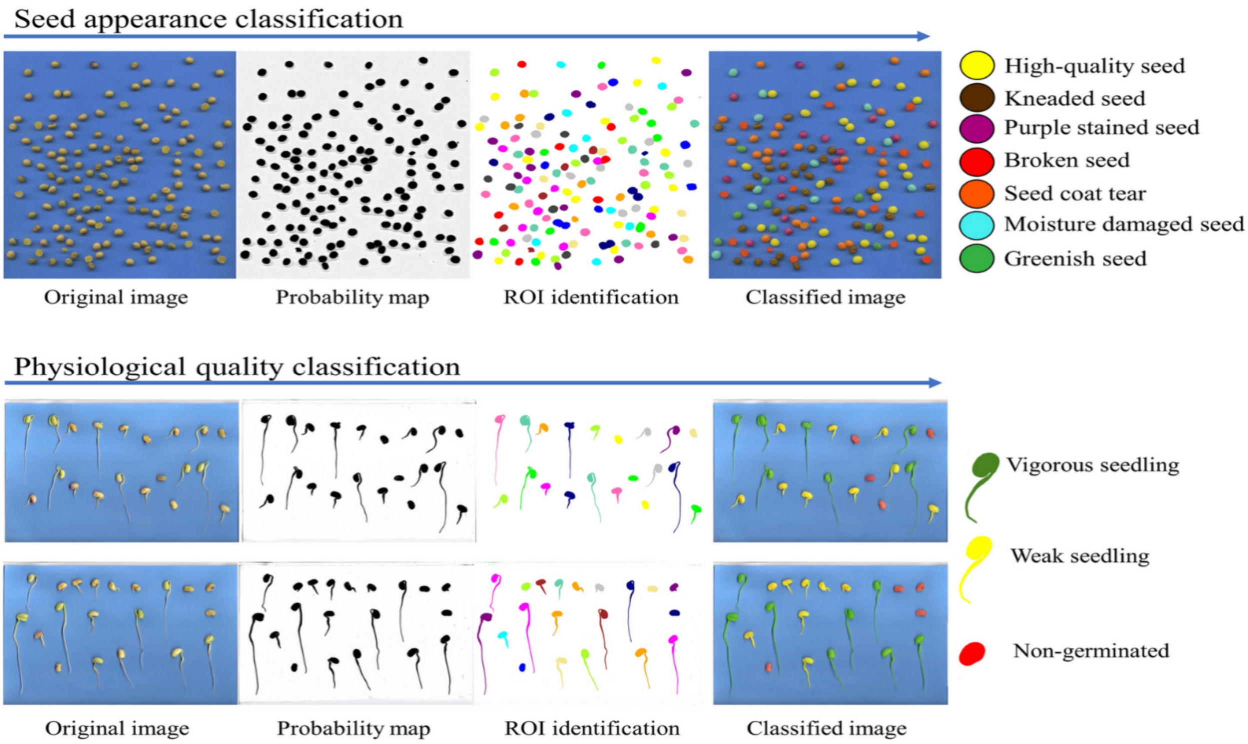

Fig. 5 : Biological standard rating alongside potrayal of dynamic computational learning phases of soy grains (de Medeiros *et al*., 2020).

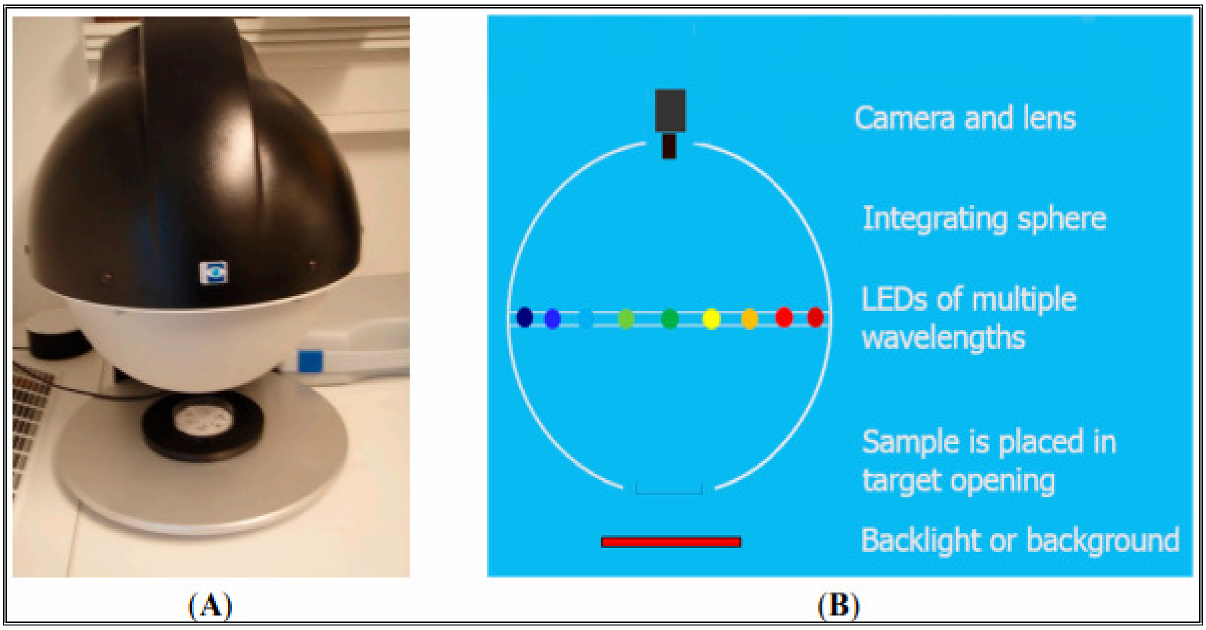

Fig. 6 : (A) An image of Videometer Lab apparatus and (B) Layout of the Videometer Lab apparatus (Olesen *et al*., 2015).

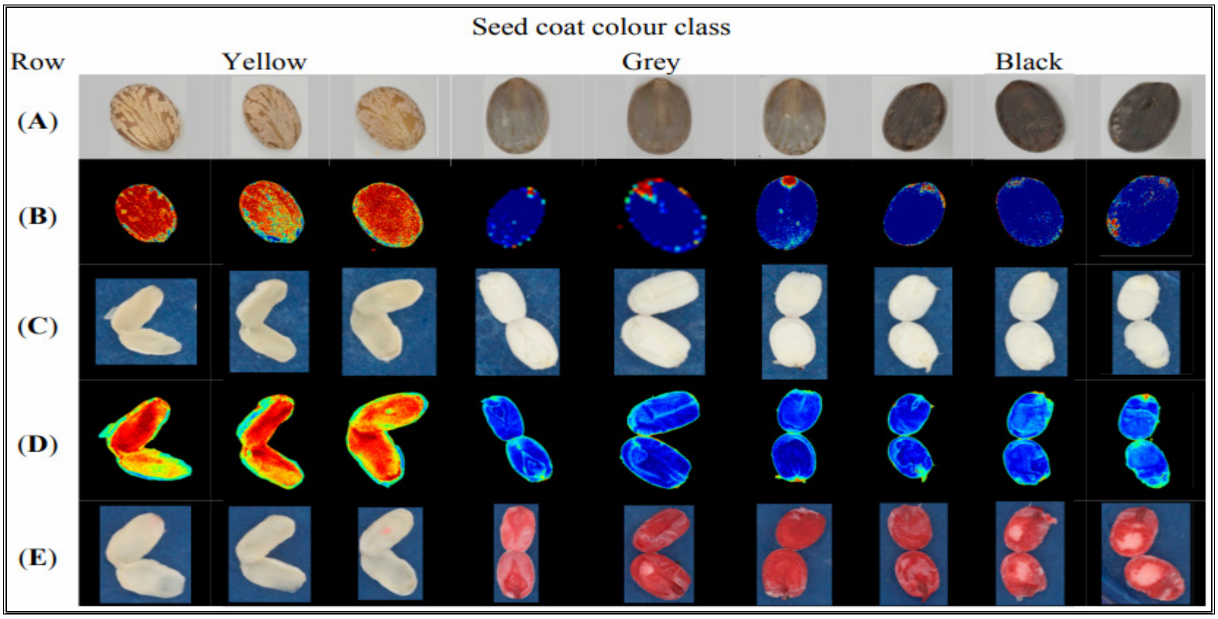

Fig. 7 : Row (A) -RGB depicts of grains, Row (B)- Original pictures changed by nCDA to distinguish living and deceased grains (Whole grain), Row (C)- RGB photos showcasing the chopped grains, Row (D)- Original artworks impacted to divide dead and live grain (depends on chopped grain) and Row (E)- RGB pics obtained that follows tetrazolium test (Olesen *et al*., 2015).

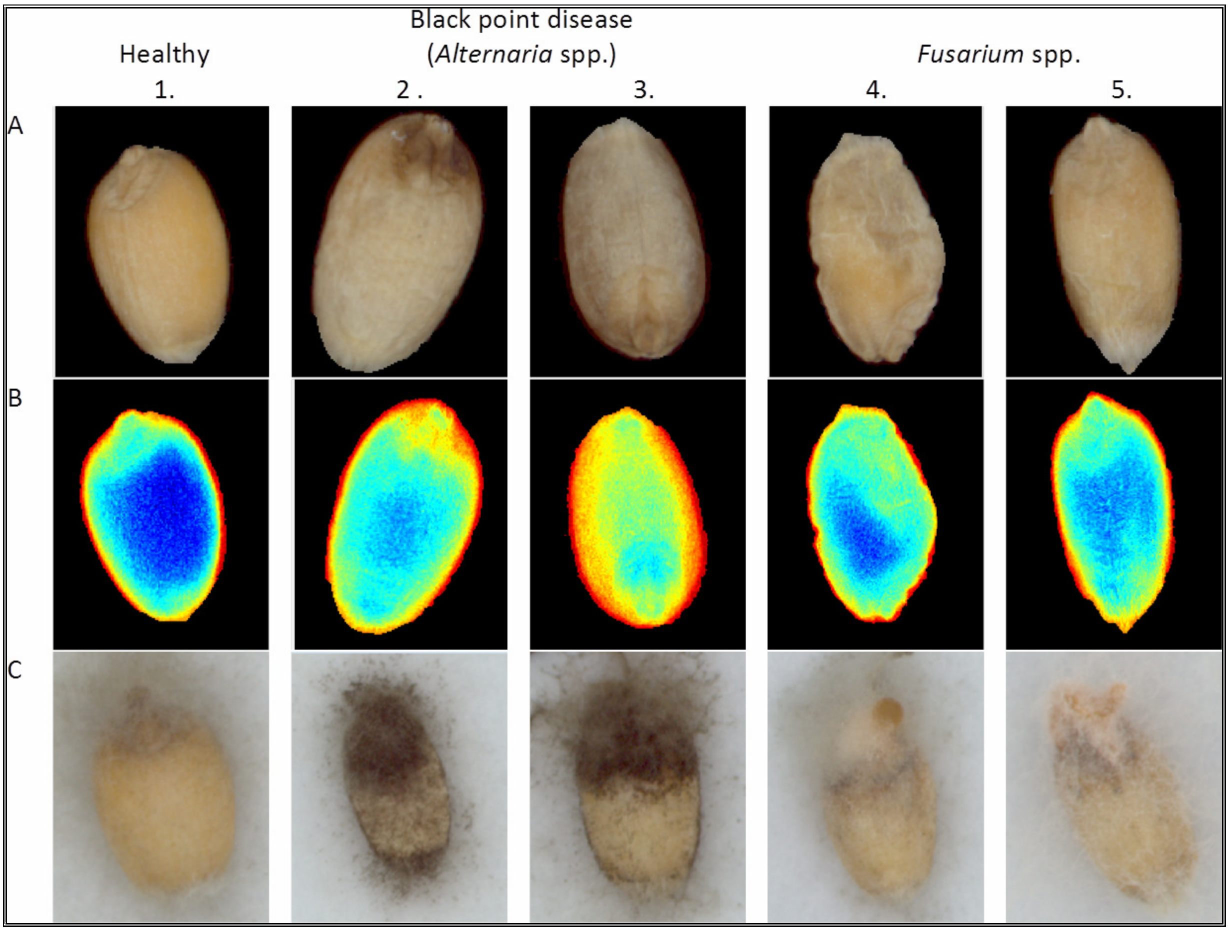

Fig. 8 : An examination of normal and contaminated seed visuals-black point disease (*Alternaria sp.*) and *Fusarium sp.* (A) photographs took in RGB colors (B) nCDA-altered photos (C) RGB pics upon seed incubation step (Vresak *et al.,* 2016).

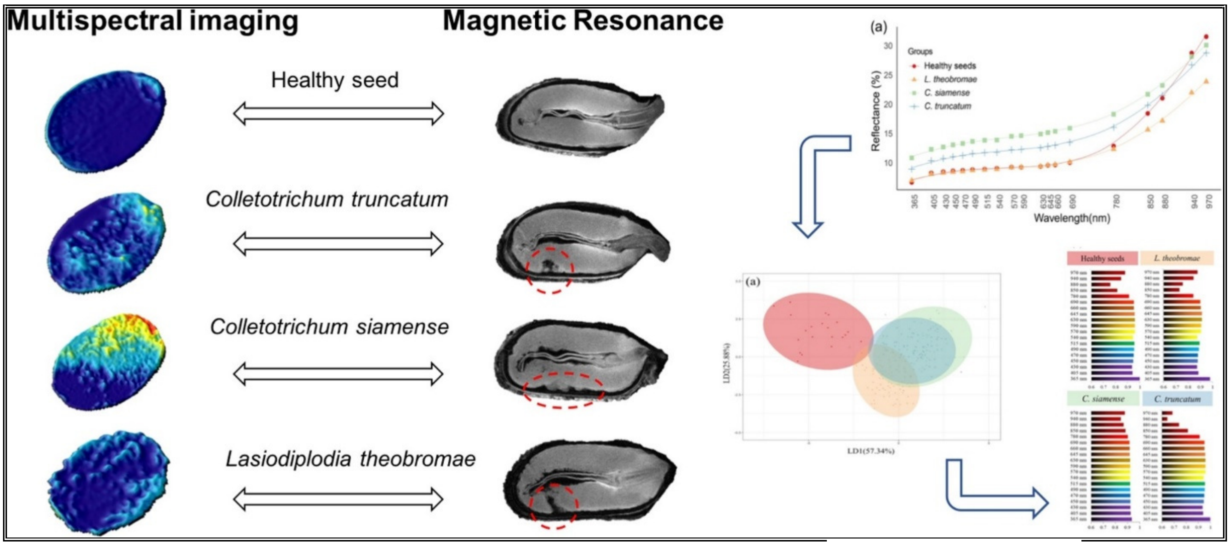

Fig. 9 : Graphical abstract with spectral analysis, and MRI (da Silva *et al*., 2021).

Author Contributions

This work was carried out in collaboration among all authors. This review paper has prepared by the author AK and SP under conceptualization, direct supervision and guidelines of the author's AK, SP and RPJM for writing-original draft. The author's MB and

VN was extensively involved in supervision, formal analysis and editing the original draft of this paper, whereas the author's JWCM and MSC kept contribution in verifying and finalizing the manuscript. All authors have read and agreed to the final version of the manuscript.

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References

Abbaspour Gilandeh Y, Molaee A, Sabzi S, Nabipur N, Shamshirband S and Mosavi (2020) A combined method of image processing and artificial neural network for the identification of 13 Iranian rice cultivars. *Agronomy*. 10 (1): 117.

Ahmed, M.R., Yasmin, J., Collins, W. and Cho, B.K. (2018). X-ray CT image analysis for morphology of muskmelon seed in relation to germination. *Biosystems Engineering*, **175**: 183-193.

Ambrose, A., Lohumi, S., Lee, W.H. and Cho, B.K. (2016). Comparative nondestructive measurement of corn seed viability using Fourier transform near-infrared (FT-NIR) and Raman spectroscopy. *Sensors and Actuators B: Chemical*, **224**: 500-506.

Audu J and Aremu AK (2021) Development, evaluation, and optimization of an automated device for quality detection and separation of cowpea seeds. *Artificial Intelligence in Agriculture*. 5: 240-251.

Baek, I., Kusumaningrum, D., Kandpal, L.M., Lohumi, S., MoC, Kim, M.S. and Cho, B.K. (2019). Rapid measurement of soybean seed viability using Kernel-based multispectral image analysis. *Sensors*, **19**(2): 271.

da Silva CB, Bianchini VDJM, de Medeiros AD, de Moraes MHD, Marassi AG and Tannus A (2021) A novel approach for Jatropha curcas seed health analysis based on multispectral and resonance imaging techniques. *Industrial Crops and Products*. 161:113186.

de Medeiros, A.D., Capobiango, N.P., da Silva, J.M., da Silva, L.J., da Silva, C.B. and dos Santos Dias, D.C.F. (2020). Interactive machine learning for soybean seed and seedling quality classification. *Scientific reports*. **10**(1): 11267.

de Medeiros, A.D., Pinheiro, D.T., Xavier, W.A., da Silva, L.J. and dos Santos, Dias D.C.F. (2020). Quality classification of *Jatropha curcas* seeds using radiographic images and machine learning. *Industrial Crops and Products*, **146**: 112162.

Egesel C and Kahriman F (2012) Determination of quality parameters in maize grain by NIR reflectance spectroscopy. *Journal of Agricultural Sciences*. 18(1): pp.31-42.

ElMasry, G., Mandour, N., Wagner, M.H., Demilly, D., Verdier, J., Belin, E. and Rousseau, D. (2019). Utilization of computer vision and multispectral imaging techniques for classification of cowpea (*Vigna unguiculata*) seeds. *Plant methods*, **15**: 1-16.

Gujjar HS and Siddappa DM (2013) A method for identification of basmati rice grain of india and its quality using pattern classification. *International Journal of Engineering Research and Applications*. *3*(1): pp.268-273.

Hong, S.J., Park, S., Lee, C.H., Kim, S., Roh, S.W., Nurhisna, N.I. and Kim, G. (2023). Application of X-ray imaging and convolutional neural networks in the prediction of tomato seed viability. *IEEE Access*.

Isaksson, T., Yang, H., Kemeny, G.J., Jackson, R.S., Wang, Q., Alam, M.K. and Griffiths, P.R. (2003). Accurate wavelength measurements of a putative standard for near-infrared diffuse reflection spectrometry. *Applied spectroscopy*. **57**(2): pp.176-185.

ISTA (2019) International rules for seed testing, Full Issue. i–19-8 (300). ISTA, Zurich. https://doi.org/10.15258/istarules. 2019

Javanmardi, S., Ashtiani, S.H.M., Verbeek, F.J. and Martynenko, A. (2021). Computer-vision classification of corn seed varieties using deep convolutional neural network. *Journal of Stored Products Research*. 92: 101800.

Lee H, Kim MS, Qin J, Park E, Song YR, Oh CS and Cho BK (2017) Raman hyperspectral imaging for detection of watermelon seeds infected with *Acidovorax citrulli*. *Sensors*. 17(10): 2188.

Lin, L., He, Y., Xiao, Z., Zhao, K., Dong, T. and Nie, P. (2019). Rapid-detection sensor for rice grain moisture based on NIR spectroscopy. *Applied Sciences*, **9**(8): 1654.

Liu, W., Liu, C. and Zheng, L. (2014). Discrimination in varieties of rice seeds with multispectral imaging using support vector machine. *Transactions of the Chinese Society of Agricultural Engineering*, **30**(10): 145-151.

Lu X, Al-Qadiri HM, Lin M and Rasco BA (2011) Application of mid-infrared and Raman spectroscopy to the study of bacteria. *Food and Bioprocess Technology*. 4: 919-935.

Musaev, F., Priyatkin, N., Potrakhov, N., Beletskiy, S. and Chesnokov, Y. (2022). Assessment of Brassicaceae seeds quality by X-ray analysis. *Horticulturae*, **8**(1): 29.

Natsuga M and Kawamura S (2006) Visible and near-infrared reflectance spectroscopy for determining physicochemical properties of rice. *Transactions of the ASABE*. 49(4): pp.1069-1076.

Olesen, M.H., Carstensen, J.M and Boelt, B (2011). Multispectral imaging as a potential tool for seed health testing of spinach (Spinacia oleracea L.). *Seed Science and Technology*, *39*(1), pp.140-150.

Olesen, M.H., Nikneshan, P., Shrestha, S., Tadayyon, A., Deleuran, L.C., Boelt, B. and Gislum, R. (2015). Viability prediction of *Ricinus cummunis* L. seeds using multispectral imaging. *Sensors*, **15**(2): 4592-4604.

Ponglangka, W. (2015). Paddy rice moisture content meter. In 2015 *15th International Conference on Control, Automation and Systems (ICCAS)*. pp. 1709-1713). IEEE.

Poudel A and Devkota B (2022) Varietal Identification of Rice Seed Using Deep Convolutional Neural Network. Journal of Engineering and Sciences. 267: pp.378-384.

Sendin K, Manley M and Williams PJ (2018) Classification of white maize defects with multispectral imaging. *Food chemistry*. 243: 311-318.

Seo YW, Ahn CK, Lee H, Park E, Mo C and Cho BK (2016) Non-destructive sorting techniques for viable pepper (*Capsicum annuum* L.) seeds using Fourier transform near-infrared and raman spectroscopy. *Journal of Biosystems Engineering*. 41(1): 51-59.

Sharma A, Satish D, Sharma S and Gupta D (2020) iRSVPred: a web server for artificial intelligence based prediction of major basmati paddy seed varieties. *Frontiers in Plant Science*. 10: 1791.

Shrestha S, Deleuran L, Olesen M and Gislum R (2015) Use of multispectral imaging in varietal identification of tomato. S*ensors*. 15: 4496-4512.

Sumathi S and Balamurugan P (2013) Characterization of oats (*Avena sativa* L.) cultivars using machine vision. *Pakistan Journal of Biological Sciences. PJBS*. 16 (20): 1179-1183.

Sun, J., Jin, X., Mao, H., Wu, X. and Yang, N. (2014). Application of hyperspectral imaging technology for detecting adulterate rice. *Transactions of the Chinese Society of Agricultural Engineering*. **30**(21): 301-307.

Sun, Z., Han, T.S., Jiang, J.Y., Li, C.X., Xu, K.X. (2017). Study on Surface Reflection Light Elimination of Biological Tissue with Cross-Polarization. *Spectrosc. Spectr. Anal.* **37**: 3520–3524.

Vresak, M., Halkjaer Olesen, M., Gislum, R., Bavec, F. and Ravn Jorgensen, J. (2016). The use of image-spectroscopy technology as a diagnostic method for seed health testing and variety identification. *PLoS One*. **11**(3): e0152011.

Wakholi, C., Kandpal, L.M., Lee, H., Bae, H., Park, E., Kim, M.S., Mo, C., Lee, W.H. and Cho, B.K. (2018). Rapid assessment of corn seed viability using short wave infrared line-scan hyperspectral imaging and chemometrics. *Sensors and Actuators B: Chemical*, **255**: 498-507.

Yang G, Wang Q, Liu C, Wang X, Fan S and Huang W (2018) Rapid and visual detection of the main chemical compositions in maize seeds based on Raman hyperspectral imaging. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*. 200: 186-194.

Zhang, T., Wei, W., Zhao, B., Wang, R., Li, M., Yang, L., Wang, J. and Sun, Q. (2018). A reliable methodology for determining seed viability by using hyperspectral data from two sides of wheat seeds. *Sensors*, **18**(3): p.813.

Zhang, Y. and Guo, W. (2020). Moisture content detection of maize seed based on visible/near-infrared and near‐infrared hyperspectral imaging technology. *International Journal of Food Science and Technology*, **55**(2): 631-640.