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USE OF IMAGE FOR CLASSIFICATION AND IDENTIFICATION OF FOREST SEEDS QUALITY

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ABSTRACT – *Seeds are essential inputs in agriculture and forestry, being the viability, crucial criteria for determining their quality. Image processing and analysis methods were explored to assess seed quality. The vigor of seeds is vital for the establishment of crops, being defined as their ability to germinate and grow in different environments, often inhospitable. Conventional methods, such as germination tests, tetrazolium and the accelerated aging test, have their limitations to determine aspects of predictions and vigor, promoting the search for non-destructive and automated approaches. Image analysis, including near-infrared spectroscopy (NIR) and hyperspectral imaging (HSI), is an effective tool for evaluating various seed characteristics such as size, color and shape. Equipment such as GroundEye® allows for accurate and quick analysis of seed quality. Image analysis has expanded rapidly, offering alternative options to ensure the determination of seed quality of forest and agricultural species, with the potential to revolutionize the selection of plant varieties and increase productivity.*

Palavras-Chave: Technology; GroundEye®; Viability; Plant material.

1. INTRODUCTION

Seeds are fundamental in both agriculture and forestry, with viability being a crucial factor for maintaining quality. Viability reflects germination potential, necessitating swift and effective methods to ascertain their condition prior to cultivation, sale, and planting. To assess the quality of diverse seeds, research has delved into image processing and analysis, aiming to achieve segmentation and spectral correction methods for predicting their quality using both traditional and novel approaches

Seed quality is of utmost importance in the fields of vegetables, fruits, forages, and high-impact economic forest crops, with seeds being one of the fundamental elements extensively employed in establishing various crops. (PEREIRA, et. al 2012).

Seed vigor is a crucial aspect that must be evaluated to determine its quality. According to the International Seed Testing Association (ISTA), seed vigor is defined as the sum of characteristics that determine the activity and performance of seed lots with an acceptable germination capacity in a wide range of environments. A vigorous seed lot is one that has the potential to thrive in environmental conditions that are not considered optimal for the species. Seeds with high vigor possess the ability to germinate uniformly, quickly, and produce more resilient seedlings. (MARCOS FILHO, 2015).

In reality, seed vigor is the result of a complex interplay of characteristics and multiple factors involved in its determination and expression. Among these factors are genetic makeup, environmental conditions during seed development and storage (RAHMAN; CHO, 2016), which makes establishing a precise and standardized definition for seed vigor challenging (QUN, et al., 2007). Because of this, many researchers have dedicated themselves to assessing seed viability instead of solely focusing on vigor, using non-destructive techniques.

Currently, various conventional methods are employed to assess seed vigor, such as the standard germination test, electrical conductivity test, seedling growth test, accelerated aging test, cold test, and tetrazolium test. However, these approaches often lack automation, are destructive, involve slower evaluations, and require specialized training.

Due to the mentioned limitations, these methods are not suitable for large-scale applications or compatible with the conservation of endangered species. Therefore, it is of paramount importance to develop non-invasive, high-throughput screening methods that can be readily adopted by the seed industry to provide high-vigor materials to farmers prior to planting. In this regard, image analysis is an ideal tool for achieving such outcomes (XIA, et al., 2019).

Image analysis is composed of finite elements, each with a specific value and location. These finite elements are the "pixels" and constitute the building blocks of a digital matrix (TEIXEIRA; CÍCERO; DOURADO NETO, 2006).

The technique employed in image analysis yields dimensional features while also identifying the scene. These features are quantified by "pixels," which involve methods of counting or frequency of the elements constituting the image. (TEIXEIRA; CÍCERO; NETO, 2006).

1.1 Image acquisition process and importance

The image acquisition processes essentially comprise four stages: image capture, pre-processing, segmentation, and analysis. Pre-processing aims to enhance the image, while segmentation aims to facilitate thresholding, which involves identifying pixels and recognizing objects. (GONZALEZ; WOODS, 2010).

Thus, image analysis enables a rapid, objective, concise, cost-effective, and non-destructive characterization of the study material. According to Venora et al. (2007), this technique allows for swift image acquisition, taking less than a minute for digitization.

Currently, there are several devices that enable the identification of seed quality. Image analysis and spectroscopy techniques have rapidly evolved in the last decades, finding extensive applications in non-destructive determination of agri-food quality. Significant progress has been made in computational technology, materials, and electronics, leading to notable enhancements in optical systems. These advances have enabled the swift and precise assessment of quality indices, both in static and dynamic classification devices, as well as in online systems, reducing the need for manual intervention. (GOWEN, et al., 2007).

As examples of such non-destructive techniques, we can mention the use of Near-Infrared Spectroscopy (NIR), Hyperspectral Imaging (HSI), or soft X-ray imaging, along with analysis equipment for generated images like the GroundEye®.

The technique of Near-Infrared Spectroscopy (NIR) is based on the absorption of electromagnetic radiation in wavelengths ranging from 780 to 2500 nm (HUANG et al., 2008; NICOLAÏ et al., 2007). As this radiation penetrates agricultural and forestry products, their spectral characteristics undergo changes due to wavelength-dependent absorption and scattering processes.

NIR spectra encompass broad wavelength bands resulting from overlapping absorptions primarily corresponding to harmonics and combinations of these chemical bonds, enabling the detection of organic and biological materials. (XIA, et al., 2018; NICOLAÏ et al., 2007).

The structural tissues of products, composed of cells, as well as internal and extracellular environments, contribute to the scattering of radiation. Meanwhile, absorption is primarily caused by the bonds of major compounds such as water, sugars, chlorophylls, carotenoids, among others, involving single bonds of H, single bonds of O, and single bonds of N (HUANG et al., 2008).

The multivariate nature of NIR spectra makes it challenging to explain and select the analytical information contained within them, rendering it nearly impossible to differentiate very subtle spectral differences among samples. To extract useful

Source: KUSUMANINGRUM et al., (2018).

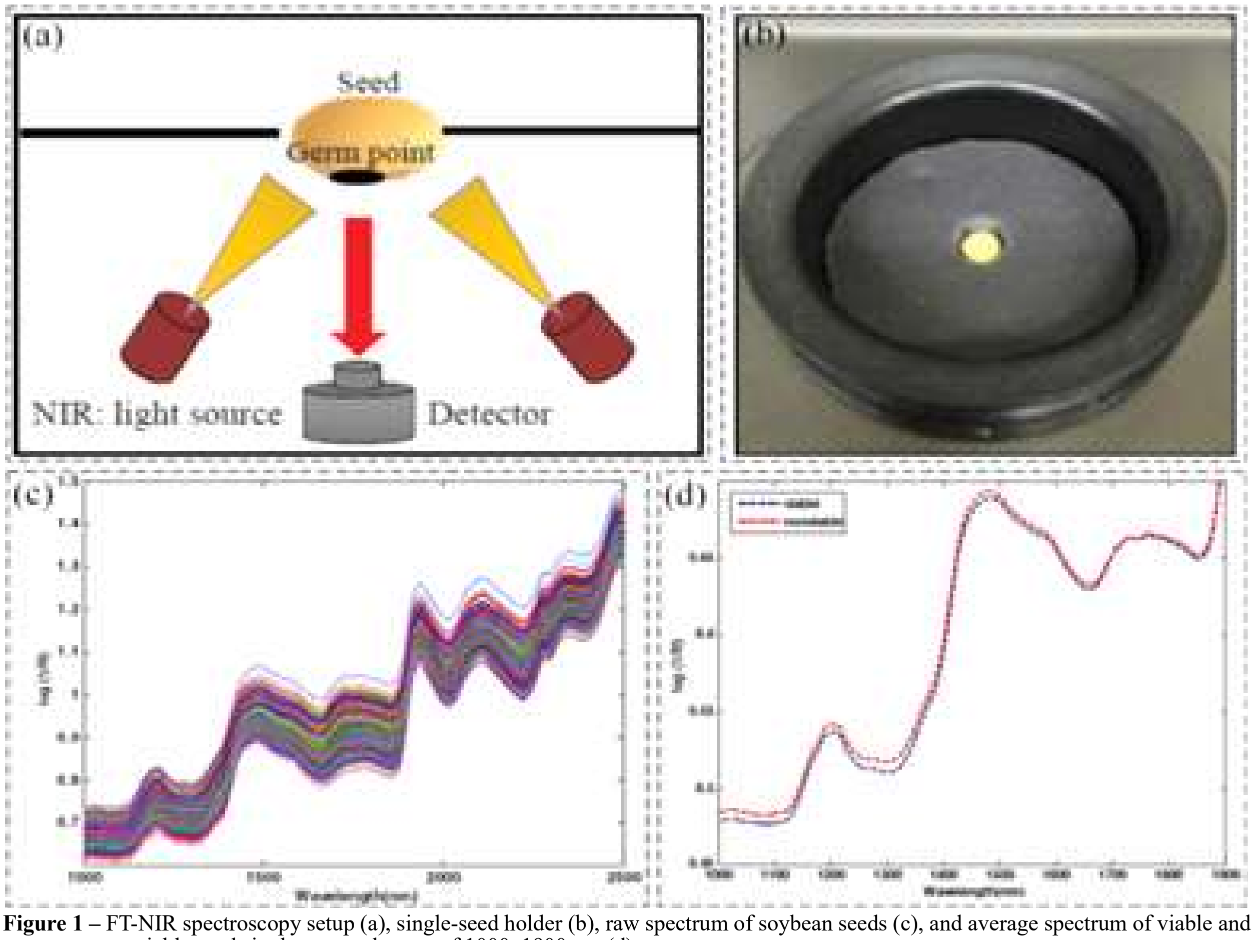

Figure 1 – FT-NIR spectroscopy setup (a), single-seed holder (b), raw spectrum of soybean seeds (c), and average spectrum of viable and non-viable seeds in the spectral range of 1000–1900 nm (d).

information from extensive spectral data swiftly and efficiently, advanced chemometric algorithms are required. These algorithms can conduct data preprocessing and perform quantitative or qualitative analyses as needed (XIA, et al.,2019).

The hyperspectral imaging (HSI) system is an integration of spectroscopic and imaging techniques into a single system, resulting in a set of monochromatic images with hundreds of nearly continuous wavelengths (ZHANG et al., 2014). This integration combines NIR spectroscopy with digital imaging to provide information about the spatial distribution of compounds. Thus, the HSI system generates three-dimensional (3D) data sets, known as "hyperspectral cubes," comprising two spatial dimensions and a unique spectral dimension (ZHANG et al., 2014).

The extended acquisition time required to collect high-dimensional hyperspectral images presents significant challenges for real-time inspections, limiting the practical application of the technology. As a result, HSI is typically applied offline to select the optimal wavelengths to be used for forming multispectral images. A multispectral image (MSI) aims to acquire spatial and spectral information that is directly relevant to a specific application. Instead of using optical fiber probes to obtain average concentrations of various quality attributes in local regions of agricultural samples, hyperspectral or multispectral imaging systems have the capability to generate classification maps or visualize the distribution of these attributes throughout the sample. The application of HSI or MSI has been reported in the identification of viable seeds in the past few decades. (XIA, et al.,2019).

In the current context, the use of Multispectral Imaging (MSI) technique in assessing seed viability has received less attention compared to Hyperspectral Imaging (HSI). There are substantially fewer studies focusing on this approach. The primary goal in employing HSI systems is to establish the integration of MSI systems as a vital component of computerized machine vision systems for various real-time applications (SENDIN et al., 2018). Considering that MSI systems have a smaller number of spectral channels, this results in reduced acquisition and processing times compared to HSI systems. In general terms, the presence of a smaller set of characteristic wavelengths facilitates the development of more agile sensors and contributes to minimizing the collection time (ELMASRY et al., 2019).

In addition to the mentioned techniques and equipment, there is the GroundEye®, developed by the company Tbit at the Federal University of Lavras in Lavras, MG, Brazil. This equipment comprises high-quality cameras and analysis software. The camera consists of a transparent acrylic tray or a conveyor belt, along with LED lamps for illumination. Samples, whether seeds or seedlings, are placed on this tray or conveyor belt for analysis.

The capturing chamber's background is colored blue to provide greater contrast with the object of interest in the image. Before capturing and analyzing the image, it is necessary for the equipment user to define the background to use, effectively setting the pattern for image segmentation. In the GroundEye®, segmentation is achieved by detecting color diferences (MANUAL GROUNDEYE®, 2016).

The equipment enables the use of the system for assessing the color, size, and shape of seeds. It also facilitates the evaluation of seed vigor through measurements of seedling and their parts' length, either in a digital or automated manner. This process is referred to as automatic calibration. It involves associating the images of seedlings from a specific seed batch with the vigor test value (selected according to the specific crop) for the same batch. This way, the software learns and establishes the correct calibration for the particular crop, completing the calibration process (PINTO, 2014).

The evaluation of seed vigor is conducted by the system through comparing the vigor values calculated from laboratory tests with the software values. The calculation requires several pieces of information, such as: the mean of the ratio between the primary root and shoot; the mean of the total size; the quantity of dead or non-germinated seeds; the mean size of the shoot; the mean size of the primary root; the standard deviation of shoot size; the standard deviation of primary root size; the standard deviation of the ratio between primary root and shoot; the standard deviation of the total size, and the average size of the skeleton (MANUAL GROUNDEYE®, 2016).

Furthermore, this equipment has the potential to differentiate species and developmental stages, as indicated by Marques et al. (2019), who studied the distinction of species and maturity stages of *Comanthera* spp. seeds using image analysis and flow cytometry.

The interpretation of the data is based on graphs, colors, shapes, reports, and artificial tools that guide the device. The index is established through inferences made by the equipment itself (MANUAL GROUNDEYE®, 2016). However, further research is still needed to make this practice feasible for a wider range of species and to achieve consistent, rapid, and accurate results compared to conventional laboratory tests.

Focusing on species of forest seeds, the use of image analysis has emerged as a highly interesting technique for determining the quality of these seeds. With the objective of assessing the feasibility of using seed and seedling image analysis to evaluate the physical and physiological quality of *Senna siamea* seeds, an article titled "Analysis of the quality of *Senna siamea* Lam. seeds through image analysis techniques" was published in 2018. In this article, radiographic images of seeds from five lots were obtained, and from these images, morphological and tissue integrity descriptors were generated. After obtaining the seed images, they underwent germination and seedling growth tests, from which variables related to physiological quality were extracted. The generated seedlings were scanned and analyzed using the ImageJ software (SILVA et al., 2020).

The data were analyzed through analysis of variance, correlation, and principal component analysis. The results demonstrated differences among seed lots in terms of their physiological quality and internal tissue integrity. The use of techniques involving the analysis of seed radiographs and seedling images allows access to information regarding the physical and physiological integrity of *Senna siamea* seeds. (SILVA et al., 2020).

As the development and length of seedlings are closely tied to qualitative aspects, the number of scientific studies using equipment like the GroundEye® to analyze seedlings subjected to different treatments affecting their longevity has been growing. In a dissertation titled "Loss of desiccation tolerance in forest species seeds," for characterizing the loss of desiccation tolerance during

Well-formed seeds displaying their main parts (a) and seeds exhibiting different characteristics, such as damage from predation and malformed embryos (b). Source: SILVA, et al., (2020).

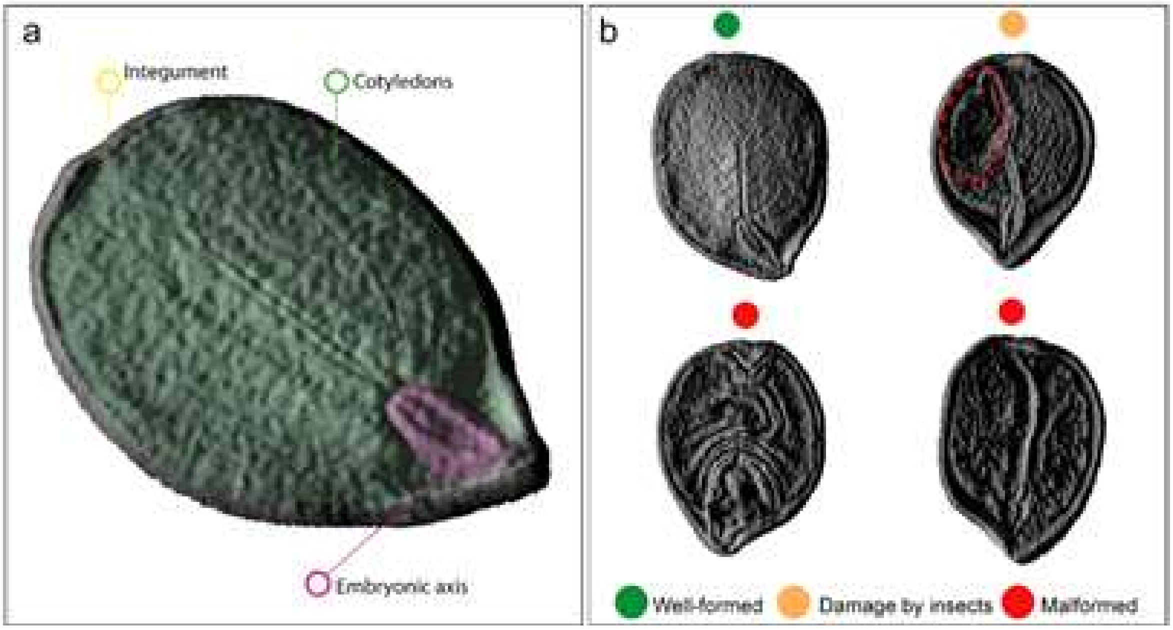

Figure 2 – Three-dimensional projections of Senna siamea seed radiographs using false color and texture enhancement techniques.

Source: FERNANDES (2020).

Figure 3 – Aspects of the shape, color, texture, measurement locations for length (greater dimension), and width (smaller dimension) of *Anadenanthera* peregrina seeds.

the germination of orthodox seeds of A*nadenanthera peregrina* (red angico), *Psidium guajava* (guava), and *Bixa orellana* (annatto), imbibition curves for seeds of each species were conducted. Based on these, moments for interrupting germination were determined, followed by subsequent drying and rehydration to characterize the loss of desiccation tolerance. In this experiment, GroundEye® was used for morphometric characterization. For this purpose, four replicates of 50 seeds were obtained using the GroundEye® apparatus and software, version L 800. The following seed characteristics were selected for analysis: length, width, and area. Individual seed mass and thousand seed weight were determined using an analytical balance with a precision of 10-4 g (FERNANDES, 2020). The seed analysis proved to be accurate and advantageous, enabling subsequent use for germination tests, as there was no destruction of the samples (Figure 3).

Seed image analysis has been advancing rapidly and offering promising opportunities for the improvement of forest species and the assurance of seed quality. With the ongoing development of image acquisition and processing technologies, as well as the increasing use of machine learning techniques, seed image analysis has the potential to revolutionize the selection and characterization of plant varieties (ZAHO, et al., 2022).

Non-invasive and high-throughput approaches enable the automatic assessment of attributes such as germination, vigor, size, and seed uniformity. Furthermore, the integration of multispectral images and 3D analysis techniques will provide detailed insights into the chemical composition, internal structure, and development of seeds, contributing to the advancement of seed science knowledge and enhancing production efficiency (SMITH; JOHNSON, 2021).

2. CONCLUSION

Future research in seed image analysis is likely to focus on enhancing the accuracy and efficiency of analysis algorithms, as well as aiming for standardization and synergy among different methods and platforms. Exploring new imaging acquisition techniques, such as using hyperspectral cameras and 3D technologies, will enable a more comprehensive assessment of seeds, paving the way for more efficient selection of agricultural varieties based on complex and relevant characteristics for crop productivity and quality. Additionally, the development of approaches that consider privacy and ethical aspects in the use of seed images will be essential to ensure the acceptance and responsible use of these technologies in agricultural contexts. The ongoing advancement of seed image analysis will offer significant benefits to the agricultural and forestry sectors, contributing to increased production and global food security (SILVA, et al.,2022).

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