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5. Insights from Seed Image Analysis: Driving Forces in Seed Industry

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Abstract:

Seeds are the fundamental of the agriculture cycle. The quality of the seeds is of utmost importance in nurturing vigorous and healthy seedlings, establishing a strong plant stand in the field, and ultimately guaranteeing a plentiful crop harvest. Therefore, to guarantee seed quality, it is imperative to subject the seeds to rigorous quality assessments.

The traditional seed quality testing methods are not only time-consuming but also lack reproducibility. Hence, they are being challenged, prompting a shift towards innovative techniques. Seed image analysis has emerged as a promising solution to this challenge. Seed image analysis is the extraction of numerical data from a captured picture.

Therein, an automated image analysis system utilizes a flatbed scanner to capture images, followed by processing with software to generate numerical data for subsequent statistical analysis. This innovative approach is very advantageous over the traditional methods. It is very fast, non-invasive and accurate. Once the workflow of the system has been designed, the entire process is automated. Also, during Image Analysis seeds are not exposed to any type of damage or treatment.

By leveraging such technologies, the scientific community aims to enhance the accuracy and efficiency of studying various processes related to seeds within the shortest possible time frame. The diverse applications of image analysis in seed science research encompasses varietal identification, Distinctness Uniformity and Stability (DUS) testing, moisture content determination, germination studies, vigour assessment and seed processing. The adoption of this innovative technology of seed image analysis holds great potential in revolutionizing how we assess seed quality in the seed industry.

Keywords:

Agriculture, image analysis, quality assessment, seed

5.1 Introduction:

Seeds play a pivotal role in agricultural practices, serving as both the beginning and the end of the farming cycle. The quality of seeds holds paramount importance for fostering healthy and robust seedlings, ensuring a strong plant stand in the field, and ultimately securing a bountiful crop harvest. The fundamental criteria for seed quality encompass genetic purity, physical purity, germination, vigour, and freedom from diseases. In the commercial seed chain, the maintenance of quality is upheld through standardized seed testing procedures.

However, traditional seed testing methods have certain limitations as they tend to be time-consuming, and occasionally yield results that may not be entirely reproducible under actual field conditions. Recognizing these challenges, scientists are actively redirecting their focus towards adopting new techniques for seed testing. Furthermore, there is a growing emphasis at the international level on developing methods that are not only rapid but also reliable for seed testing.

One promising avenue in this endeavor is the application of image analysis techniques, such as machine vision systems. These cutting-edge systems offer the potential for researchers to scrutinize seed morphology and anatomical activity during germination and seedling growth with unprecedented precision. By leveraging such technologies, the scientific community aims to enhance the accuracy and efficiency of studying various processes related to seeds within the shortest possible time frame.

Distinguishing between plant varieties through classical taxonomic approaches proves to be a formidable task due to its inherent challenges that it is time-consuming, labor-intensive and expensive. Recognizing these limitations, international efforts are underway to introduce new techniques that are better suited for the task. These efforts focus on the development of appropriate laboratory techniques, including the utilization of image analysis for studying seeds or plant organs, as well as employing biochemical and molecular markers.

Among these innovative approaches, the application of image analysis techniques emerges as a promising solution. Image Analysis system provides researchers with the opportunity to closely examine the features of seeds, thereby increasing the availability of character sets for analysis. This machine vision system holds great potential across various applications, extending from determining the identity of a cultivar to testing the distinctiveness of new cultivars which is an essential step for awarding breeders' rights and cultivar registration (Keefe and Draper, 1986).

As highlighted by Kamilaris and Prenafeta-Boldu (2018), image analysis has emerged as a research area of great interest in agriculture, playing a pivotal role in anomaly detection, image classification and disease identification. The focus of this research extends to plant science, particularly in the realm of carpology - a discipline dedicated to the morphological and structural study of seeds and fruits in spermatophytes. Seed Image Analysis highlights the profound impact of in-depth structural analysis of living elements on biological research. Specifically, the examination of seeds offers valuable insights into the history of agriculture, plant domestication, evolution and dietary practices of ancient times.

Advancements in image analysis techniques, particularly with the integration of fluorescence and high-resolution microscopes, have bolstered their reliability and captured the interest of biologists. These technological strides have led to numerous studies in the field of plants, focusing on the identification of plant seed materials previously unknown in archaeobotany (Bouby et al., 2013; Sabato et al., 2015; Ucchesu et al., 2016; Ucchesu et al., 2017). In essence, the synergy between image analysis and biological research has opened new avenues for understanding the intricacies of plant life and its historical significance.

A. Why Image Analysis?

Seed analysis is increasingly becoming important especially for research purposes because the more insights can be obtained from the seeds the better. Image Analysis provides rapid analysis in comparison to the conventional methods because the system that works is only designed once, followed by the automation of the entire process.

Also, after the initial outlay for equipment and research, image analysis unlike other systems has very few additional costs. During Image Analysis, seeds are not exposed to any type of damage or treatment.

B. What is Image Analysis?

"Image analysis" is the extraction of numerical data from a captured picture. The process is carried out by a computerized apparatus called as Machine Vision System, which works similar to human observations. The fundamental step is acquiring data, such as shape, size, and color, through a video or still camera. Subsequently, the acquired data is analyzed using appropriate computer software (Dell'Aquila, 2004).

5.2 Principle of Image Analysis:

The operator of the automated image analysis system captures the image through a flatbed scanner. Unlike the digital camera, the flatbed scanner provides consistent illumination, best quality results and high speed of execution of workflow.

Also, it has an image scale, expressed in dots per inch (DPI) (Lind, 2012). Thereafter, the captured image is processed using suitable software thereby generating numerical data that is subsequently utilized for statistical analysis. Post processing, the data can also be stored in a hard disk for using later.

This data can be utilized in understanding the relationships between the size and shape of seeds and the timeline of their growth. It may also help in knowing the growth patterns that produce inflection points and curvature. If the dimensions of the plant structure are in millimeters or microns, in such cases when these structures pass from a steady state to a proliferating state, subjective monitoring can hide morphological variation (Sik, 1984). The fundamental methodology of image analysis remains unchanged with slight modifications when used for different purposes *i.e.,* grading and sorting, germination studies, moisture studies, vigour assessment, *etc.*

5.3 Basic elements of Machine Vision System:

The basic elements of the machine vision system which used for image analysis as reported by Draper and Keefe (1988) are:

a. Image capture with a video camera / other electronic system (*e.g.* a charge-coupled device)
b. Conversion of the image data from analogue to digital
c. *Image processing*: Computerized manipulation of the image data
d. *Image analysis*: Extraction of information from the processed image followed by pattern recognition to sort and compare objects (*e.g.* varieties)
e. Use of computerized techniques for decision making
f. Presentation of results
g. Assessment of results for its statistical significance

In order to minimize the operator intervention, the Machine Vision System has an automated or robotic mechanism for movement of the sample (or the camera).

5.4 Various software's used for Image Analysis:

Nowadays, the most commonly used software is ImageJ (2021) (Landini, 2008; Lind, 2012). Additionally, the different software's used in image analysis studies have been enlisted below:

Table 5.1: The Different Software's Used in Image Analysis

Sr. No.	Name of the software	Crop	Parameters studied	References
1.	Matrox image processing board	Lettuce, Sorghum	Germination studies	Howarth and Stanwood (1993)
2.	Seed Vigor Imaging System (SVIS®).	Various crops	Analysis of seedling images, providing indexes of growth, uniformity and vigor	Sako et al. (2001)
3.	ImageJ software	Sunflower	X and Y position of the inertia centre and curve length	Ducournau et al. (2004)
4.	LUCIA 3.52 software package	Flax, Lentil	Seed area, perimeter, mean chord, MinFeret	Wiesnerova and Wiesner (2008), FiratligilDurmuş et al. (2008)
5.	KS-400 V.3.0	Vetch, Pea	Seed morphometric and clorimrtric features (Varietal identification)	Grillo et al. (2011), Smykalova et al. (2011)

Sr. No.	Name of the software	Crop	Parameters studied	References
6.	Delta-T© image analysis system having software ‘‘winDIAS’ Mustard	Oat	Characterization by measuring variation in seed morphology	Vijaya Geetha et al. (2011) Sumathi and Balamurgan (2013)
7.	ImageTool v.3.0 software	*Medicago sativa, Onobrychis viciifolia*	RGB intensities of seed images	Behtari et al. (2014)

5.5 Advantages of Seed Image Analysis:

Compared to manual analysis, the use of seed image analysis techniques brings several advantages to the process:

- The image analysis system is speedy in comparison to all the other conventional methods.
- The seeds under analysis are not exposed to any type of damage or treatment making it a completely non- invasive method.
- It minimises distortions created by natural light and microscopes.
- It automatically identifies specific features.
- It automatically classifies families or genera.
- Once the workflow of the system has been designed, the entire process is automated.
- Image analysis unlike other conventional methods, has a very few additional costs after the initial outlay for equipment and research.
- The requirement of skilled labour is minimal.

5.6 Four step workflows of Image Analysis:

The Image Analysis process employs a four-step workflow: 1) Preprocessing 2) Segmentation 3) Feature extraction and 4) Classification (Gonzales and Woods, 2018).

- ***Preprocessing:*** The image preprocessing techniques prepare the image before analyzing it by eliminating possible distortions or unnecessary data and enhancing some important features for further processing.
- ***Segmentation*****:** In this step the significant regions are divided into sets of pixels with common characteristics such as intensity, colour or texture. The purpose of segmentation is to simplify and change the image representation into something more meaningful. It also makes the analysis of the image representation easier.
- ***Extracting features*****:** The next step is the extraction of features from the regions of interest identified by segmentation. Features can be based on colour, shape or structure (Di Ruberto et al., 2015).
- ***Classification:*** The final step is classification, *i.e.* the association of a label with the object under investigation using supervised or unsupervised machine learning methods.

5.7 Application of Image Analysis in Seed Science Research:

A. Varietal identification:

The simplest method of visual varietal assessments includes the use color, size, shape and texture to distinguish among varieties. The reliability of this method depends on the experience and expertise of the specialised technicians. Additionally, the process used for seed identification by these specialized technicians is slow, subjective and gives results which may be difficult to quantify. Therefore, it is judicious to implement repeatable and quick automated methods to identify and classify seeds. Digital image analysis is a quantitative and objective method for the estimation of morphological parameters. In this process the digital images are used to measure the size of individual grains. The digital images can also be used to mathematically extract the shape and features of the sample under analysis. Numerous evidence has been reported where machine vision has been utilized for the identification and characterization of cultivars using seeds and plant parts (Draper and Travis, 1984; Van de Vooren et al., 1991)

B. DUS Testing:

In Distinctness, Uniformity and Stability (DUS) testing, new varieties are compared to the existing varieties in order to establish differences among them, before giving them an official recognition. The aim of DUS testing is to identify consistent differences between existing and new potential varieties with respect to one or more characters.

Traditionally, these differences were assessed by measurement or subjective scoring. However, the traditional techniques suffered inevitable drawbacks of being tedious and inconsistent, therefore the technicians demanded automatic and reliable methods for conducting the DUS test. These methods included straightforward use of colour meters (McMichael and Camlin, 1994) and use of image analysis to extract shape features (Keefe and Draper, 1988). These methods used majorly for the evaluation of cereal grain varieties were non-destructive and they did not damage the sample used for analysis, hence these methods have important implications in the food processing industry.

C. Moisture:

Moisture content is one of the most vital factors which influences the physical and mechanical properties of crop seeds. Tahir et al., (2007) used image analysis to determine the moisture content as well as various other properties of wheat and barley kernels. In a similar experiment Manickavasagan et al., (2008) used determined the moisture content of canadian wheat using monochromatic images.

D. Germination:

The different phases of seed germination in a controlled environment can be monitored using image analysis. Additionally, it can accurately access the changes associated with germination and prove helpful in seed viability and seedling growth studies. In the study of seed germination, the application of image analysis covers three aspects: computer-assisted image analysis systems, descriptive simulation modelling, and combined relation modelling between biological processes and morphological changes. In process, digital images are captured at various stages of seed germination. The computer image analysis technology diagnoses these images as a two-dimensional object which can be measured in size, shape and colour density.

E. Vigour Assessment:

The International Seed Testing Association (ISTA) defines seed vigour as the sum total of all the attributes of seed which determine the level of activity and performances of the seed during germination and seedling emergence. The International Seed Testing Association (ISTA) and Association of Official Seed Analysts (AOSA) have published guidelines for manually testing seed vigour. However, there are many limitations of manual vigour testing which can be easily avoided by using computer-aided image analysis of seedling (McDonald et al., 2001). Image analysis not only measure physical characteristics swiftly but it also enables quantitative and objective observations (Kranzler, 1985) without direct human intervention. Initially, McCormac et al. (1990) developed an automatic system of image analysis to determine the average primary root length of tomato seedlings. Furthermore, Sako et al. (2001) developed “Seed Vigor Imaging System®” (SVIS) to assess the seed vigor of lettuce. It functions by capturing images of three-day old seedling for the determination of vigor, uniformity indices, root/hypocotyl ratio, hypocotyl length and primary root length. Even today, SVIS is a promising software for the evaluation of vigour providing an accurate, rapid and objective measurement of seedlings, while avoiding human error.

F. Characterization:

Image Analysis has a potential use in determining the cultivar identity of seed lots and the characterization of new cultivars for the cultivar registration and the award of breeders' right (Keefe and Draper, 1986). Yan et al. (2017) conducted purity identification of seeds of four maize hybrids based on colour characteristics.

G. Sorting and grading:

The traditional techniques for seed quality evaluation and sorting were based on the detection of various physiological and physical properties of seeds. Nowadays, the greatest efforts are focused towards producing sophisticated non-destructive methods. The use of machine vision systems in post-harvest operations is becoming convenient. The major reason behind this are the development of new algorithms software architectures and the availability of appropriate image analysis soft-ware tools.

H. Seed processing:

In order to design the processing equipments, it is very important to know the geometric features of seed. Digital image analysis is the best technique to determine the physical dimensions of seeds and grains of various crops. Sakai et al. (1996) used computer vision system to evaluate the shape and size of rice seeds. Similarly, Shahin and Symons (2003) designed a machine vision system based on flatbed scanner to grade lentils seeds and assess their seed size. Also, image analysis an alternate to the traditional sizing equipments currently used in the seed processing industry.

5.8 Scope of Seed imaging analysis:

Spectral imaging is revolutionizing how we assess seed quality in the seed industry. While traditional methods involving physical, physiological, biochemical, and molecular evaluations are effective, they can be time-consuming, labor-intensive, and destructive. Moreover, they often require highly trained seed experts. The decreasing cost and improved speed and capabilities of computer hardware, on integration with controlled environmental condition systems have made computer vision more appealing option for use in automatic inspection of crop seeds. This shift towards using technology for seed image analysis holds great promise for enhancing the efficiency and accuracy of seed quality assessments.

5.9 Conclusion:

The technology of image analysis, which mimics human intelligence in interpreting visual information, plays a crucial role in various applications, such as identifying different plant varieties and certifying seeds. This technology is already highly effective and is expected to get even better with advancements in computing, sensory technology and central processing. In the field of seed production and processing, image analysis techniques can handle the variations effectively, making them versatile tools with broad applications in the seed industry.

5.10 Future Thrust:

While seed imaging should not be the sole method for capturing the characteristics of seed phenotypes, it stands out as a key foundation for a seed phenotype database. This is due to its rapid, non-destructive, and versatile measurement capabilities. Ongoing efforts in image processing within the agriculture and seed industry, particularly in varietal identification and quality assessment, showcase the potential of this technology. Reported accuracy rates of image analysis range from 70% to 99%. However, significant research is still required in the field of seed image analysis, focusing on advancements in computing technology, sensory components, and central processing elements. Addressing this need is crucial for minimizing human error and enhancing the accuracy of seed image analysis. Developing both software and hardware solutions is essential for achieving better returns on investment and reducing costs in this context. Future applications of computer vision should incorporate new advances in pattern recognition and massive data processing to further improve the robustness and accuracy of decision-making processes.

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