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Multispectral Imaging –Tool for Seed Phenotyping and Quality Assessment

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Multispectral imaging (MSI) of seeds is a non-destructive technique for simultaneously measuring spectral and spatial information about the seed phenotype and quality attributes by imaging their surface reflectance at selected wavelengths. The multispectral image can be acquired by methods based on the applications, the available optical devices, chemometrics and optical filter and illumination-based systems with the use of multispectral data models like Partial Least Squares Regression (PLSR), normalized Canonical Discriminant Analysis (nCDA) and Support Vector Machine (SVM) etc. This technology has shown favourable results for determination of various the seed quality attributes (physical, physiological and seed health). It is thus fore known that the multispectral imaging technique can be moved to practical applications in the form of real-time seed monitoring systems to meet the requirements of the modern industrial control and sorting systems. The increasing speed and capability of computer hardware and artificial intelligence will push this mission forward and make this technology more attractive for potential usage in quality control and automatic inspection of seeds.

Keywords: Multispectral imaging, Image acquisition methods, Applications of MSI

Introduction

Approximately 40% of the earth's surface is occupied by the global agriculture system and has the main objective of producing food for an ever-increasing population (7.5 billion people today and nearly 10 billion by 2050). Seed is a carrier of new technology and the basic tool for secured food supply. Seed phenotype consists of all observable characteristics of a seed resulting from the seed genotype expressed through the lifetime environment of the seed and seed quality is the possession of seed with required genetic and physical purity that is accompanied with physiological soundness and health status. Thus, quality seed is an important aspect of the modern cultivation strategies since uniform germination and high seedling vigour contribute to successful establishment and crop performance.

The riotous desire to provide high quality criteria seeds in the seed markets requires more engrossed efforts and cooperative actions to develop advanced and innovative technological systems that can satisfy all stakeholders' expectations with the unique quality seeds. The ordinary practices of seed quality evaluation are usually performed by germination tests, vigour tests and seedling growth characteristic measurement and seed health testing for fungal, virus, nematode associated pathogen testing via visual or microscopic inspection and other tests. Whilst proven to be efficient, such methods are criticized as being tedious, destructive, laborious and requiring trained seed analysts and difficulty in pooling out physiological and biochemical variation when some of seeds in the lots are dormant. Thus, for accurate, reliable and faster quality assessment with minimum human intervention, the non-destructive methods such as NIR spectroscopy or precise remote sensors or multispectral imaging techniques as gained increased attention. It is also an efficient tool to test and evaluate individual seeds to explore the imbibition process, to investigate the germination capacity and vigour differences among seeds lots.

Multispectral imaging

In recent years, the near infrared spectroscopy (NIRS) method has demonstrated its ability to carry out simultaneous assessment of different quality traits with accuracy comparable to that of traditional wet chemistry analytical methods. It utilises spectroscopy *i.e.* the study of interaction of the electromagnetic radiation with matter. It depends upon the absorption of near infrared radiation and the spectral information extracted is presumably limited to only a little portion of a sample where the measuring probe is positioned. It does not consider the spatial information. Sample to be analyzed should be reasonably homogeneous to get representative spectral image of the whole sample. This disadvantage of conventional spectroscopy can be easily alleviated by combining both spectral and spatial information by using multispectral (MIS) imaging techniques. Multispectral imaging was first developed by NASA in the 1950s to determine the composition of objects in space (Landgrebe, 1999). It was developed originally for use in military target identification and reconnaissance. In multispectral imaging, the data of the image is captured within specific wavelength ranges across the electromagnetic spectrum. The wavelengths are discrete by use of filters or sensitive instrument detection to particular wavelengths, including light from frequencies beyond the light range, *i.e.*, infrared and ultra-violet.

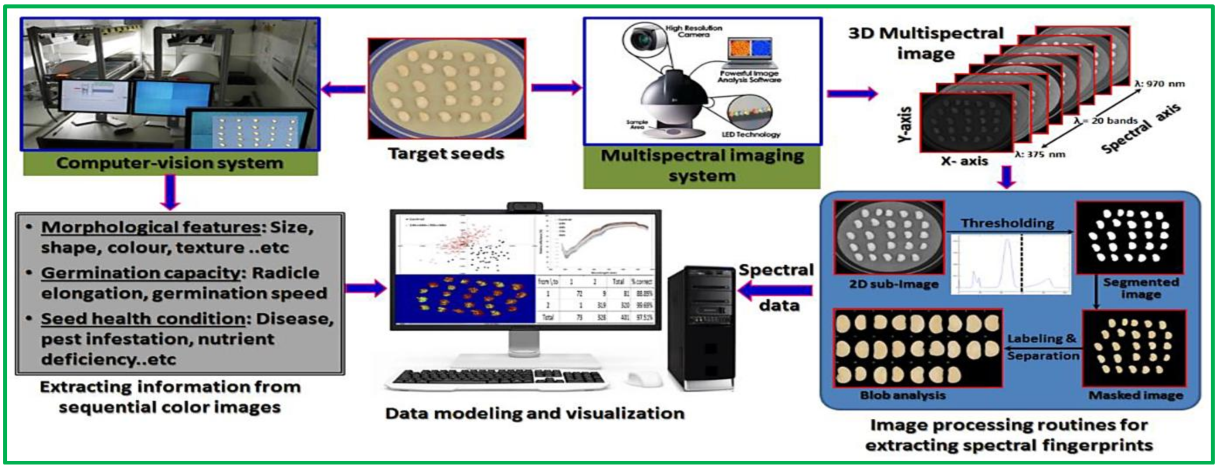


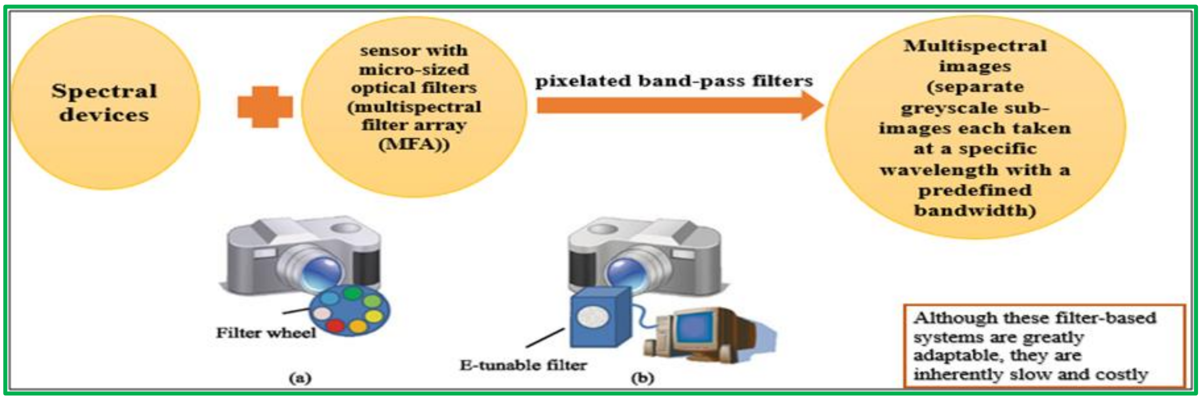
Fig. 1. Schematic representation of a computer-aided image analysis system for seed quality evaluation based on computer-vision and multispectral imaging techniques (ElMasry *et al.* 2019)

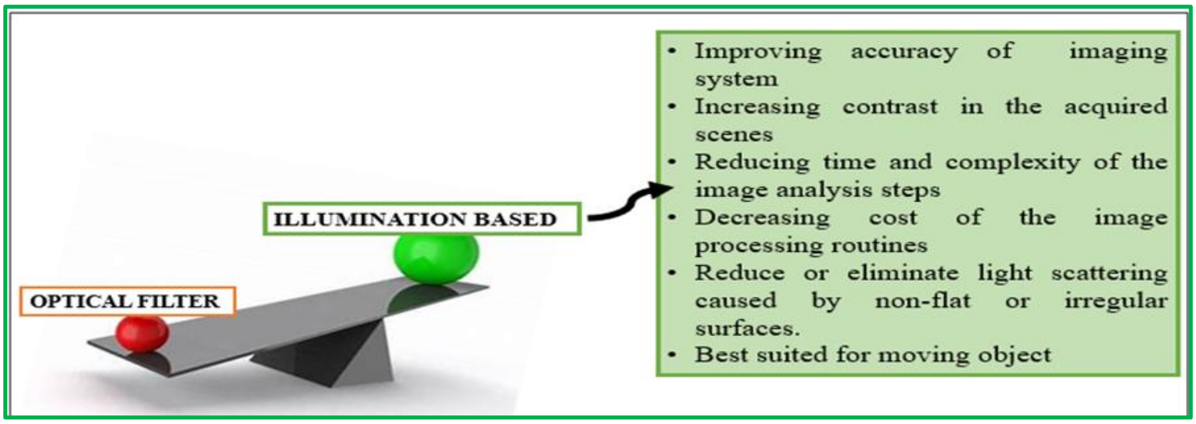
Image acquisition methods

1) **Based on the available optical devices and applications**
- Point-scanning (whiskbroom scanning)
- Line scanning (push-broom scanning)
- Wavelength-scanning (area or plane scanning)

These three methods of acquiring spectral imaging data forms a three-dimensional block of data called 'data cube' or 'spectral cube' with two spatial dimensions (x, y) and one spectral dimension (λ) and 2D greyscale sub-images (slices) of the scanned object.

2) **Optical and illumination-based systems** where former forms the multispectral images of separate grey scale sub-images each taken at a specific wavelength with a predefined band width and latter using various illuminants of different spectral power distribution illuminating the scene in sequence with different narrow-band wavelength light sources (tungsten- halogen lamps, light emitting diodes (LEDs) etc.), which reduces or eliminates the light scattering caused by non-flat or irregular surfaces.





3) Chemometrics

Based on the purpose of analyses, many calibration algorithms and pattern recognition methods are utilised to perform well for qualitative (classification) and quantitative (prediction/regression) analyses of seed quality. These methods are classified into supervised and unsupervised methods.

1. The supervised techniques are used to build classification models on the basis of their spectral signatures to classify new unknown samples to predefined known classes supervised learning can be further divided into two types:

- Regression algorithms are used if there is a relationship between the input variable and the output variable. It is used for the prediction of continuous variables, e.g. PLSR model, linear regression, regression trees, non-linear regression etc.
- Classification algorithms are used when the output variable is categorical, which means there are two classes such as yes-no, true-false. e.g., random forest, support vector machines

2. The unsupervised methods do not require a prior knowledge about the grouping of the samples. The goal of unsupervised learning is to find the underlying structure of dataset, group that data according to similarities and represent that data set in a compressed format. The unsupervised learning algorithm can be further categorized into two types:

- Clustering is a method of grouping the objects into clusters such that objects with most similarities remains into a group and has less or no similarities with the objects of another group. Cluster analysis finds the commonalities between the data objects and categorizes them as per the presence and absence of those commonalities. e.g., k-NN, PCA
- An association rule is an unsupervised learning method which is used for finding the relationships between variables in the large database. It determines the set of items that occurs together in the dataset. e.g., Apriori

Applications of multispectral imaging system

1) Physical seed purity

a) Variety identity and purity
b) Inert matter, OCS, weed seeds
c) Damage/ defects to seed structure

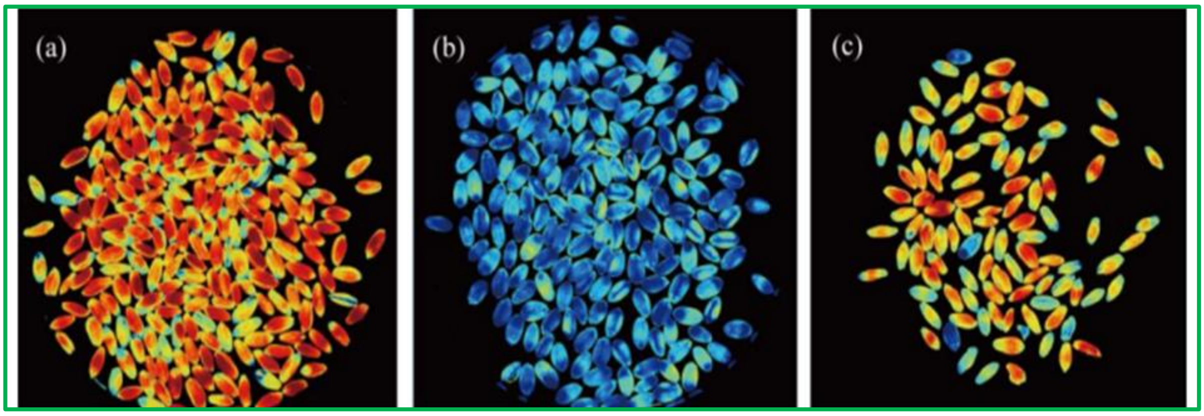


Fig. 2. Seed purity and variety determination. Images generated using nCDA algorithm for: (a) 100% *T. durum* wheat grains, (b) 100% *T. aestivum* wheat, (c) Adulteration of *T. durum* wheat grains with *T. aestivum* wheat grains (Olesen *et al.* 2015)

2) Physiological seed quality

- Viability prediction
- Vigour prediction

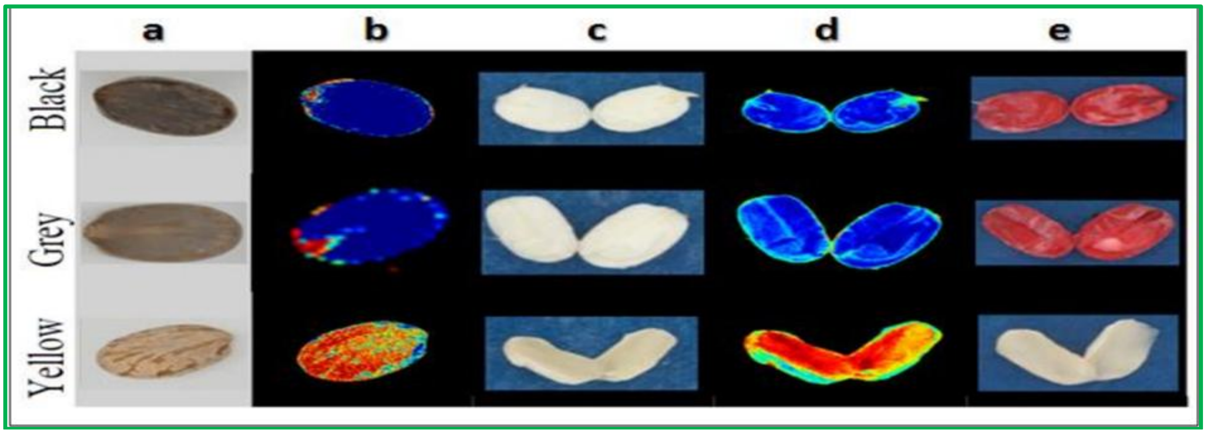


Fig. 3. Classification of castor seeds into three classes based on visual color of seed coat (yellow, grey and black). (a) RGB images of the intact seeds; (b) transformed images of intact seeds by nCDA; (c) RGB images of cut seeds; (d) transformed images of cut seeds by nCDA and (e) RGB images of cut seeds after immersion in tetrazolium solution (Wilkes *et al.* 2016)

3) Seed health

- Disease infection
- Pest infestation detection

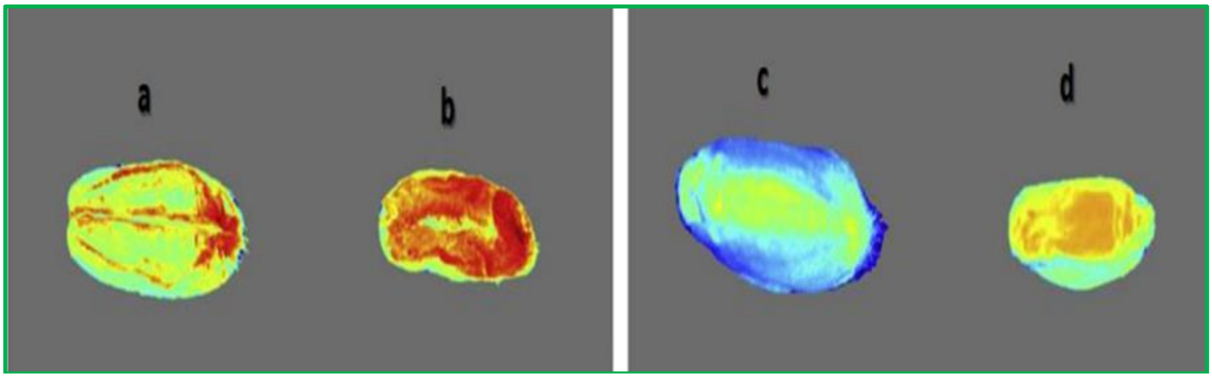


Fig. 4.PCA score-images issued from PCA on whole images for the (a) resistant and (b) susceptible wheat genotypes; and the predicted contamination images resulting from SMLR model in the (c) resistant and (d) susceptible wheat genotypes kernels in which a kernel highly contaminated have a lot of red pixels (Jaillais *et al.* 2015)

Conclusion

The potential integration of digital imaging methods with non-destructive seed quality evaluation techniques utilizing spectroscopy and chemometric approaches has emerged as an ideal tool for studying various seed quality attributes. The increased capabilities of computers and software have further enabled fast, accurate and reliable results, thereby helping achieve the targets of producing unique quality seeds in the seed market. Moreover, multispectral imaging provides a holistic approach to seed phenotyping by simultaneously capturing morphological, physiological and biochemical traits. Its ability to detect hidden defects, seed vigour and genetic purity makes it a powerful innovation in modern seed science. Thus, multispectral imaging is not only a tool for precision seed quality assessment but also a futuristic technology paving the way for smart seed phenotyping and sustainable agriculture.

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