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Research Paper

X-ray CT image analysis for morphology of muskmelon seed in relation to germination

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Internal morphological damage can have critical effects on the development and germination power of seeds. This study investigates the morphological characteristics of naturally aged muskmelon seed in relation to germination ability. An X-ray microCT scanner was employed to generate CT images and then several image processing techniques such as re-slicing, contrast enhancement, noise reduction, and segmentation were performed on the images. Afterwards, fifteen preprocessed images were nominated from each sample, and features of interest (i.e., local binary pattern, Gabor, local Fourier (FFT), texture, contrast and Haralick textural (Tx) features) were extracted. The sequential forward selection (SFS) method was applied as a search strategy to identify the most relevant features using a variety of different objective functions. It was determined that the Fisher discriminant objective function performed the best. A germination test was performed to evaluate the seed viability and the information was used to construct the training and validation data set. The seeds were divided into 2 groups: viable (group-1) and non-viable (group-0). Different classifiers were probed to determine the optimal performer, where the linear discriminant classifier resulted in an accuracy of 98.9%, with 10-fold cross-validation using eighteen selected features. The findings of this study indicate that CT imaging is a potential tool for the classification of seeds based on the characterisation of internal morphologically.

1. Introduction

Muskmelon is a great source of nutrition because of its high fibre and mineral content, which includes potassium, vitamins A, and vitamin C. Apart from the fruit, the seed of muskmelon is also consumed as a source of protein, vitamins, minerals, and omega-3 fatty acids, the latter which helps to promote good cardiovascular health. Therefore, the production of muskmelon is important from both a nutritional, and ultimately, from an economic perspective.

To produce the highest amount of quality fruits, a high rate of seed germination is critical during the cultivation period. Hence, the determination of the viability of a seed is an important precursor to planting. Morphological damage or

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chemical compositional changes in the internal structure are common problems that reduce the germination power of the seed. A seed's morphological and chemical deterioration may occur due to field weathering, as the seed is exposure to the adverse conditions. During harvesting, damage and mechanical injury can occur due to inappropriate handling (Jyoti & Malik, 2013). When seeds are stored, their chemical components deteriorate due to the oxidation of polyunsaturated fatty acids, which reduces the membrane permeability and fluidity of the seed. This leads to changes in enzymatic activity and consequently, the viability of the seeds decrease (Mazliak, 1983). Several different biochemical and physiological changes associated with deterioration were evaluated by McDonald (1999) for the assessment of seed quality.

Both the external and the internal conditions of seeds are crucial in determining their quality. The external condition can be readily examined with the unaided eye, but a non-destructive assessment of the internal structure is comparatively difficult. With regard to the morphology of a seed, the three main structures are the seed coat, endosperm (cotyledons), and internal cavity (air space). A viable seed must contain a viable seed coat, a regularly shaped endosperm and an internal cavity. In contrast, broken seed coat permits the germ or mycoflora to directly contact the endosperm. This deforms the cotyledons, in addition to the internal cavity size and shape. High temperatures can lead to a reduction of the moisture content of a seed, which can also alter the endosperm and air space volume. These factors can lead to the non-viability of a seed. Conventional methods for the assessment of seed viability such as the tetrazolium and paper germination test are time-consuming, require extensive sample preparation, and involve the use of harsh chemicals. In addition, all these methods are destructive to the seed samples. X-ray microCT image analysis is a relatively recent alternative for evaluating the seed viability by characterising the internal morphological structure.

X-ray computed tomography (CT) is a widely utilised technique for the evaluation of internal structures. The use of X-ray CT imaging in the evaluation of agricultural commodities is at a preliminary stage. In recent years, CT imaging has been successfully employed to investigate the anatomical details in the microstructure level of the tissue of plants and plant-based food materials (Herremans et al., 2015; Mendoza et al., 2007). CT imaging technology has been used for internal quality evaluation of peach, mango, and chestnuts (Barcelon, Tojo, & Watanabe, 1999a; Barcelon, Tojo, & Watanabe, 1999b; Donis-Gonzalez, Fulbright, Ryser, & Guyer, 2010; Donis-Gonzalez, Guyer, & Pease, 2012). Donis-Gonzalez, Guyer, and Pease (2016) used a CT system with pattern recognition algorithms as a tool to classify carrots according to the content of undesirable fibrous tissue. Moreover, X-ray CT has proved to be valuable for the quantification of 3D pore space in apple tissue and characterisation of the multiscale gas transport pathway in apple and pome fruit (Herremans et al., 2015; Mendoza et al., 2007; Verboven et al., 2008). Rahman, Joardder, and Karim (2018) adequately documented the applications of X-ray CT imaging for agricultural commodities. However, characterisation analysis of seed morphology based on CT systems is very limited. In a previous study, Jorge and Ray (2005) applied X-ray imaging analysis to guayule seeds to examine the relationship between the morphology of the internal structure and seed viability. Gomes, Matos, Martins, and Martins (2016) used X-ray tests to evaluate the morphology of *Platypodium elegans Vog.* seeds, to assess the relationship between this property and germination. Furthermore, X-ray imaging has been used to investigate the internal structure of several other types of seeds, including tomato seeds (Burg, Aartse, Zwol, Jalink, & Bino, 1994; Zhao et al., 2016), *Physalis peruviana* seeds (Fernandes, Silva, Santos, & Pinho, 2016), wild species seeds from Saudi Arabia (Al-Turki & Baskin, 2017), and bean seeds (Sood, Mahajan, Doegar, & Das, 2016). For more detailed information, see Ahmed, Yasmin, Lee, Mo, and Cho (2017).

In computer vision systems, pattern recognition algorithms are powerful tools (Duda, Hart, & Stork, 2000; Mery & Soto, 2008) for classifying products in relation to their quality attributes. Donis-Gonzalez, Guyer, Fulbright, and Pease (2014) and Donis-Gonzalez et al. (2016) described the application of CT systems with pattern recognition capability to efficiently classify and analyse data for chestnut and carrots. With regards to statistical pattern recognition techniques, further discussion can be found in numerous articles including Jain, Duin, and Mao (2000), Duda, Hart, and Stork (2000), Bishop (2007), and Holmstrom and Koistinen (2010).

In this study, the main objective was to present a methodology to establish a classification algorithm for analysing the morphological structure of muskmelon seeds to determine their germination ability (viability). Five year-old, naturally aged seeds were used and a X-ray CT scanner was adopted for image acquisition. After analysing the images, a classification model was developed based on the characterisation of the seed morphology. To the best of our knowledge, this study is the first to use X-ray CT images in combination with model-based pattern recognition techniques to separate naturally aged muskmelon seeds into viable and non-viable groups, according to their morphological characteristics. Furthermore, the X-ray CT imaging has potential for optimising 2D X-ray imaging for rapid evaluation of seed viability after further research.

2. Materials and methods

2.1. *Seed collection and preparation*

The procedure for developing the pattern classification algorithm for muskmelon seeds, based on their internal structure (morphology) as determined using CT imaging in connection with viability, is illustrated in Fig. 1. The muskmelon seeds for the experiments were collected from the Korea Seed and Variety Service (KSVS) institute. The seeds were five years old (2012–2017) and were kept in storage at ambient temperature. A total of 100 seeds were randomly selected for sampling using X-ray CT image analysis. All samples were stored in a refrigerator at 4 °C until use. The steps involved in the utilisation of the pattern classification algorithm with CT images are described below.

2.2. *computed tomography image acquisition*

CT scans were performed using a Skyscan 1172 (Bruker) with an X-ray source of 20–100 kV, 10 W and the X-ray detector