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Detection of infestation by *Callosobruchus maculatus* in mung bean using near-infrared hyperspectral imaging

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ABSTRACT

Mung bean (*Vigna radiata* (L.) R. Wilczek) is one of the major pulse crops grown in India. Cowpea weevil (*Callosobruchus maculates* F.) is the major insect that causes qualitative and quantitative losses of mung bean kernels during storage. There is an increasing demand from grain buyers and consumers toward zero-tolerance to contamination by insects in grains and grain products. Uninfested mung bean kernels and kernels infested with different stages of *C. maculatus* were imaged using a near-infrared (NIR) hyperspectral imaging system within the wavelength region of 1000–1600 nm at 10 nm intervals. The wavelengths corresponding to the highest principal components (PC) factor loadings (1100, 1290 and 1450 nm) were considered to be significant. Six statistical features (maximum, minimum, mean, median, standard deviation, and variance) and ten histogram features from images at the significant wavelengths were extracted and given as input to non-parametric statistical classifiers. Average classification accuracies of more than 85% and 82% were obtained using statistical classifiers for identifying uninfested and infested mung bean kernels, respectively. Mung beans kernels with pupal and adult stages of infestation had higher classification accuracies than the egg and larval stages of infestation using both the classifiers.

1. Introduction

Pulses, which belong to the family *Leguminosae*, represent an important component of agricultural food crops consumed in developing countries and are considered as a vital crop for achieving food and nutritional security for consumers. India is the largest producer, consumer, and importer of pulses with a production of 17 million tonnes (Mt) in 2010–11 (Ali and Gupta, 2012). Though India contributes 24% to the global pulse production, there was a sharp decline in the availability of pulses from 41 g per capita pet day (gpd) in 1990–91 to 33 gpd in 2009–10, requiring a doubling of imports (from 1.3 to 2.4 Mt). India produces 1.6 Mt mung bean (45% of total world production), with total production area of 3.8 million hectares (Mha) (Ali and Gupta, 2012). In India, 2.4% post-harvest losses occur at the producer level due to improper threshing, winnowing, transportation, and 7.5% losses occur due to improper storage. The storage loss includes the quantitative and qualitative losses by insect infestation and fungal infection.

The major insects causing damage to mung bean are bruchids. *Callosobruchus maculatus* is the most common bruchid, causing weight loss (56–73% in an individual seed), nutritional quality deterioration, and loss of seed viability (Booker, 1967). Larvae of the insect penetrate into the seed and feed on the endosperm as they grow. The adult chews through the seed coat and emerges from the bean (Beck and Blumer, 2009). Since major part of the life cycle of the insect is completed within the kernel, it is very difficult to detect the infestation without dissecting the grain. The insect detection methods, such as visual inspection, Berlese funnel extraction, carbon dioxide production method, whole grain flotation method, acoustic method, X-ray imaging, thermal imaging, and near-infrared (NIR) spectroscopic method are found to have one or more draw backs in detecting these types of hidden infestations. They are found to be time consuming, sample destructive, less accurate, subjective, and unable to detect the egg and larval stages of infestation within the grain.

The three advanced methods: soft X-ray imaging (Karunakaran et al., 2003), thermal imaging (Manickavasagan et al., 2008), and NIR spectroscopy (Maghirang et al., 2003) have shown potential

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for accurate and consistent results in real-time applications. However, the X-ray imaging and thermal imaging detect only the later stages (pupal and adult) of infestation. The NIR spectroscopy which is widely used in the grain industry also had some draw backs, as it gives only spectral information, one cannot locate the exact position of the hidden insect inside the grain, and it requires robust calibration models and sometimes gives inconsistent results.

Hyperspectral imaging is an emerging technique that integrates attributes of conventional imaging and spectroscopy to attain both spatial and spectral information from an object (Gowen et al., 2007). Hyperspectral imaging provides a large data set, otherwise called a hypercube, which facilitates a complete and reliable analysis of intrinsic properties and external characteristics of samples. This technology has many advantages such as the method is fairly accurate, non-destructive, and gives consistent results. This technique has been proven to be a reliable method to measure the moisture and oil content in maize (Cogdill et al., 2004), protein and oil content in wheat (Mahesh et al., 2008), detection of fungi in wheat (Singh et al., 2007), and detection of insect damaged wheat kernels (Singh et al., 2009). Though hyperspectral imaging is having many advantages, nobody has tried its usage with regards to beans. Insects are the major deteriorating organisms in beans; after attacking the grains, they leave the grains only on complete deterioration. The particular insect *C. maculatus* is the major insect which attacks the grain either in the field or during storage, and grows inside the grain (hidden infestation). These types of hidden infestations can be detected either on dissecting the grain or by X-ray imaging or NIR spectroscopy which are having one or more disadvantages. The hyperspectral imaging system has a capacity to detect hidden infestations in quick time without any destruction to the seeds. The hyperspectral imaging technique has not been fully applied for in-line quality assessment of major parameters due to its time consumption for acquiring the image (Mehl et al., 2002). But, Lee et al. (2005) reported that this problem could be overcome by using the optimal wavelength to acquire the image and then the in-line quality assessment could be done by using the multispectral imaging technique. Therefore, objective of this study was to investigate the feasibility of NIR hyperspectral imaging system to detect infestation by *C. maculatus* in mung bean by selecting the significant wavelengths and developing discriminant algorithms (linear and quadratic).

2. Materials and methods

2.1. Sample preparation

Mung beans having 12% moisture content (w.b.) were used in this study. Moisture content was determined by drying 10 g samples, in triplicate, at 130 °C for 20 h in a hot air convection oven (Tang and Sokhansanj, 1991). About 150 freshly emerged insects were added to 250 g of sound mung bean and the kernels with a single egg were collected after 24 h by observing the kernels under the microscope. Kernels with a single egg were separated into seven groups (300 kernels in each group) and were incubated at 30 °C and 70% r.h. for 4, 8, 11, 15, 22, and 25 days to obtain first, second, third and fourth instar larvae, pupae and adults, respectively (Mookherjee and Chawla, 1962).

2.2. NIR hyperspectral imaging system and image acquisition

The imaging system used in this study is the same as reported in the earlier studies (Mahesh et al., 2008; Singh et al., 2009) and is described briefly here for enhanced readability and completeness of this manuscript. The major components of the system include a thermoelectrically cooled Indium Gallium Arsenide (InGaAs) camera (Model No. SU640-1.7RT-D, Sensors Unlimited Inc., Princeton, NJ), with two VariSpec liquid crystal tunable filters (LCTFs) (Model No. MIR06, Cambridge Research and Instrumentation Inc., Woburn, MA), a 25 mm F1.4 C-mount lens (Electrophysics Corp., Fairfield, NJ), a sample stage, and a light source controlled through a Dell Optiplex GX280 Intel(R) (Dell Inc., Round Rock, TX) computer (Fig. 1). The camera could be operated in a room with temperature between 20 and 27 °C and the images can be acquired within an NIR region of 900–1700 nm. This system had a spatial resolution of 640 × 480 pixels with 27 μm pitch and a spectral resolution of 0.01 nm.

The electronically tunable, liquid crystal tunable filter (LCTF) is a high quality interference filter which had an aperture of 20 mm and a transmission bandwidth of 10 mm. This filter helps to select a wavelength in the NIR region without any vibration. The sample was illuminated by a pair of 300 W halogen-tungsten bulbs (USHIO Inc., Chiyoda-ku, Tokyo, Japan) emitting light in a wavelength range of 400–2500 nm. The data acquisition board (NI PCI-1422, National Instruments Corp., Austin, TX) was attuned to RS-422 signals generated from the camera system for image acquisition. A control

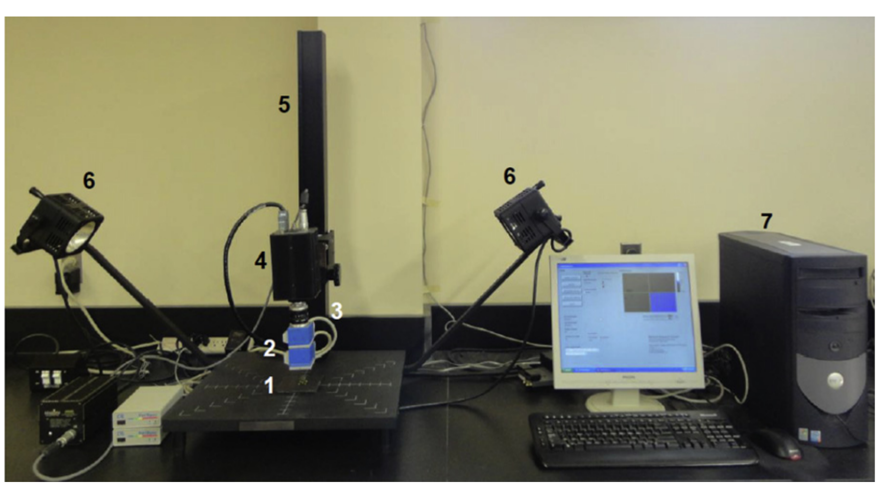

Fig. 1. Long-wave near-infrared hyperspectral imaging system 1. Mung bean sample, 2. Liquid crystal tunable filter (LCTF), 3. Lens, 4. NIR camera, 5. Copy stand, 6. Illumination (Halogen-tungsten lamp), 7. Data processing system.