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Detection of *Callosobruchus Maculatus* (F.) Infestation in Mung Bean (*Vigna Radiata*) using Thermal Imaging Technique

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Abstract. Mung bean (*Vigna radiata*) is a major pulse crop grown in India and other parts of the world and consumed by human beings for its high protein content. Cowpea seed beetle (*Callosobruchus maculatus* (F.)) causes major portion of storage losses in pulses. Detection of cowpea seed beetle at early stages of its life stages could help to implement suitable control practices for insect disinfestations in order to minimize the storage losses. Thermal images of uninfested mung beans and beans infested by egg, larval, pupal stages of *C. maculatus* (F.) along with completely infested mung beans (hollowed out) were acquired using an infrared thermal camera. Features extracted from thermal images were used to develop linear and quadratic discriminant (LDA and QDA) classification models. LDA models gave 55.24-77.84% classification accuracies, and QDA classifiers had classification accuracies of 75.45-91%. The QDA classification model correctly identified more than 80% mung beans infested with initial stages of *C. maculatus* infestation. The results have proven that thermal imaging has a potential to detect the *C. maculatus* infestation in mung beans.

A Community of

Keywords. Thermal Imaging, Mung bean, Storage, *Callosobruchus Maculatus*

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Introduction

Pulses are the dry seeds of leguminous plants which are distinguished from leguminous oil seeds which have high fat content (CODEX, 1995). India is the world-leading producer and consumer of pulses. Of these pulses, mung bean (*Vigna radiata* (L.) R. Wilczek) is a major pulse crop in Asia, and it is consumed throughout the world for its high protein content. India is the largest producer of mung bean and produced around 1.24 Mt (45% of total world production) in 2008-09 (DES, 2011).. Stored-product insects cause 6 to 7.5% post-harvest losses to mung beans every year. Cowpea beetle (*Callosobruchus maculatus (F.)*) is the most common field-carryover-storage pest of mung bean in tropical and subtropical regions (NRI, 1996). This insect can cause quality as well as quantity loss (Metcalf and Metcalf, 1993), and if not controlled in early stages this may cause total loss of seeds (Singh and Jackai, 1985). Therefore, detection of *C. maculatus infestation* in early stages may help reduce storage losses by initiating management practices at the right time. Traditional insect detection techniques are destructive and time consuming processes.

Numerous studies have been conducted for rapid insect detection and hidden infestations in cereals and pulses. Shuman (2003) developed an automated system with acoustic sensors to detect insect infestation in wheat, which detected infestation by *Tribolium castaneum*, *Rhyzopertha dominica* (F.) and *Oryzaephilus surinamensis* (L.) adult insects, but could not detect early stages (larval and pupal) of infestation. Application of machine vision system with charge coupled device (CCD) camera was investigated to detect adult insects in bulk wheat samples by Zayas and Flinn (1998), and this system correctly identified 93% of samples with *R. dominica* (F.) insects. Near-infrared (NIR) spectroscopy (Maghirang et al., 2003) was used to detect hidden infestations (live and dead insects) in wheat kernels. Application of hyperspectral imaging was investigated to detect *C. maculatus* infestation in soybeans, and the back propagation neural network (BPNN) model developed from hyperspectral spectrometry data correctly identified 87.5% of infested soybeans (Zhou et al., 2010). Ultrasonic signals (Shade et al., 1990) also have been used to detect hidden *C. maculatus* infestation in cowpeas. These techniques require trained personnel and are difficult to implement for inline monitoring.

Thermal imaging is a technique in which the invisible heat radiation emitted by an object is converted into a visible image (which is called as thermogram or thermal image) by infrared thermal cameras. Thermal infrared regions (2.5-5 µm and 8-14 µm) are useful for thermal imaging applications (Gonzalez and Woods, 2002). Infrared thermal imaging was used in military and construction applications for a long time, and it has a wide range of applications in medical, electrical, mechanical and civil engineering. Thermal imaging has also been used to evaluate fruit maturity, and bruise detection in fruits and vegetables (Danno et al., 1977; Varith et al., 2003). Meinlschmidt and Margner (2003) used thermal imaging to detect foreign materials in food. It was also tested for detection of insect infestation and fungal infection in stored grain (Manickavasagan et al., 2008; Chelladurai et al., 2010), and sprout damage in wheat (Vadivambal et al., 2010). The objective of this study was to test the feasibility of thermal imaging system to detect various stages of *C. maculatus* infestation in mung bean.

Materials and Methods

Sample preparation

The pulse sample used in this study was clean mixed varieties of mung bean cultivated in India and was procured from a local market in Winnipeg, Manitoba, Canada. The *C. maculatus* insect was cultured on mung beans in a plastic jar kept at 30± 1°C and 70± 2% RH. The newly emerged adults were introduced to the plastic jars containing 2 kg mung beans and allowed to stay for 24 h to lay eggs on mung beans. Mung beans with single eggs were separated using a microscope and kept in four bottles, 200 g of seeds per bottle for acquiring different life stages of insects inside a climate controlled chamber (Model ATC 26, CONVIRON, Controlled Environments Limited, Winnipeg, MB) which was maintained at 30± 1° C and 70± 2% RH.. Samples from three bottles were used for collecting larvae, pupa and hollowed out samples. These samples were placed in respective bottles after imaging and the egg infested kernels kept in fourth bottle were used to check adult emergence Mung beans with larvae and pupal stage were collected 18 and 21 days after oviposition. After emergence of new adults, completely damaged (hollowed out) seeds were collected 26 days after oviposition. For uninfested samples, 300 mung beans were randomly selected from 200 g of beans procured from the store.

Image acquisition

Images of uninfested and infested mung beans were acquired using an uncooled focal planar array type infrared thermal camera with 320 x 240 pixels resolution (Model: ThermaCAM™ SC500 of FLIR systems, Burlington, ON, Canada; Spectral range: 7.5 – 13.0 μm). This camera has the thermal sensitivity of 0.07^{o}C at 30^{o}C, and ThermoCAM ResearcherPro 2.8 software was used to acquire the images. Emissivity of the mung bean was set as 0.98 throughout the experiments (Manickavasagan et al., 2007). For each insect life stage, 300 random mung beans were selected from the cultured seeds. A plate heater with a temperature control mechanism was used as a background for imaging and it was maintained at 40^{o}C. Mung beans were placed on a glass petridish kept inside a thermocol box filled with ice for 90 s and then placed on plate heater and thermal images were acquired. The room temperature was maintained at 24-25^{o}C throughout the experiments and the experimental set-up of the thermal camera is shown in Figure 1.

Data extraction and model development

Algorithms were developed in Matlab (version 7.9.0, The Mathworks Inc., Natick, MA) to extract temperature data of the mung beans. The size of the original image was 240 x 320 pixels (76,800 temperature values) in which grain occupied approximately 10,000 pixels (small variation occurs depending on the size of each kernel) (Manickavasagan et al., 2007). Global image thersholding method was used to segment the grain kernels from the background. The features extracted were average temperature of the grain, maximum temperature of the grain, minimum temperature of the grain, range (temperature difference between maximum and minimum temperature (Δt)), and standard deviation.

Linear discriminant analysis (LDA) and quadratic discriminant analysis (QDA) methods were used to classify the infested and uninfested mung beans. The LDA and QDA models were developed using all 5 extracted temperature features. The DISCRIM procedure used for model development and means of temperature features were compared by Scheffe grouping method using SAS 9.1.3 (Statistical Analysis Systems Institute, Inc., Cary, NC, USA).

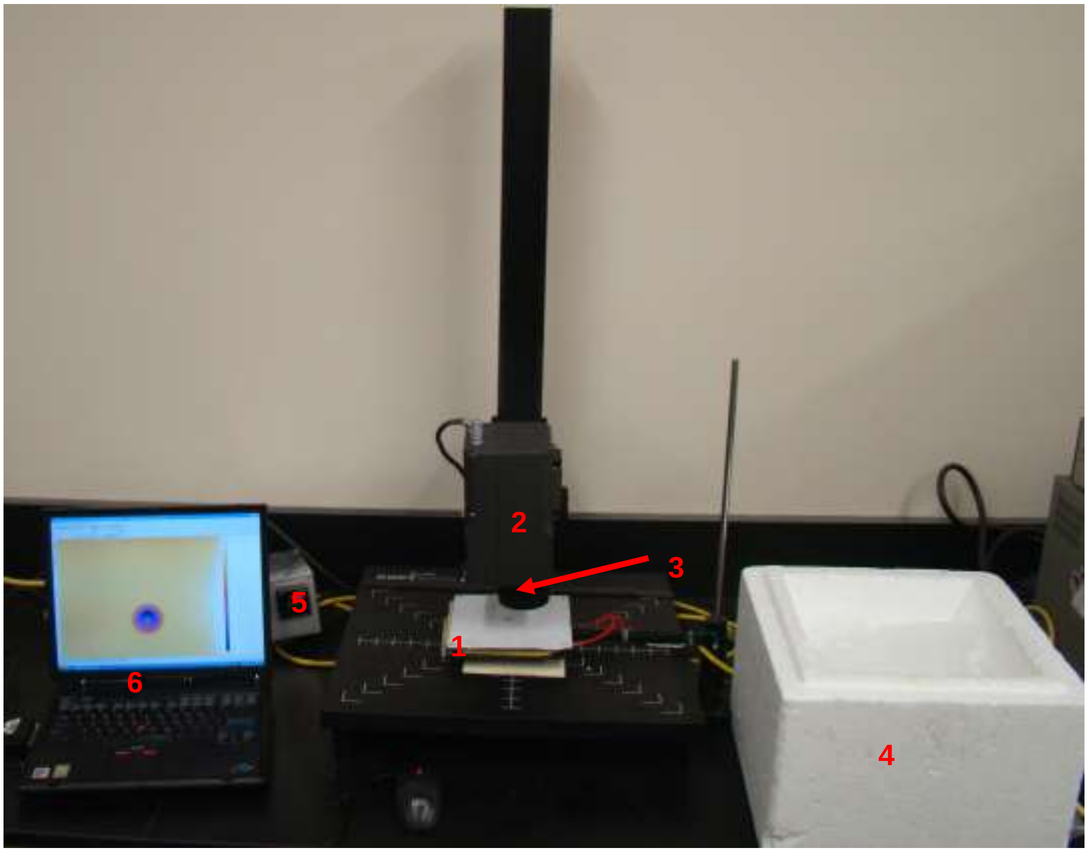

Figure 1. Experimental set-up for thermal imaging system

1. Plate heater, 2. Thermal camera, 3. Close-up lens, 4. Thermocol box with ice 5. PID controller, 6. Data acquisition system.

Results and Discussion

Temperature features of uninfested and infested mung beans

The average temperature of uninfested and *C. maculatus* larval infested mung beans were 39.87 and 40.18ºC, respectively. All five temperature features of uninfested and infested by various life stages of *C. maculatus* mung beans were significantly different ($P< 0.001$) except hollowed out samples. There was no significant difference ($P< 0.001$) between mung beans infested by egg and larval stages using average, maximum and minimum temperatures of beans.

Table 1. Mean temperature values of uninfested and infested mung beans

Feature	Stage of infestation				
	Uninfested mung bean	Egg	Larvae	Pupa	Hollowed out
Average temperature	39.87 [a*]	40.14 [b]	40.18 [b]	39.65 [c]	39.85 [a]
Maximum temperature	40.22 [a]	40.41 [b]	40.34 [b]	40.02 [c]	40.19 [a]
Minimum temperature	39.49 [a]	39.79 [b]	39.89 [b]	39.23 [c]	39.56 [a]
Range (Δt)	0.72 [a]	0.62 [b]	0.45 [c]	0.79 [d]	0.63 [b]
Standard deviation	0.14 [a]	0.12 [b]	0.09 [c]	0.15 [d]	0.12 [e]

***** Values with same letters in a row are not significantly different (*α*=0.05) by Scheffe test** n=300

Classification Using Statistical Classifier

The classification accuracies of uninfested and infested mung beans are given in figure 2. The classification accuracy of the LDA classifier developed from temperature features of uninfested and C. maculatus larval infested mung beans were 55.24 and 77.84%, respectively. The QDA classifier developed from thermal features gave more than 75% classification accuracy for all samples. The QDA classifier yielded higher classification accuracy than the LDA classifier. In most cases uninfested mung beans were misclassified with hollowed out mung beans. There were some misclassification between mung beans infested with egg and larval stages of *C. maculatus* infestation. Mung beans infested with *C. maculatus* larvae had highest classification accuracies for- both LDA and QDA classification models (77.84, and 91%, respectively). Respiration of insect and difference in thermal conductivity of grain kernel and insects causes the difference in cooling rate. After emergence of adults hollowed out beans did not had any living insects, and also cooled similar to the uninfested samples which caused misclassification between uninfested and hollowed out samples in statistical classifiers as well as in Scheffe grouping test.

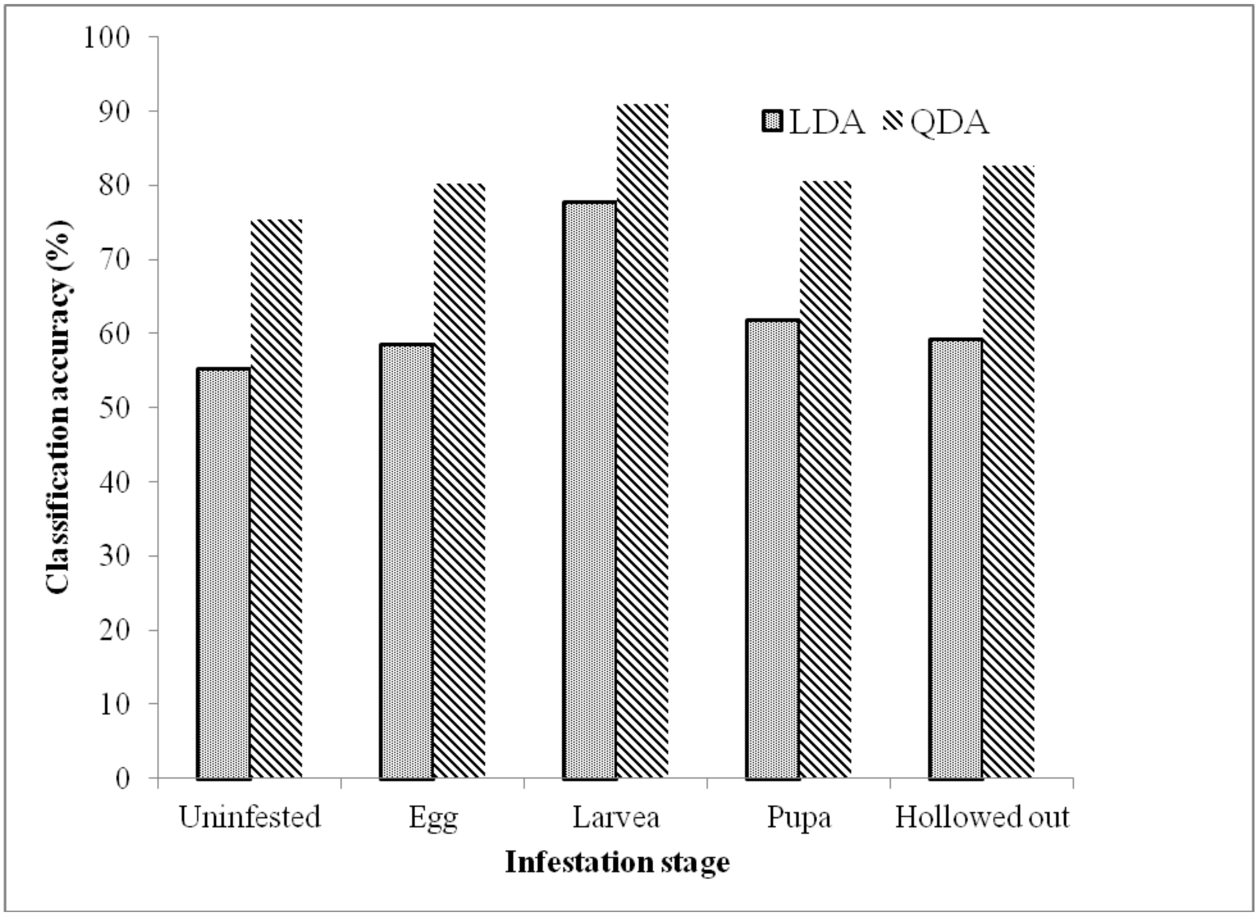

Figure 2. Classification accuracies of LDA and QDA classifiers

Conclusion

The QDA classifier correctly identified 91% of mung beans with *C. maculatus* larvae and 75.45% uninfested mung beans using themal features extracted from thermal images. Classification accuracies of the LDA models were low (55.24-77.84%) compared with the QDA classifiers (75.45-91%). The QDA classification model correctly identified more than 80% mung beans infested with initial stages of C. maculatus infestation. The results of this study have shown that, thermal imaging system has a potential to detect *C. maculatus* (F.) infestation in mung beans.

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References

Chelladurai, V., D. S. Jayas, and N. D. G. White. 2010. Thermal imaging for detection of fungal infection in stored wheat. *Journal of Stored Products Research* 46(3): 174-179.

CODEX. 1995. Codex standard for certain pulses- CODEX STAN 171-1989 (rev. 1- 1995) – Codex Alimentarius Commission. Available at: www.codexalimentarius.net. Accessed on 21 December 2011.

Danno, A., M. Miyazato, and E. Ishiguro. 1977. Quality evaluation of agricultural products by infrared imaging method: Grading of fruits for bruise and other surface defects. *Memoirs of Faculty of Agriculture, Kagoshima University* 14: 123-138.

DES. 2011. Area, Production and Average Yield of Pulses in India: 2008-2009. Directorate of Economics and Statistics. Department of Agriculture and Cooperation. New Delhi, India. Available at: www.agmarknet.nic.in. Accessed on 20 November 2011.

Maghirang, E. B., F. E. Dowell, J. E. Baker, and J. E. Throne. 2003. Automated detection of single wheat kernels containing live or dead insects using near-infrared reflectance spectroscopy. *Transactions of the ASAE* 46 (4): 1277-82.

Manickavasagan, A., D. S. Jayas, and N. D. G. White. 2007. Thermal imaging to detect infestation by *Cryptolestes ferrugineus* inside wheat kernels. *Journal of Stored Products Research* 44(2): 186-192.

Meinlschmidt, P., and V. Margner. 2003. Thermographic techniques and adopted algorithms for automatic detection of foreign bodies in food. In *Proceedings of Thermosense XXV,* 168-177. Bellingham, WA.: The International Society for Optical Engineering.

Metcalf, R. L., and R. A. Metcalf. 1993. *Destructive and useful insects: Their habits and control*. Chicago, IL: R.R. Dinnelley & Sons Company.

NRI. 1996. *Insect pests of Nigerian crops: Identification, biology and control.* Kent, UK: National Resource Institute.

Shade, R. E., S. F. Eric, and L. L. Murdock. 1996. Detection of hidden insect infestations by feeding-generated ultrasonic signals. *American Entomologist* 36 (3): 231-5.

Shuman, D. 2003. Monitoring system counts insects identifies species. *Agricultural Research Magazine* 51 (7): 12-3.

Singh, S. R., and L. E. N. Jackai. 1985. Insect pests of cowpea in Africa: Their life cycle, economic importance and potential for control. In *Cowpea research, production and utilisation.*, eds. S. R. Singh, O. Rachiek, 217-231. Chichester, UK: Wiley Interscience Publications/John Wiley and Sons Ltd.

Vadivambal, R., V. Chelladurai, D. S. Jayas, and N. D. G White. 2010. Detection of sprout damaged wheat using thermal imaging. *Applied Engineering in Agriculture* 26(6): 999-1004.

Varith, J., G. M. Hyde, A. L. Baritelle, J. K. Fellman, and T. Sattabongkot. 2003. Non-contact bruise detection in apples by thermal imaging. *Innovative Food Science and Emerging Technologies* 4(2): 211-218.

Zhou, Z., Y. Zang, B. Shen, X. Zhou, and X. Luo. 2010. Detection of cowpea weevil (*Callosobruchus maculatus* (F.)) in soybean with hyperspectral spectrometry and a back propagation neural network. *In Proc. 2010 Sixth International Conference on Natural Computation,* Yantai, China. 10-12 August.