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**Research Article**

# Continuous-wave Terahertz Imaging Applied to Detect Infestations Caused by Insects in Grain

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**Abstract:** Detection infestations caused by insects in grain are important control measures for ensuring storage longevity, seed quality and food safety. The efficiency of the continuous wave terahertz imaging method to detect infestations caused by insects in wheat kernels was determined in this study. A continuous wave terahertz experimental setup was designed for recording of THz images corresponding to different infestations caused by different life stages of insects. The experimental results indicate that the absorbance is generally highest for un-infested wheat kernels and decreased at later growth stages from THz pseudo-color images. Our study intended to demonstrate how the method of continuous wave Terahertz imaging could be applied to detect Infestations Caused by Insects in Grain.

**Keywords:** Detection, infestation, insect, terahertz imaging, wheat grain

## INTRODUCTION

Cereal grains, oilseeds and legumes (hereinafter referred to as grains) are the major source of food for humans and most domesticated animals in the world (Ventakrao *et al*., 1960). Stored grain can have losses in both quantity and quality. Losses occur when the grain is attacked by insects, mites, rodents, birds and microorganisms. Insect infestations in grain cause quantity and quality losses and lower crop values. In many developing countries, overall post-harvest losses of grains of about 10-15% are fairly common (White, 1995). The total economic losses in China due to stored-product insects and microorganisms in grains and oilseeds can be in the millions of dollars annually (China State Grain Administration (CGSA), 2006).

Grain destined for domestic and export markets are inspected to take preventative actions to reduce quality and quantity losses that might occur during storage and transport. Stored grain is vulnerable to both external and internal damage by insects (Milner *et al*., 2005). Insect infestations adversely affect the chemical characteristics of grain. Different methods have been developed to detect insect infestations in grain. Insect infestations in grain may be detected by sieving, sound detection, carbon dioxide measurement, cracking-flotation, uric acid measurement, the Berlese funnel method, Near-Infrared Reflectance (NIR), nuclear Magnetic spectroscopy (MIR) and the soft X-ray method (Neethirajan and Karunakaran, 2007; Sun *et al*., 2013; Bhuvaneswari *et al*., 2011; Singh *et al*., 2009). Terahertz (THz) imaging is a rapidly developing novel imaging technique that has broadened its application into food quality monitoring (Gowen *et al*., 2012). THz time-domain spectroscopy has been used to measure the moisture content of crushed wheat grains (Chua *et al*., 2005). THz radiation is readily transmitted through most non-metallic and non-polar mediums, thus enabling THz systems to 'see through' concealing barriers. Compared with other vibrational spectroscopic methods, such as NIR and MIR spectroscopy, Terahertz spectroscopy has the distinct advantage that is can penetrate many organic materials (e.g., paper, skin, plastic). Terahertz imaging has advantages over X-rays images. X-rays have no depth resolution and poor spatial resolution. T-ray's low photon energy levels allow the imaging of biological tissue without harmful ionizing radiation, making them safer than X-rays. Unlike NIR chemical imaging, THz imaging enables direct measurement of sample thickness, refractive index and absorption coefficient (Bandyopadhyay *et al*., 2012; Xu and Zhang, 2007).

In this report, we provide evidence that THz imaging can be efficient in detecting infestations caused by internal and external grain feeders. The objective of this research was to determine the efficiency of the THz imaging method to detect infestations caused by different life stages of Sitophilus zeamais (Motschulsky) (Coleoptera: Curculionidae) in wheat kernels.

## MATERIALS AND METHODS

The stored-product insects used were Sitophilus zeamais (Motschulsky) (Coleoptera: Curculionidae), which were supplied by College of Plant Science and

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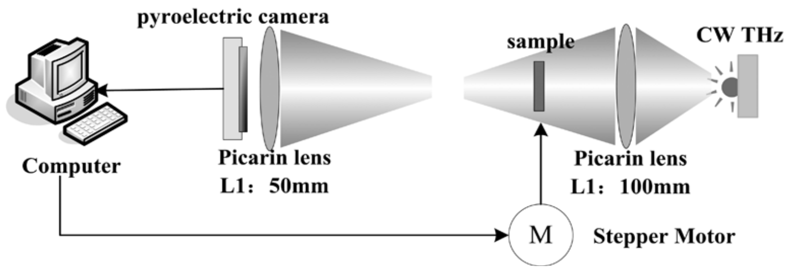
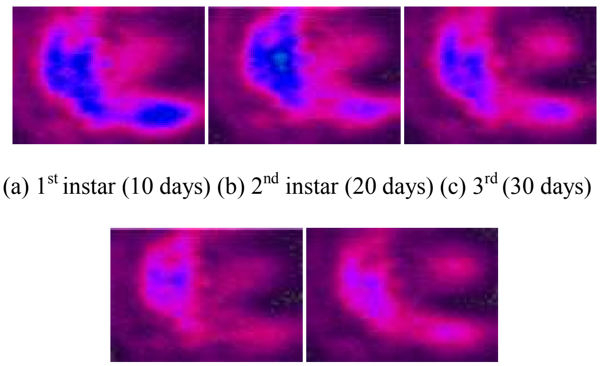



Fig. 1: Experimental installation figure

Technology at Huazhong Agriculture University. Wheat kernels infested by *S. zeamais* were prepared by artificial implantation of insect eggs in the germ of wheat kernels. Each single-infested kernel was placed in a gelatin capsule and infested kernels thus prepared were incubated continuously 30°C and 70% RH until the adults exited from the kernels. The kernels were removed at different time intervals for taking THz images for different life stages of the insects. Kernels infested by eggs were THz-imaged at 15 day intervals for the four larval, pupal and adult stages.

**Methods:** Figure 1 shows the experimental setup used for recording of THz images corresponding to different infestations caused by different life stages of Sitophilus zeamais. The THz imaging system was developed using a $CO_2$ laser-pumped THz laser (SIFIR-50 laser from Coherent Inc) as the light source. Pyroelectric camera (Pyrocam III) is used as the array detector with a wavelength range of 1.06 μm~3 mm. The size of the active area is with elements. THz laser is collimated through two pieces of Picarin lens. Picarin is a plastic used to make optics such as lenses for terahertz radiation because it is highly transparent in both the THz and visible spectral ranges. The transmission beam from the sample enters into the detector. The THz images are displayed and stored by the control software of the THz imaging system. The sample is positioned on a two dimension platform and the stepper motor of the platform is controlled by the software. In this experiment, the THz laser outputs continuous wave and the frequency are chosen as 2.52 THz because the THz laser operates steadily at this frequency with the output power of 30 mW. THz images of un-infested and infested wheat kernels were acquired using the THz imaging system. Single kernels were placed manually on the platform. The computer was used for saving the images and performing the data analysis.

**Analysis methods:** In this experiment, the THz images are influenced by a series factor such as the variety of the sample condition, interference and scattering. To extract the infestation information systematically out of the THz images, thresholding procedure was used to remove the kernel from the background. Every THz pseudo-color image was segmented into three parts: the satiation region (R0), the infested region (R1) and the surrounding region (R2). The blue component of one pixel which was more than TB was segmented into R0, the red component of one pixel which was more than TR was segmented into R1. The remain pixels were segmented into R2. The number of pixels belonging to R0 and R1 were denoted as N0 and N1, N2 is the pixel number of corresponding kernel region. We defined the Satiation Coefficient (SC) and the Infestation Coefficient (IC) to represent the infestation of the wheat kernels. The SC and the IC were defined as:



(a) 1st instar (10 days) (b) 2nd instar (20 days) (c) 3rd (30 days)

(d) 4th (40 days)   (e) 5th (50 days)

Fig. 2: THz pseudo-color images of a kernel infested by different life stages of *Sitophilus zeamais*

$$SC = N0/N2 \quad (1)$$

$$IC = N1/N2 \quad (2)$$

## RESULTS AND DISCUSSION

Typical THz images of un-infested and infested wheat kernels are shown in Fig. 2. From Fig. 2, we can see that wheat kernel infested with insects at different life stages have a big difference in THz pseudo-color images. The high-contrast THz images of Wheat kernel revealed the location and size of the infestation. In THz pseudo-color images, the blue area with the weaker absorption is in good with un-infested kernel. The amplitudes of the THz images of the infested part with pink area were higher than those of un-infested part. Absorbance was generally highest for un-infested wheat kernels and decreased at later growth stages. These may be due to the loss of starch from the kernel that was replaced and consumed by the developing larvae.

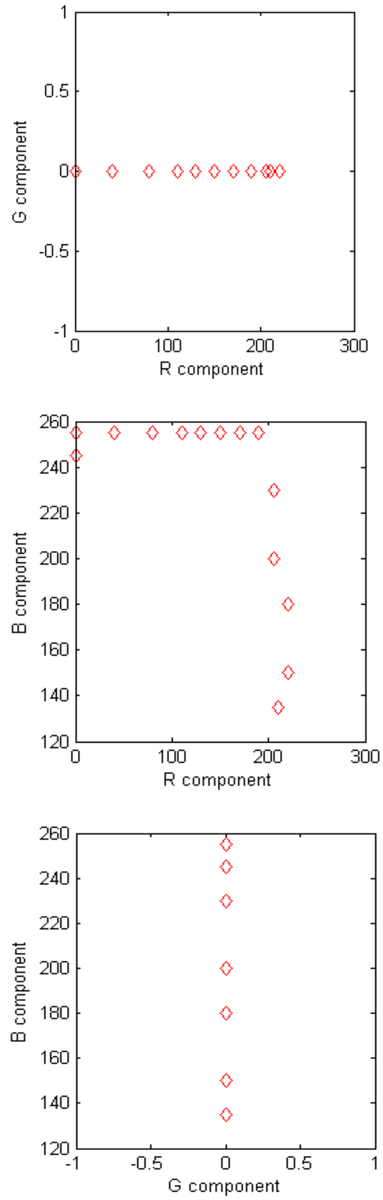



Fig. 3: R-G-B components scatter diagram for kernel region

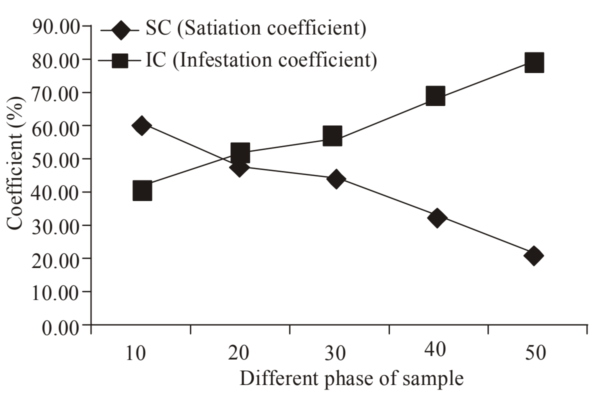



Fig. 4: The infestation degree difference of the wheat on THz images

Table 1: The number of pixels and their proportion for satiation and infestation parts of wheat kernels

| Days | $N_0$ | $N_1$ | $N_2$ | SC | IC |
|---|---|---|---|---|---|
| 10 | 34804 | 23538 | 58342 | 59.66 | 40.34 |
| 20 | 22878 | 24035 | 46913 | 48.77 | 51.23 |
| 30 | 18301 | 23824 | 42125 | 43.44 | 56.56 |
| 40 | 14458 | 30322 | 44780 | 32.29 | 67.71 |
| 50 | 9894 | 37876 | 47770 | 20.71 | 79.29 |

SC: Satiation coefficient, %; IC: Infestation coefficient, %

The R-G-B components scatter diagram of kernel region was shown in Fig. 3. Based on this figure and the analysis above, the green component of every image was close to zero, the red and blue components were close to the max, 255, so we can segment the uninfected and infected region of the kernel separately based on these two components. Here two thresholds (TR, TB) were selected for red and blue components; TR and TB were set to 255*0.8 = 204.

The numbers for every image in Fig. 2 were shown in Table 1. The variation curve of SC and IC was shown in Fig. 4. From this diagram, we could find that the erosion degree of the wheat kernel was more and more seriously with the larvae growing up.

Utilizing the presented method, the infestations caused by internal and external grain feeders can be detected by THz imaging efficiently. We can see that the absorbance is generally highest for un-infested wheat kernels and decreased at later growth stages from THz pseudo-color images. From analysis of THz images, we could find that the infested degree of the wheat kernel was more and more seriously with the larvae growing up.

## CONCLUSION

In summary, we provide evidence that THz imaging can be efficient in detecting infestations caused by internal and external grain feeders. We designed the experimental setup used for recording of THz images corresponding to different infestations caused by different life stages of *Sitophilus zeamais*. THz images of un-infested and infested wheat kernels were acquired using the THz imaging system. Our study intended to demonstrate how the method of continuous wave Terahertz imaging could be applied to detect Infestations Caused by Insects in Grain. We are aware that much further work is needed to broaden the basis on which our results stand and broaden the insect species. Nonetheless, we think it necessary to make them widely known. We are aware that much further work is needed to explore this technology in any realistic way.

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