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Detection of internally infested popcorn using electrically conductive roller mills☆

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ABSTRACT

To detect popcorn kernels infested by the internal feeding stored-product insect pest *Sitophilus zeamais*, maize weevil, a laboratory roller mill was modified so that the electrical conductivity of the grain is measured while the kernels are milled between the rolls. When a kernel with a *S. zeamais* larvae inside is milled, the moisture from the crushed insect abruptly changes the conductivity of the test circuit. The objective of this study was to determine the potential of the modified conductance mill to detect popcorn infested with different developmental stages. Two laboratory milling units were tested that had differing sharpness, which affected the feed-rate through the rolls. One mill averaged 135 s to feed 1 kg of popcorn while the second mill with sharper teeth averaged 100 s to feed 1 kg of popcorn. Four popcorn varieties were evaluated, with their average kernel weight ranging from 12.5 g to 18.5 g per 100 kernels. Known numbers of infested popcorn kernels were added to 1 kg samples of popcorn. The slower feeding mill detected 81% of the pupae, 91% of the medium larvae, and 47% of the small larvae. The faster feeding mill detected 75% of the pupae, 80% of the medium larvae, and 43% of the small larvae. Our results indicate that the conductance mill is a good method for quickly evaluating popcorn samples for kernels infested with late stage larvae and pupae.

1. Introduction

Grain is commonly inspected for insect contamination by sieving grain samples and looking for adult insects or inspection for insect-damaged kernels (GIPSA, 2009). The grain inspection handbook states “Infested corn is corn that is infested with live weevils or other live insects injurious to stored grain”. However, internal infestations are not evident with visual methods alone and there can be a poor relationship between these methods of insect detection and the current level of internal infestation (Perez-Mendoza et al., 2004). These hidden infestations can contribute to fragment counts, and if the grain is stored before use, the immature stages inside the kernels can develop and the resulting adults reproduce potentially causing a greater reduction in grain quality and triggering the application of different management tactics.

A range of methods are available for detecting internal insect infestations in grain, including laboratory entoleters (Brabec et al., 2015), enzyme test (Piaseck-Kwiatkowska et al., 2014), weevil egg-plug staining (Frankenfeld, 1948), and near-infrared reflectance spectroscopy (NIR) analysis, which have been overviewed by Brader et al. (2002) and Neethirajan et al. (2007). X-ray images provide the most accurate method to detect internal insects and are a good reference technique (Haff and Slaughter, 2004; Karunakaran et al., 2004; Fornal et al., 2007), but is an expensive and time- and labor-intensive process. In practical applications, grain is often sampled during receiving or moving between bins and it is necessary to quickly determine insect infestation levels since accept, reject, or treat decisions need to be made in a timely manner. Most currently available methods to detect internal infestation are just to time consuming to fit into commercial practice. There still remains a need by the grain industry for accurate methods that can be used to evaluate a large grain sample in a relatively quick period of time.

The conductance mill developed by Pearson and Brabec (2007)

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monitors the electrical conductance through crushed wheat. When a kernel with an internal insect infestation is milled, the moisture from the crushed insect abruptly changes the conductivity of the test circuit triggering a detection response. The conductance mill detected over 70% of the kernels infested with medium and large larvae and pupae of *Rhyzopertha dominica,* F., (lesser grain borer), and was able to test 1 kg of wheat in about one minute. The early models of the conductance mill were designed for wheat (Brabec et al., 2010) and were later modified for rice (Brabec et al., 2012).

Popcorn (*Zea mays everta* Sturt) is a high value commodity that is sold as a food product and US popcorn processors have very active pest control programs and are vigilant regarding potential insect infestations and product damages. Popcorn is vulnerable to infestation by internal feeding stored-product insects, especially weevils of the genus *Sitophilus* (Coleoptera: Curculionidae). Popcorn is generally less vulnerable to weevil infestation than other corn varieties, but there can be considerable variation among popcorn varieties in susceptibility to weevils. *Sitophilus zeamais* Motschulsky (maize weevil) and *S. oryzae* (L.) (rice weevil) have been reported to develop in popcorn (Suleiman et al., 2015; Zunjare et al., 2015). *Sitophilus* spp. females deposit eggs singly in holes that they excavate in the grain kernel and then seal with a plug (Longstaff, 1981). Egg, larvae, pupae, and adult developmental stages occur inside the kernel, with adult chewing an exit hole and emerging to mate and reproduce. Infestation by weevils reduces market value of popcorn and infestation of consumer products can lead to recalls and customer complaints.

Popcorn is a significantly larger seed than wheat or rice and the mill required modification for popcorn to be processed. The conductivity and detection ability of infested popcorn was unknown. The objective of this study was to investigate the potential of the modified conductance mill to detect popcorn samples infested with different developmental stages of *S. zeamais*. Here we evaluated the ability of conductance mill to quickly and accurately detect pupae, medium larvae and small larvae in four different popcorn varieties. This information could help food industry management evaluate popcorn and determine the pest control practices for maintaining the quality of their stored product.

2. Materials and methods

2.1. Popcorn samples

Four 300lb lots of popcorn were purchased from commercial sources in 2015. The popcorn originated from northeast Nebraska, southwest Iowa, central Iowa, and central Indiana. The specific varieties of popcorn were unknown. The popcorn lots were cleaned and packaged in 50lb bags by the vendors. The four lots were labeled in the experiments as pc1, pc2, pc3, and pc4. Their average weights were 18.5 g, 16.0 g, 14.5 g, and 12.5 g, respectively per 100 kernels. Lots pc1, pc2, and pc3 were yellow popcorn while lot pc4 was white popcorn (Fig. 1). The popcorn moisture content was ~13% as received.

To insure that no seeds were infested with live insects, the popcorn was placed into a walk-in freezer for 48 h. The center of each bag reached 3 °C after 12 h and −8 °C after 24 h. The popcorn was transferred to buckets and stored in a cooler at 10 °C for over three weeks prior to testing. This allowed any potential larvae or pupae to dry below detectable limit with the conductance mill.

2.2. Preparation of infested popcorn

The popcorn samples were tempered to 14% moisture. Colonies of infested popcorn were prepared by adding ~150 adult maize weevils to 200 g of popcorn. Colonies were prepared using each of the four varieties of popcorn and over many weeks of time. The colonies were stored in an environmental chamber which was maintained at 27 °C and 65% relative humidity. After 5–6 weeks of incubation, the adults and insect frass were sifted off the popcorn colony to be test.

Popcorn subsamples were x-rayed (MX20-dc44, Faxitron X-ray Corp., Wheeling, Il.). A sub-sample contained ~25 g of popcorn kernels and was placed on a dish in a single layer and set in the x-ray cabinet. After x-ray exposure, a digital image of the popcorn kernels appeared on the pc display within ~20 s. From the x-ray image, the infested seeds were picked from the dish and sorted into three separate size categories (Fig. 2). The x-ray images of infested kernels were visually assessed by a technician for stage of development; small larvae (1–2nd instar), medium larvae (3rd-4th instar), pupae, and adults (Kirkpatrick and Wilbur, 1965).

Infested seeds were packaged into groups of either 10 pupae/adults, 10 medium larvae, or 10 small larvae. A single pack of 10 infested seeds was added to a pan holding 1 kg of popcorn. The infested kernels were mixed as the grain was pour from the pan and into a plastic bag. A batch of 1 kg samples were prepared on the evening before testing in the conductance mill to allow the infested seeds to equilibrate with the moisture of the sample.

2.3. Modifications of the conductive mill

The conductance mill system and data acquisition software is manufactured by National Manufacturing (Lincoln, NE) (Fig. 3). Initial tests with the conductance mill found product feeding problems with popcorn. The gap was set for wheat at ~0.50 mm (~0.020″) between the two mill-rolls. Because popcorn kernels are about five times larger than wheat kernels, the mill gaps were widen and gaps of 0.64 mm, 0.76 mm, 0.89 mm and 1.02 mm (0.025″, 0.030″, 0.035″, and 0.040") were tested. Preliminary testing indicated the detection rate of the medium and small larvae was decreased as the gap was widened to 1.0 mm.

Widening the gap did not fully improve feeding. The feeding was still intermittent and rough. To improve feeding, extra space was added to help grip and feed the popcorn into the nip of the mill. The 3" diameter roll originally contained 180 teeth. The tooth pattern on one of the rolls was modified to contain a blank-gap

Fig. 1. Photograph of the popcorn kernels from the varieties in this test and showing example of the kernel sizes and color. The samples order from left to right; pc1, pc2, pc3, pc4.

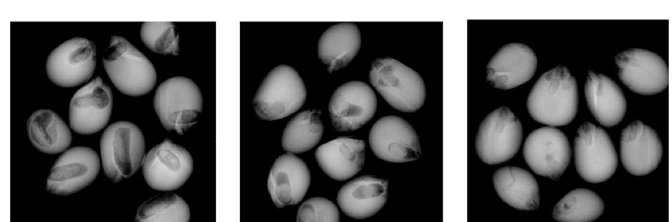

Fig. 2. X-ray images of infested popcorn containing maize weevil at several development stages; pupae (left), medium size larvae (center), and small larvae (right).