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# Characterization of sounds in maize produced by internally feeding insects: investigations to develop inexpensive devices for detection of *Prostephanus truncatus* (Coleoptera: Bostrichidae) and *Sitophilus zeamais* (Coleoptera: Curculionidae) in small-scale storage facilities in sub-Saharan Africa

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**Abstract**

Infestations by *Prostephanus truncatus* Horn (Coleoptera: Bostrichidae) and *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) are prevalent in small-scale *Zea mays* L. storage facilities in Tanzania and other regions of sub-Saharan Africa. It is especially difficult to detect these species' larvae, which feed unseen inside the grain kernels. An electronic device that acoustically detects and reliably indicates the presence of such larvae could assist pest managers in maintaining the quality of the stored maize. A study was conducted in a sound- and vibration-controlled environment to estimate the amplitudes and spectral ranges of signals that an inexpensive electronic system would encounter while detecting insects in maize storage facilities. Larva-infested wheat kernels from a laboratory colony of *Sitophilus oryzae* (L.), a species similar in size and behavior to *S. zeamais*, were placed in a pouch and inserted near the side or the bottom of a bag of maize. An acoustic probe was inserted into the bag, and recordings were made at multiple positions, 5–35 cm from the pouch. Numerous sounds of 4 different types were detected over a range of frequencies extending to 7 kHz, well within the signal-processing capabilities of currently available low-cost microcontroller platforms. Larval sound impulses were detected frequently within 25 cm from the pouch, but not at 35 cm. However, adjustable-length probes could be used to reach within 30 cm of all maize kernels in the types of containers commonly used in regional storage facilities. Thus, there is considerable potential to develop an inexpensive sensor/microcontroller system useful for managing stored product insect pests in sub-Saharan Africa.

Key Words: acoustic probe; post-harvest; hidden infestation; grain; signal processing; Tanzania

**Resumen**

Las infestaciones de *Prostephanus truncatus* Horn (Coleoptera: Bostrichidae) y *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) son frecuentes en instalaciones de pequeña escala de *Zea mays* L. almacenado en Tanzania y otras regiones del África subsahariana. Es especialmente difícil de detectar larvas de estas especies que se alimentan de manera invisible dentro de los granos de cereales. Un aparato electrónico que pueda detectar acústicamente y confiablemente la presencia de estas larvas podría ayudar a los profesionales den el manejo de plagas en el mantenimiento de la calidad del maíz almacenado. Se condujo un estudio en un ambiente de sonido y vibración controlada para calcular las amplitudes y rangos espectrales de las señales que un sistema electrónico de bajo costo podría encontrarse al detectar insectos en las instalaciones de almacenamiento de maíz. Granos de trigo infestados por una colonia de laboratorio de larvas de *Sitophilus oryzae* (L.), una especie similar en tamaño y comportamiento a *S. zeamais*, fueron colocados en una bolsa y puestos cerca del lado o de la parte inferior de una bolsa de maíz. Se insertó una sonda acústica en la bolsa y se realizaron grabaciones en múltiples posiciones, 5-35 cm de la bolsa. Se detectaron numerosos sonidos de 4 tipos diferentes en un rango de frecuencias que se extiende a 7 kHz, que estan dentro de las capacidades de procesamiento de señales de plataformas de microcontroladores de bajo costo disponibles actualmente. Se detectaron los impulsos de sonido de larvas con frecuencia dentro

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de 25 cm de la bolsa, pero no a los 35 cm. Sin embargo, se podrían utilizar las sondas de longitud ajustable para llegar dentro de los 30 cm de todos los granos de maíz en los tipos de recipientes utilizados comúnmente en las instalaciones de almacenamiento regionales. Por lo tanto, existe un gran potencial para desarrollar un sistema barato de sensor/microcontrolador útil para el manejo de plagas de insectos en productos almacenados en África subsahariana.

Palabras Clave: sonda acústica; poscosecha; infestación oculta; gra/nos; procesamiento de señales; Tanzania

Maize is an important source of income and caloric intake in sub-Saharan Africa, accounting for almost 20% of the plant-based food supply (Jones et al. 2011). However, the maize crop can experience up to 20–30% loss yearly because farmers often lack effective post-harvest storage technologies (Mwololo et al. 2010). In rural regions where maize typically is stored in bags or other containers (De Groote et al. 2013; Abass et al. 2014), these losses are due primarily to 2 internally feeding post-harvest insect pests, *Prostephanus truncatus* Horn (Coleoptera: Bostrichidae) and *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) (Vowotor et al. 2005; Omondi et al. 2009; Tefera et al. 2011). In Tanzania, indigenous storage facilities include the traditional kihenge, a raised grass-thatched, mud-plastered hut on stilts (Rugumamu 2003; Makalle 2012). Efforts to detect insects in kihenge and other maize containers typically include frequently smelling and visually inspecting the maize for indications of spoilage, as well as long-term monitoring of its temperature, all of which are time-consuming and costly (Anonymous 2011; Abass et al. 2014). Because the larvae feed unseen inside the kernels, infestations often remain undetected until considerable damage has occurred. Consequently, there is need for nondestructive instruments that can help guide the efforts of pest managers by inexpensively and rapidly detecting infestations in traditional, small-scale storage facilities (Rugumamu 2003).

Acoustic methods are available for detecting infestations of internally feeding insects, but commercially marketed instruments (Litzkow et al. 1990; Hagstrum et al. 1996; Neethirajan et al. 2007; Mankin et al. 2011; Rohde et al. 2013) have been too expensive for general use in small-scale storage facilities in developing countries. However, recent innovations and improvements in the usability of electronic sensing systems suggest it may be possible to develop a low-cost acoustic detection device (e.g., Mankin et al. 2010, 2013; Dillman et al. 2014) incorporating Arduino, Raspberry Pi, or other microcontrollers that could be adopted more widely than previous devices as a tool for insect pest management in maize- and other grain-storage facilities in sub-Saharan Africa.

To distinguish the sounds of a targeted insect species from background noise, such a device amplifies and records incoming sounds and then matches the spectra of individually detected sound impulses to amplitudes and mean spectra (profiles) of sound impulses verified to be produced by that species (Mankin et al. 2011). Some of the first studies of the spectra of sounds produced by internally feeding stored product insects were conducted by Vick et al. (1988b) on *Sitophilus oryzae* (L.), *Rhyzopertha dominica* (F.), and *Sitotroga cerealella* (Olivier) in maize, wheat, and rice kernels. No consistent differences were observed in the spectral ranges of sounds produced by the 3 insects. The peak signal amplitudes were at 587, 1,200, and 1,475 Hz, for larvae feeding in maize, wheat, and rice, respectively. These differences in peak frequency are consistent with differences in the sizes of the grain kernels, in that the resonant frequencies of structural fibers in larger kernels would be expected to be lower than the resonant frequencies of structural fibers in smaller kernels (Mankin et al. 2011).

The stored product insect study of Vick et al. (1988b) did not characterize the full spectral range of sound impulses produced by internally feeding larvae, which extends broadly into ultrasonic frequencies (Pittendrigh et al. 1997; Mankin 2011). To develop a more complete set of larval sound profiles that would be useful for matching to signals collected by an electronic device in a storage facility, we conducted a study of sounds produced in maize by *S. oryzae* larvae. To determine effects of distance from sensor on the detectability of larval sounds, we examined signals at several different distances between the larvae and the sensor. *Sitophilus oryzae* is a widely distributed stored product insect pest whose larvae are slightly smaller than those of *S. zeamais*, but the 2 species are similar in their feeding behavior (Alleoni & Ferreira 2006).

## Materials and Methods

*Sitophilus oryzae* larvae were obtained from a colony at the United States Department of Agriculture (USDA) Agricultural Research Service (ARS) Center for Medical, Agricultural, and Veterinary Entomology (CMAVE), Gainesville, Florida, USA. Infested wheat kernels from the colony (25 mL) were put in a 60 mL plastic pouch, which then was placed near the bottom or near the outer edge of a 27.7 kg polyethylene bag of cracked corn during testing. The number and ages of larvae that produced sound during each recording were undetermined, but we estimated that multiple 4th instars were feeding during each test, given that 83 adult *S. oryzae* had emerged within the pouch 10 d after the experiment was completed. The typical pattern of *S. oryzae* development in grain kernels is: first instar at day 5 after egg is laid, 2nd at day 9, 3rd at day 13, 4th at day 16, and adult emergence at day 32 (Howe 1952).

To record signals at different distances between larvae and sensors, a 15-cm-length waveguide (probe) was attached to a sensor/preamplifier (Model SP-1L, Acoustic Emission Consulting [AEC] Inc., Sacramento, California, USA) of an acoustic insect detection system (Model AED-2010, AEC. Inc.). The probe was inserted into the bag of corn at different horizontal or vertical distances 5–35 cm from the nearest edge of the pouch. The tests were conducted at 24–27 °C in a sound- and vibration-shielded anechoic chamber that reduced background noise to negligible levels (Vick et al. 1988a; Mankin et al. 1996). Three recordings conducted on different days without the pouch in the bag of corn confirmed that background sounds occurred at a rate of < 0.01 $s^{-1}$.

Intervals of 180 s that contained 3- to 30-ms sound impulses (Vick et al. 1988b; Mankin et al. 1996, 2011) were amplified 78 dB (Model AED-2010, AEC, Inc.), where dB is 20 $\log_{10}(V_{output})$ and $V_{output}$ is the signal delivered by the amplifier in units of microvolts. The amplified signals were collected at a 44.1 kHz sampling rate onto a digital audio recorder (Model PMD661, Marantz, Mahwah, New Jersey, USA). General-purpose sound analysis software (Raven Pro Version 1.5; Charif et al. 2008) was used to screen and preprocess the recordings. Spectral and temporal pattern analyses of the larval impulses were conducted using DAVIS, a custom-written insect sound analysis program (Herrick & Mankin 2012; Dosunmu et al. 2014). It should be noted that the AED-2010, whose frequency bandwidth extends to 2 MHz, filters out signals below 1 kHz to reduce the level of background noise.

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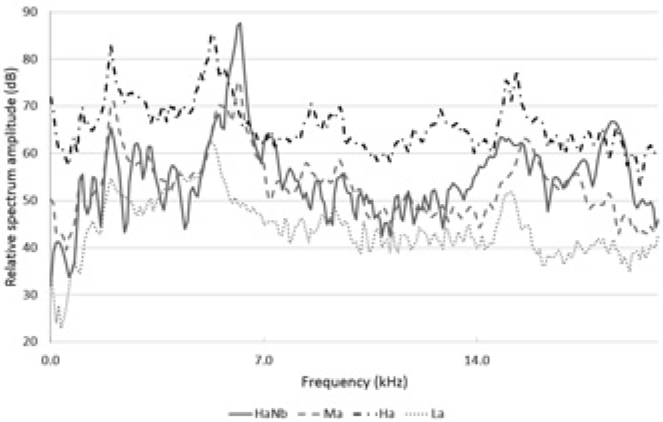


**Fig. 1.** Spectral profiles of 4 distinctive types of larval sound impulses detected in cracked corn: HaNb, solid line; Ma, dashed line, Ha, dash-dot-dotted line, and La, dotted line. Horizontal axis indicates frequency in kHz and vertical axis indicates relative spectrum amplitude in dB.

## Results

Four distinct types of impulses were identified in the initial screening. Spectral profiles of each type (Mankin et al. 2011) were generated in DAVIS by calculating the mean spectrum of a series of consecutive impulses of the same type observed in a single recording. Each impulse detected in the recordings was assigned to the type from which it had the smallest total mean-square difference (Dosunmu et al. 2014). About 1% of the detected signals had a total least-squares difference greater than 50 dB against all of the profiles, and these were discarded as background noise. For designative purposes, the 4 signal types were labeled: HaNb (High amplitude-Narrow band), Ma (Mid-range amplitude), Ha (High amplitude), and La (Low amplitude). The spectral profiles of the *S. oryzae* larval impulse types are shown in Fig. 1 in order of lowest to highest occurrence of impulse matches. Only 39 of 2,741 larval impulses total were best-fit matched to the HaNb profile, and impulses of this type were found in only 3 of the 11 tests where larval impulses were detected. However, these impulses were very prominent whenever they occurred, because HaNb had the highest amplitude of all the profiles, primarily in a narrow band of frequencies around 6.2 kHz. The HaNb profile was generated as an average of 7 consecutive impulses in a recording of signals 10 cm from the larval pouch.

There were 196 impulses that matched the mid-range amplitude profile, type Ma, which was generated as an average of 97 consecutive impulses in a recording at 10 cm from the larval pouch. Ten of the 11 tests with larval impulses contained examples of Ma impulses, and all of them contained examples that matched the type Ha and type La profiles. The Ha profile was generated as an average of 41 consecutive impulses in a recording of signals at 5 cm distance from the larval pouch, and the La profile was generated from an average of 8 consecutive impulses in a test at a 20 cm distance from the larval pouch. A total of 1,132 impulses of type Ha were detected, and 1,374 of type La. Figure 2 shows a 1 s interval recorded 10 cm away from the larval pouch and includes 3 of the 4 types of sound impulses. Six impulses of type Ha precede the type Ha impulse marked at 0.37 s. A pair of type La impulses is marked at 0.52 s, and 2 type HaNb impulses appear at the end of the interval, near 0.97 s.

For mean and standard error calculations to consider the effects of distance between the larval pouch and sensor on the detectability of larvae in maize, the rates of larval sound impulses of each profile type were summed and averaged over the test duration to obtain an overall

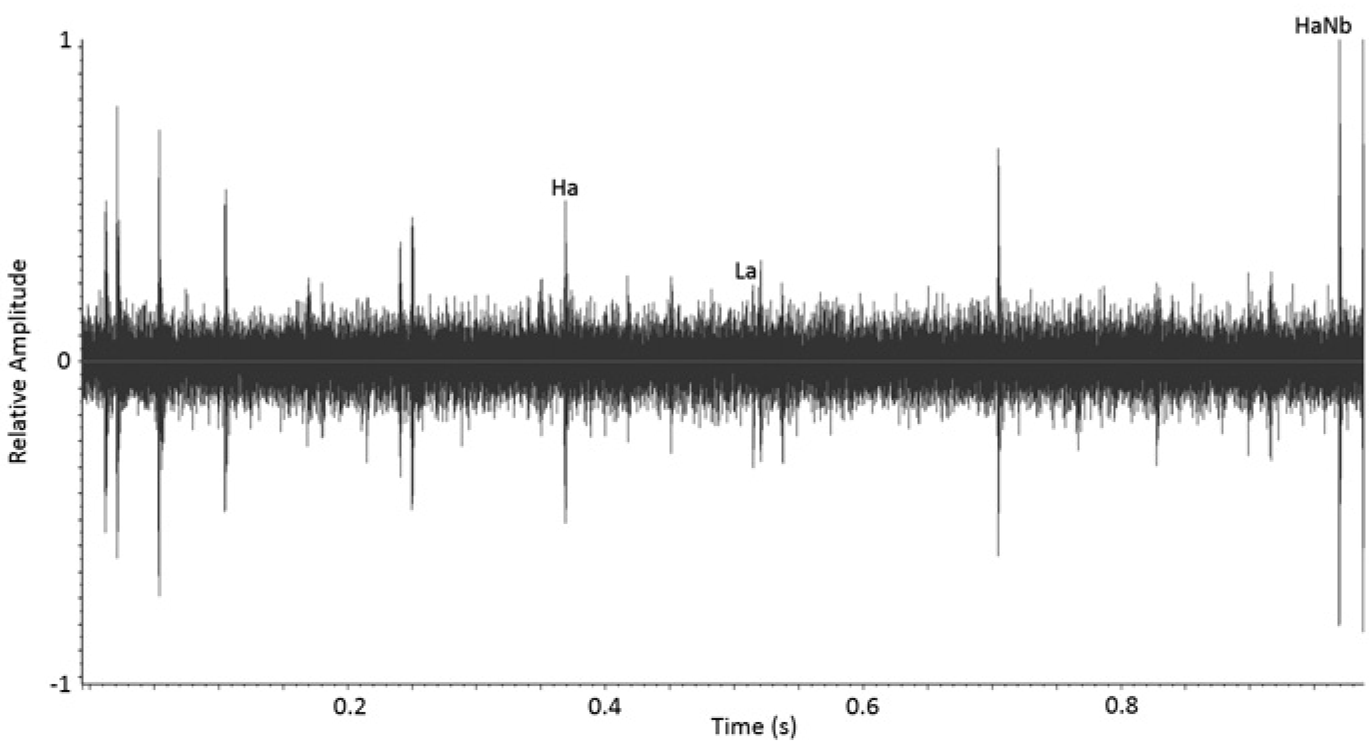


**Fig. 2.** Oscillogram of sound impulses recorded 10 cm from pouch containing *Sitophilus oryzae* larvae. Examples of 3 types of larval sound impulse occur during the 1 s period, and one example each of type (Ha, La, and HaNb) is marked above the impulse. Horizontal axis indicates time in seconds and vertical axis indicates relative signal amplitude.

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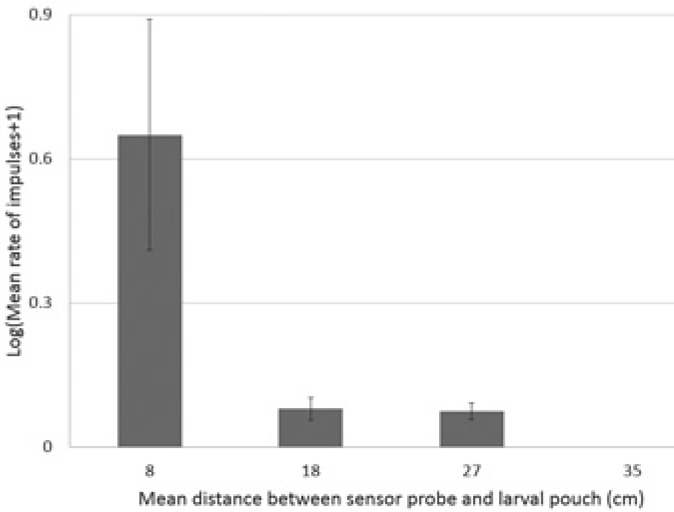


**Fig. 3.** Effects of distance on detectability of larval sound impulses. Horizontal axis indicates the mean distance between the larval pouch and the sensor; vertical axis indicates the $log_{10}$-transformed mean rate of impulses detected at that distance. Bars indicate the standard error of mean transformed rate.

rate of impulses for each recording. Because the variability of rates was similar for recordings collected at the same horizontal and vertical distances from the pouch, overall rates were combined into 4 groupings of mean distance: 8, 18, 27, and 35 cm, with *n* = 4, 4, 3, and 3 tests, respectively. The results are shown in Fig. 3. The larvae were easily detected at mean distances of 8 cm but were undetectable at distances of 35 cm. In general, the effect of distance was consistent with the conclusion of Vick et al. (1988a) that the rate of sounds decreased approximately logarithmically with distance between the larvae and the sensor. The pattern of detectable sounds in Fig. 3 suggests that, except for very loud larvae, the maximum range of detection is no greater than about 30 cm in a quiet environment.

## Discussion

The spectral ranges of impulses detected in this study are similar to those observed in other studies of insect sounds produced in stored maize or wheat (Vick et al. 1988b; Mankin et al. 2011). Therefore, it can be expected that any insect acoustic detection instrument designed for small-scale storage facilities would need to detect signals in the range of 500–7,000 Hz to ensure coverage of the most prominent frequencies of signals produced by internally feeding stored product insects in maize. Fortunately, such capabilities could be incorporated into an inexpensive computer system, such as an Arduino microcontroller (http://arduino.cc/en/Main/ArduinoBoardUno) or a Raspberry Pi platform (http://www.raspberrypi.org), which can be used with open-source or custom-written data collection and analysis software and inexpensive memory storage cards. Such systems offer the added advantage that they can be battery powered, as many parts of sub-Saharan Africa do not have reliable electrical power; it would also be beneficial to include a feature that enables the device to communicate with increasingly available mobile phones (Aker & Mbiti 2010). Because it is unlikely that any low-cost insect acoustic detection instrument would have greater sensitivity than the state-of-art system used in this study, it can be expected that *P. truncatus* and *S. zeamais* would be detected by any instrument only rarely at distances greater than 30 cm from the sensor. However, probes of different sizes could be developed to adapt the sensors for use with the different types of storage containers used in the region (e.g., polyethylene bags, jute bags, and kihenge). Thus, if an inexpensive, robust sensor can be developed and operated with a low-cost microcontroller system, there is considerable potential for its use in insect pest management activities in rural Tanzania and other regions of sub-Saharan Africa.

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## References Cited


Abass AB, Ndunguru G, Mamiro P, Alenkhe B, Mlingi N, Bekunda M. 2014. Post-harvest food losses in a maize-based farming system of semi-arid savannah area of Tanzania. Journal of Stored Product Research 57: 49-57.

Akers JC, Mbiti IM. 2010. Mobile phones and economic development in Africa. Journal of Economic Perspectives 24: 207-232.

Alleoni B, Ferreira W. 2006. Control of *Sitophilus zeamais* Mots., 1958 and *Sitophilus oryzae* (L., 1763) weevils (Coleoptera, Curculionidae) in stored corn grain (*Zea mays* L.) with insecticide pirimiphos methyl (Actellic 500 CE), pp. 1218-1225 *In* Proceedings of the 9th International Working Conference on Stored Product Protection. ABRAPOS. Passo Fundo, Brazil, 15-18 Oct 2006.

Anonymous. 2011. Tanzania Agriculture and Food Security Investment Plan (TAFSIP) 2011-12 to 2020-21. 2011. www.grain.org/attachments/2688/download (last accessed 31 Mar 2015).

Charif RA, Waack AM, Strickman LM. 2008. Raven Pro user's manual. Cornell Laboratory of Ornithology, Ithaca, New York, USA.

De Groote H, Kimenju SC, Likhayo P, Kanampiu F, Tefera T, Hellin J. 2013. Effectiveness of hermetic systems in controlling maize storage pests in Kenya. Journal of Stored Product Research 53: 27-36.

Dillman AR, Cronin CJ, Tang J, Gray DA., Sternberg PW. 2014. A modified mole cricket lure and description of *Scapteriscus borellii* (Orthoptera: Gryllotalpidae) range expansion and calling song in California. Environmental Entomology 43: 146-156.

Dosunmu OG, Herrick NJ, Haseeb M, Hix RL, Mankin RW. 2014. Acoustic detectability of *Rhynchophorus cruentatus* (Coleoptera: Dryophthoridae). Florida Entomologist 97: 431-438.

Hagstrum DW, Flinn PW, Shuman D. 1996. Automated monitoring using acoustical sensors for insects in farm-stored wheat. Journal of Economic Entomology 89: 211-217.

Herrick NJ, Mankin RW. 2012. Acoustical detection of early instar *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae) in Canary Island date palm, *Phoenix canariensis* (Arecales: Arecaceae). Florida Entomologist 95: 983-990.

Howe RW. 1952. The biology of the rice weevil *Calandra oryzae*. L. Annals of Applied Biology 39: 168-180.

Jones M, Alexander C, Lowenberg-Deboer J. 2011. An initial investigation of the potential for hermetic Purdue Improved Crop Storage (PICS) bags to improve incomes for maize producers in Sub-Saharan Africa. Working Paper 11-3, Department of Agricultural Economics, Purdue University, Lafayette, Indiana, USA, Sep 2011.

Litzkow CA, Webb JC, Vick KW. 1990. Piezoelectric apparatus and process for detection of insect infestation in an agricultural commodity, 12 pp., US Patent: 4,937,555.

Makalle AM. 2012. Post harvest storage as a rural household food security strategy in Tanzania. Journal of Science and Technology 2: 814-821.

Mankin RW. 2011. Eavesdropping on coconut rhinoceros beetles, red palm weevils, Asian longhorned beetles and other invasive travelers. Proceedings of Meetings on Acoustics 14:010001;1-8.

Mankin RW, Shuman D, Coffelt JA. 1996. Noise shielding of acoustic devices for insect detection. Journal of Economic Entomology 89: 1301-1308.


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Mankin RW, Hodges RD, Nagle HT, Schal C, Pereira RM, Koehler PG. 2010. Acoustic indicators for targeted detection of stored product and urban insect pests by inexpensive infrared, acoustic, and vibrational detection of movement. Journal of Economic Entomology 103: 1636-1646.

Mankin RW, Hagstrum DW, Smith MT, Roda AL, Kairo MTK. 2011. Perspective and promise: a century of insect acoustic detection and monitoring. American Entomologist 57: 30-44.

Mankin RW, Rohde BB, McNeill SA, Paris TM, Zagvazdina NI, Greenfeder S. 2013. *Diaphorina citri* (Hemiptera: Liviidae) responses to microcontroller–buzzer communication signals of potential use in vibration traps. Florida Entomologist 96: 1546-1555.

Mwololo JK, Mugo S, Okori P, Tadele T, Munyiri SW. 2010. Genetic diversity for resistance to larger grain borer in maize hybrids and open pollinated varieties in Kenya, pp. 535-539 *In* Second Regional Universities Forum for Capacity Building in Agriculture Biennial Mtg. Entebbe, Uganda, 20-24 Sep 2010.

Neethirajan S, Karunakaran C, Jayas DS, White NDG. 2007. Detection techniques for stored-product in grain. Food Control 18: 157-162.

Omondi AB, Orantes LC, Van Den Berg J, Masiga D, Schulthess F. 2009. Isolation and characterization of microsatellite markers from *Teretrius nigrescens* Lewis (Coleoptera: Histeridae), predator of the storage pest *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). Molecular Ecology Resources 9: 1236-1239.

Pittendrigh BR, Huesing JE, Shade RE, Murdock LL. 1997. Monitoring of rice weevil, *Sitophilus oryzae*, feeding behavior in maize seeds and the occurrence of supernumerary molts in low-humidity conditions. Entomologia Experimentalis et Applicata 83: 225-231.

Rohde BB, Paris TM, Heatherington EM, Hall DG, Mankin RW. 2013. Responses of *Diaphorina citri* (Hemiptera: Psyllidae) to conspecific vibrational signals and synthetic mimics. Annals of the Entomological Society of America 106: 392-399.

Rugumamu CP. 2003. Insect infestations and losses of maize, *Zea mays* (L.) in indigenous storage structures in Morogoro region, Tanzania. Tanzanian Journal of Science 29(2): 1-9.

Tefera T, Kanampiu F, De Groote H, Hellin J, Mugo S, Kimenju S, Beyene Y, Boddupalli PM, Shiferaw B, Banziger M. 2011. The metal silo: an effective grain storage technology for reducing post-harvest insect and pathogen losses in maize while improving smallholder farmers' food security in developing countries. Crop Protection 30: 240-245.

Vick KW, Webb JC, Hagstrum DW, Weaver BA, Litzkow CA. 1988a. A sound-insulated room suitable for use with an acoustic insect detection system and design parameters for a grain sample holding container. Florida Entomologist 71: 478-484.

Vick KW, Webb JC, Weaver BA, Litzkow C. 1988b. Sound detection of stored product insects that feed inside kernels of grain. Journal of Economic Entomology 81: 1489-1493.

Vowotor KA, Meikle WG, Ayertey JN, Markham RH. 2005. Distribution of and association between the larger grain borer *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) and the maize weevil *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) in maize stores. Journal of Stored Product Research 41: 498-512.

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