LIAO, M. S., CHUANG, C. L., LIN, T. S., CHEN, C. P., ZHENG, X. Y., CHEN, P. T. AND J. A JIANG,. 2012:. Development of an autonomous early warning system for *Bactrocera dorsalis* (Hendel) outbreaks in remote fruit orchards. Computers and electronics in agriculture **88**: 1-12.

LÓPEZ, O., RACH, M.M., MIGALLON, H., MALUMBRES, M.P., BONASTRE, A. AND J. J. SERRANO, 2012:. Monitoring pest insect traps by means of low-power image sensor technologies. Sensors **12**: 15801-15819.

NEETHIRAJAN, S., KARUNAKARAN, C., JAYAS, D.S. AND N.D.G. WHITE, 2007. Detection techniques for stored-product insects in grain. Food Control **18**: 157-162.

PORTER J.H., NAGY, E., KRATZ, T.K. AND P. HANSON, 2009: New eyes on the world: advanced sensors for ecology. BioScience **59**: 385-397.

REED, C.R., WRIGHT, V.F., MIZE, T.W., PEDERSEN, J.R. AND B.J. EVANS 1991: Pitfall traps and grain samples as indicators of insects in farm-stored wheat. Journal of Economic Entomology **84**: 1381-1387.

SHIEH, J.C., WANG, J. Y., LIN, T.S., LIN, C.H., YANG, E.C., TSAI, Y.J. AND J.A. JIANG, 2011: A GSM-based field monitoring system for *Spodoptera litura* (Fabricius). Engineering in agriculture, environment and food **4:** 77-82.

TREMATERRA P., 2013: Aspects related to decision support tools and Integrated Pest Management in food chains. Food Control **34:** 733–742.

WHITE, N. D. G., ARBOGAST, R. T., FIELDS, P. G., HILLMANN, R. C., LOSCHIAVO, S. R., SUBRAMANYAM, B., THRONE, J.E. AND V.F. WRIGHT, 1990: The development and use of pitfall and probe traps for capturing insects in stored grain. Journal of the Kansas Entomological Society **63**: 506-525.

XIA, C., LEE, J. M., LI, Y., CHUNG, B. K. AND T. CHON, 2012: In situ detection of small-size insect pests sampled on traps using multifractal analysis. Optical Engineering **51**: 027001-1.

Detection and estimation of population density of bean weevils (Coleoptera: Bruchidae) in stored pulses via bioacoustic analysis

Panagiotis A. Eliopoulos*[1], Ilyas Potamitis[2]

[1]Technological Educational Institute of Thessaly, Department of Agriculture Technologists, 41110 Larissa, Greece, eliopoulos@teilar.gr.

[2]Technological Educational Institute of Crete, Department of Music Technology and Acoustics, 74100 Rethymno, Greece, potamitis@staff.teicrete.gr

*Corresponding author: eliopoulos@teilar.gr

DOI 10.5073/jka.2018.463.064

Abstract

Stored product insects, produce acoustic emissions by moving, feeding or ovipositing inside the grain mass. These sounds can be used not only for detection purposes, but also for population density estimation. Acoustic emissions of adults of *Acanthoscelides obtectus* (Coleoptera: Bruchidae) and *Callosobruchus maculatus* (Coleoptera: Chrysomelidae) were recorded infesting various pulses in varying population densities from 1 to 500 adults/kg product. The acoustic analysis system is being described. Population density, type of grain and pest species had significant influence on the number of sounds. The system was 100% precise in negative predictions and considerably successful in positive predictions. The system was very accurate (80-100%) in detecting insect presence even in the "critical" density of 1 adult/kg product, the most common threshold for classifying a stored mass as "infested" or "not infested". Our study suggests that automatic monitoring of the infestation state in bulk grain is feasible in small containers. This kind of service can assist reliable decision making if it can be transferred to larger storage establishments (eg. silos). Our results are discussed on the basis of enhancing the use of acoustic sensors as a decision support system in stored product IPM.

Keywords: Stored Pulses, Bioacoustic, Detection, bean beetles, Density Estimation

Introduction

More than 500 species of beetles have been reported to be associated with various stored grain products (cereals and pulses) and almost 100 of them may cause significant quantitative or qualitative losses. It has been estimated that between one quarter and one third of the world grain crop is lost each year during storage. The key for successful management of stored grain pests is not only early detection, but also an accurate population density estimation of the pest (Rajendran and Steve, 2005).

Acoustic detection is a very promising method for early detection of insects inside the grain mass (Eliopoulos et al., 2015; Hagstrum et al., 1996; Mankin et al., 2011; Potamitis et al., 2009 and others). Insects of stored grain generate sound by eating, flying, egg laying, or locomotion. Reliability and efficacy of acoustic sensors has been greatly increased in the last few years as a result of the development of improved acoustic devices and signal processing methods (Mankin et al., 2011). Apart from detection, very few studies have evaluated the potential of the acoustic method in estimating the population density of the pest inside the grain mass (Hagstrum et al., 1988, 1990).

The aim of our study is to propose and evaluate an automated monitoring procedure for IPM implementation in grain handling and storing facilities. The main unit is composed of a piezoelectric sensor and a portable acoustic emission amplifier connected to a computer. The software analyses the vibration recordings of the piezoelectric sensor, performs signal parameterization and eventually classification of the infestation severity of adult beetles inside the grain mass in four classes, namely: Class A (densities ≤1 adult/kg), Class B (densities 1-2 adults/kg), Class C (densities 2-10 adults/kg) and Class D (densities >10 adults/kg). Our results are discussed on the basis of enhancing the use of acoustic sensors as a decision support system in stored product IPM.

Materials and Methods

For the purposes of our study, we used adults from two important beetle pests of stored pulses. We used the grain that each species is most commonly associated with in natural conditions. Specifically, we recorded acoustic emissions of the bean weevil *Acanthoscelides obtectus* (Say) (Bruchidae) on kidney and butter (giant) beans and the cowpea weevil *Callosobruchus maculatus* (F.) (Bruchidae) on broad (fava) beans.

Our system was adopted by Eliopoulos et al. (2015) and consisted of a 14cm long piezoelectric sensor mounted on the end of a probe that was pushed into the grain (hard wheat) and a portable acoustic emission amplifier (AED-2010L, Acoustic Emission Consulting, Inc., Fair Oaks, CA) connected with a computer. The experimental procedure (grain preparation, recording methodology etc) is described in detail by Eliopoulos et al. (2015). Each treatment (recording of the desired species and number of adults in the desired grain mass) was replicated 5 times. Recordings from uninfested pulses was used as control.

Various infestation densities were tested during the present study (1, 2, 10, 20, 50, 100, 200 & 500 beetle adults/kg grain). We proceeded into inserting the piezoelectric probe and taking 5 recordings per jar. We have grouped insects' density in 4 distinct classes: Class A (densities ≤1 adult/kg), Class B (densities 1-2 adults/kg), Class C (densities 2-10 adults/kg) and Class D (densities >10 adults/kg). We apply supervised learning techniques to our dataset as we know the class labels (i.e. we set the infestation densities). The task is given the counts/min of the unknown test jar the classification algorithm must predict the Class (i.e. severity) of the infestation.

In operational mode, the computer receives a vibration recording from the sensor which turns into counts of enumerated pulses (counts/min). From these counts/min it infers the distribution of probabilities over infestation severity classes A-D. By peaking the probability distribution the algorithm can output a single decision as well.

Our data (number of recorded sounds expressed as counts/min) were subjected to analysis of variance in order to evaluate the main effects. ANOVA was performed by using SPSS v.18.0. (SPSS Inc, 2009).

Results and Discussion

The mean numbers of counts/minute that were recorded during the present study are presented in Fig 1. The increase on population density (number of adults inside the grain mass) was always followed by an increase in recorded sounds. The differences were not always significant. The linear model was very effective in describing the relationship between population density and number of sounds given that values of R were high (>0.80) (Fig. 2).

The type of grain had notable influence on the number of sounds. This was observed in the case of *A. obtectus* in small (kidney) and large-sized (butter) beans. The number of sounds was significantly higher when bean weevils were inside the kidney bean mass irrespective of population density ($F_{1,88} = 12.61$; $P = 0.0007$) (Fig. 1).

It has been well documented that acoustic sensors may be very effective in detecting insect presence in the grain mass (Eliopoulos et al., 2015; Hagstrum et al., 1991). However, there are only a few studies focusing on the estimation of pest density using bioacoustic technology. The first attempt was made by Hagstrum et al. (1988) using various densities of *R. dominica* larvae in wheat, and counting the produced sounds, with a piezoelectric microphone and earphones. They concluded that insect sounds increase with pest density and that the accuracy of estimation of insect densities with the acoustical method was comparable to that obtained with a standard grain trier. Following studies by the same research team revealed that acoustic sensors can be used for density estimation not only in experimental bins (Hagstrum et al., 1990, 1991) but also in real silos (Hagstrum et al., 1994, 1996) with very satisfactory results. Our results cannot be compared with those of the above mentioned studies because of the completely different methodology they used. For example, Hagstrum et al. (1996) correlated the number of sounds with pest density using 140 sensors on 7 cables in grain bins, checking each sensor for 10 sec 27 times per day.

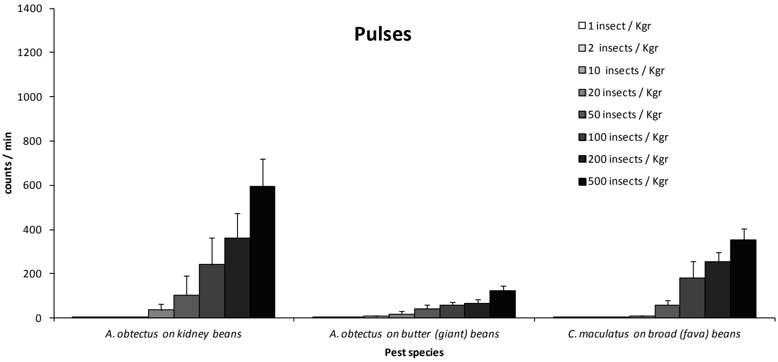

Fig. 1 Mean number of sounds recorded inside the pulses mass during the present study.

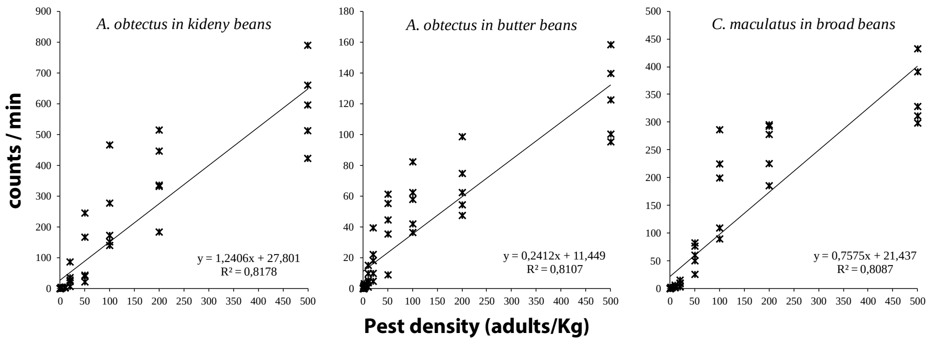

Fig. 2 Linear relationship of pest population density with number of sounds recorded in stored pulses

The type of pulse was an important factor that influenced the number of sounds. Although, sound is transmitted over longer distances in grains with a larger inter-kernel spacing, such as maize and butter beans (Hickling et al., 1997), we found that more sounds were generated when adult beetles were in small-sized grain like kidney beans. The reason for this should be that insects have smaller free space to move and they “interact” with kernels more often in small sized grains. Vick et al. (1988) also demonstrated that number of sounds produced by *S. oryzae, R. dominica* and *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelechiidae) varied significantly when they were in a different type of grain (rice, corn or wheat).

Our study suggests that automatic monitoring of the infestation state in bulk grain is feasible in small containers. This kind of service can assist reliable decision making if it can be transferred to larger storage establishments. Very soon and with further technological development (e.g. piezo electric sensors embedded in cables submerged in the grain) the acoustic methodology can provide a quick and easy way, not only of detecting, but also of estimating pest population density in larger establishments of stored grain facilities.

Acknowledgement

The present study is a part of the research project "Development of modern and novel methods of Integrated Pest Management against stored products pests" and has been co-financed by the European Union (European Social Fund - ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: ARCHIMEDES III (Grant number MIS 383555). Investing in knowledge society through the European Social Fund.

References

ELIOPOULOS, P.A., POTAMITIS, I., GIVROPOULOU, E. AND D. KONTODIMAS, 2015: Detection of adult beetles inside the stored wheat mass based on their acoustic emissions. Journal of Economic Entomology **108**: 2808-2814.

HAGSTRUM D.W., VICK, K.W. AND J.C. WEBB, 1990: Acoustical Monitoring of *Rhyzopertha dominica* (Coleoptera: Bostrichidae) Populations in Stored Wheat. Journal of Economic Entomology **83**: 625-628.

HAGSTRUM, D.W., FLINN, P.W. AND D. SHUMAN, 1996: Automated Monitoring Using Acoustical Sensors for Insects in Farm-Stored Wheat. Journal of Economic Entomology **89**: 211-217.

HAGSTRUM, D.W., VICK, K.W. AND P.W. FLINN, 1991: Automated Acoustical Monitoring of *Tribolium castaneum* (Coleoptera: Tenebrionidae) Populations in Stored Wheat. Journal of Economic Entomology **84**: 1604-1608.

HAGSTRUM, D.W., WEBB, J.C. AND K.W. VICK, 1988: Acoustical detection and estimation of *Rhyzopertha dominica* (F.) larval populations in stored wheat. Florida Entomologist **71**: 441-447.

HAGSTRUM, D.W.; FLINN, P.W. AND D. SHUMAN, 1994: Acoustical monitoring of stored-grain insects: An automated system, in: Highley, E., Wright, E.J., Banks, H.J., Champ, B.R. (Eds.), Stored Product Protection, Proceedings of the 6th International Working Conference on Stored-Product Protection, 17-23 April 1994, Canberra, Australia. CAB International, Wallingford, pp. 403-405.

HICKLING, R., WEI, W. AND D.W. HAGSTRUM, 1997: Studies of Sound Transmission in of Stored Grain for Acoustic of Insects Various Types Detection. Applied Acoustics **50**: 263-278.

MANKIN, R.W., HAGSTRUM, D.W., SMITH, M.T., RODA, A.L. AND M.T.K., KAIRO, 2011: Perspective and promise: a century of insect acoustic detection and monitoring. American Entomologist **57**: 30-44.

POTAMITIS, I., GANCHEV, T. AND D., KONTODIMAS, 2009: On Automatic Bioacoustic Detection of Pests: The Cases of Rhynchophorus ferrugineus and Sitophilus oryzae. Journal of Economic Entomology **102**: 1681-1690.

RAJENDRAN, S. AND L.T. STEVE, 2005: Detection of insect infestation in stored foods. Advances in Food Nutrition Research **49**: 163-232.

SPSS INC., 2009: PASW Statistics for Windows, Version 18.0. SPSS Inc., Chicago.

VICK, K.W., WEBB, J.C., WEAVER, B.A. AND C. LITZKOW, 1988: Sound detection of stored-product insects that feed inside kernels of grain. Journal of Economic Entomology **81**: 1489-1493.

PHID-Coleo - a database identification tool for wood-boring beetles in plant health interceptions

Olaf Zimmermann[1]*, Philipp Bauer [1,3], Iris Häußermann [2], Martin Hasselmann [2], Claus P.W. Zebitz [3]

[1] Centre for Agricultural Technology Augustenberg (LTZ), Division 3: Plant Health, Animal Feed and Analysis of Seeds, Department 33, Zoological Diagnostics, Nesslerstr. 25, 76227 Karlsruhe, Germany
[2] University of Hohenheim, Institute of Animal Science, Department of Livestock Population Genomics, Emil-Wolff-Str. 10, 70593 Stuttgart, Germany
[3] University of Hohenheim, Institute of Phytomedicine, Department of Applied Entomology, Otto-Sander-Str. 5, 70599 Stuttgart, Germany
*Corresponding author: olaf.zimmermann@ltz.bwl.de
DOI 10.5073/jka.2018.463.065