# Research Proposal

## Title: Enhanced monitoring of insect pests in stored rice based on their sound signature and evaluation of attractants for storage insects


### Summary

Significant losses occurred in rice storage predominantly caused by insect pests to as high as 10% in terms of quantity. Detection of insect pests in stored grains is important to reduce losses and combat hunger. Several systems are available in the market such as automated monitoring of insect populations that is equipped with temperature sensors but the challenge is that these are not very reliable in early detection of insect populations and manual method is laborious. Often, this lead to huge losses because counter measures are implemented too late. An acoustic system for early detection of insect pest in stored wheat and rye (InsectTap) has been developed by the Department of Agricultural Engineering at the University of Kassel. Further works need to be done to adapt the system for application to rice. The software developed can classify sound patterns of insect pests on species level which is relevant in implementing appropriate control measures. The InsectTap can be modified with thorough study on the sound patterns of storage pests in rice. The use of low cost but quality micro-electro-mechanical system (MEMS) microphone will be explored together with the use of insect attractants to minimize the number of acoustic sensors deployed in the storage bulk. The proposed project aims to achieve the following – (1) thoroughly study and document the sound patterns of insect pests and assess the effectiveness of different types of insect lures in stored rice; (2) develop a handheld acoustic measurement system to detect the insect pest species; (3) establish a working prototype that can be developed for small and large scale applications; (4) develop and test the sensors and interfaces that can be used with mobile phones; and (5) assess potential application in other systems such as hermetic storage or grain cooling.


### Introduction

The estimated weight losses of rice in traditional postharvest chain in Southeast Asia are between 30 and 55 % with significant contribution from storage losses with maximum at 10% (Hodges et al., 2011). Storage losses are predominantly caused by the presence of pests in storage facilities and early detection of pests in stored grain is important in post-harvest technology (Boyer et al., 2012). The use of acoustic devices in detecting storage insects in corn have been successfully studied by Njoroge et al (2017). The sound impulses produced by larger grain borer (*Prostephanus truncatus)* and maize weevil (*Sitophilus zeamais)* have been determined using state-of-the-art sensors and amplifier system to detect their presence and degree of infestations in maize. This system can also be adapted to rice crop to determine presence of insect pests and prevent further damage by employing appropriate corrective actions. Hagstrum et al. (1988) have effectively monitored densities of lesser grain borer (*Ryzopherta dominica*) in wheat grains using piezoelectric microphone probes without taking grain samples. The sound detected by the microphones increased as the density of insects in the grain bulk also increase. The use of acoustical sensors were also used to estimate populations of lesser grain borer that favourably increases at temperatures of 27 to 32°C (Hagstrum et al., 1990)

Several other systems have also been developed such as the portable Postharvest insect Detection System (PDS) that assesses infestations by comparing the recorded signals using electret microphones to the sound spectra of known pests; bioacoustic detection technique combined with artificial neural network (ANN) in predicting bruchids density in stored green gram, and a non-contact, non-destrucive microwave device for sensing adult insects in grain samples (Banga et al, 2020; Mankin et al, 2020; and Reimer et al, 2018). An important aspect of insect detection is understanding movement of insect pests in the grain store and what makes them aggregate in a certain location. A study conducted on red flour beetle (*Tribolium castaneum,* Herbst) showed that the insect is often inactive outside of food patches in stored grain products especially the male insects which tend to stay near the edge and move slowly and infest flour patches (Campbell and Hagstrum, 2000).

The use of attractants can increase capture probability of insects in grain stores such as the pheromones or kairomones, wheat germ oil or coconut oil and the effect of abiotic factor such as air movement can increase attraction of insects such as red flour beetle to the odour or source of lures (Campbell, 2012; Dooley et al., 2018). Most pheromones traps, however, are designed to use female-emitted attractive components to lure male insects but the polygamous nature of some untrapped males negates the benefit of using pheromones. A study by Ni et al. (2008) combined pheromones with different solutions to increase effectiveness in attracting storage insects in corn and concluded that the mixture of nutrients (i.e., honey, beer and sugar) in diluted antifreeze could be used as an effective measure to monitor and possibly manage storage insects, such as, lepidopteran and coleopteran pests. Insects of different species have been studied to be attracted to light of various wavelength. Insects such as moths, beetles, flies and other active insects are lured by light and can be trapped for control and monitoring purposes. Insects are lured by the light and fall the victim of getting trapped into the collecting chamber (Sheikh et al., 2016; Weinzierl et al., 2005). Another factor that greatly influences the growth and development of storage insects is temperature. A study conducted on development, survival, fecundity and longevity of khapra beetle (*Trogoderma granarium*), which is a serious pest of grains and stored products in the tropic and sub-tropical regions indicated that the optimum temperature for development is 35°C while egg laying is maximum at 30°C. Arthur and Casada (2005) cited (Cotton et al., 1960; Flinn and Hagstrum, 1998) that reproduction and development of the lesser grain borer is particularly high at 37°C. Insects in grain storage tend to move and respond to temperature gradients and at elevated temperatures on the surface, insects simply disperse downward into cooler areas.

Most insects are phototaxic which allow them to respond to light sources of various wavelength. Different species respond uniquely to specific portions of the visible and non-visible spectrum. A study conducted by Park and Lee (2017) stated that most stored product insects (e.g., *Tribolium castaneum, Sitophilus zeamais, Lasioderma serricorne* and *Tyrophagus putrescentiae*) are attracted to red LED (light emitting diode).

Vibrations are an important part of the communication in many insects to fulfill some behavioral needs such as mating/attraction, alarm, defence or cooperation/aggregation. There are different modalities of emitting vibratory signal such as spontaneous singing that is exhibited for example by female *Nezara viridula* (L.) to signal attraction or mating to male counterparts which is often triggered by male pheromone (Zgonik and Cokl, 2013; Polajnar et al., 2014). The use of vibration exciter and electro-magnetic shakers can simulate the vibrational signals such as the female calling song (FCS) of plant-dwelling insects (Zgonik and Cokl, 2013; Presern et al., 2018). For the male treehopper (*Umbonia crassicornis)*, the vibrational signal being emitted during courtship consists of a frequency-modulated tonal signal which is accompanied by rhythmic broad-band clicks (Miles et al., 2017).

Recent technological advances have led to reduction in costs with the novel automatic detection and monitoring systems for insects in the field and in laboratory that are connected to the internet with wireless sensor networks (Internet of Things), allowing real-time surveillance on the field level which may include opto-electronic devices, videography, thermal imaging, radio frequency identification (RFID), radio-telemetry, X-ray radiography and computed tomography, sodar and sonar (Lima et al., 2020; Reynolds and Riley, 2002).

Further studies are needed to distinguish different species, stages of insect development and their movement pattern vis-à-vis the acoustic characteristics of stored rice commodity. The development of algorithms and acoustic indicators for infestation likelihood at farmers' storage system would be an important component of the study. Developing a portable platform of storage pests detection will capacitate farmers and women in Asia to contribute to food security, health and nutrition, and sustainable livelihood for the farming community. An insect-monitoring system that is accessible via handheld mobile devices such as smartphones is aimed to be developed as a final product of this study.

## Research Questions and Objectives

The study focuses specifically on the development of an algorithm for the InsectTap system for the early detection of insect pests on stored rice in bags and the technical adaptation to the specific site conditions. Low-cost micro-electro-mechanical system (MEMS) microphones will be used to monitor acoustic signals emitted by storage insects in rice. Different types of insect attractants (i.e., smell lures, light, electro-mechanical attractant, warm environment) will be used simultaneously with MEMS microphones to optimize sensor application and minimize the number of acoustic sensors deployed in the grain bulk.

The research questions to be addressed are:

(1) What is the most effective insect attractant method for storage pests in rice that can be used alongside acoustic sensors?

(2) What are the specific sound characteristics of important storage pests in rice?

(3) Can the pests be sufficiently classified both qualitatively and quantitatively?

(4) Can mixtures of different pests also be reliably detected and quantified?

(5) How strong are the site-specific deviations and do they have an impact on the reliability of the pest classification and detection?

These relevant questions will guide in the development of a prototype device that can be further developed into systems for small and large applications.

**Methodology**

The research work will be conducted as part of a PhD study in collaboration with the University of Kassel. Collection and culture of important rice storage pests will be conducted at IRRI-Philippine which are to be used for measurement of acoustical properties and analysis of sound patterns using affordable Micro-Electro-Mechanical System (MEMS) microphones.

Laboratory experiments at IRRI-Philippines will be conducted to measure the sound characteristics of identified insect pests of rice at storage with the current system in conjunction with the use of attractants (see Figure 1). The InsecTap developed at the University of Kassel will be adapted, with components to be purchased in Germany. Four-types of insect attractants will be used which will be strategically placed alongside MEMS microphones in the GrainSafe storage with 1 ton rice grains which will not be sealed on top. The four types of insect attractants are based on the following:

a) Electro-mechanical vibration
b) LED light
c) Temperature attractant
d) Odor attractant

Common species of insect pests in stored rice such as red flour beetle, lesser grain borer and rice weevil  of equal numbers (50 insects) will be placed in stored rice grains in GrainSafe bag. Four units of acoustic sensor using MEMS microphones set-up equidistantly on the side of the

GrainSafe bag with 1 ton of rice grain will be used to monitor the storage insects based on their sound signature.

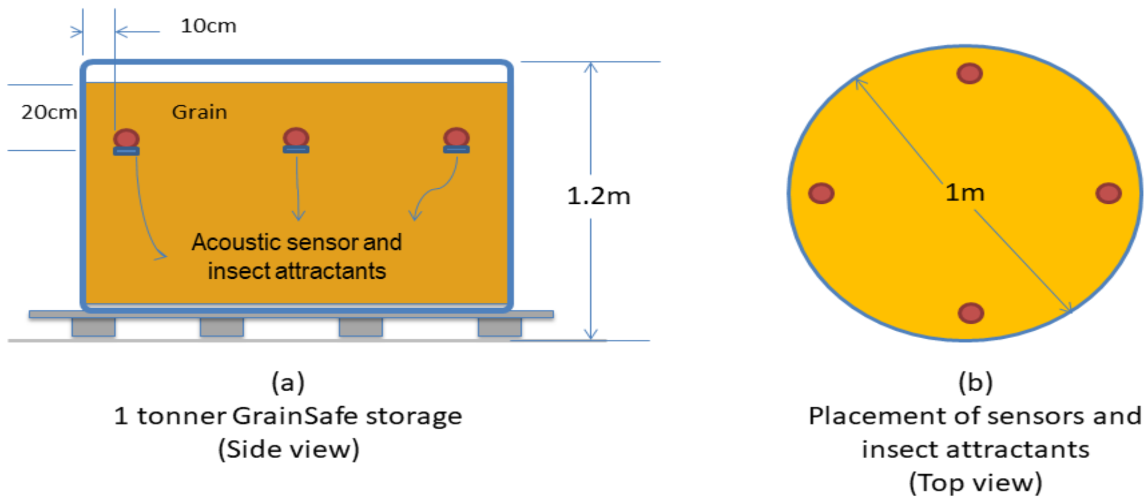


Fig. 1. Placement of acoustic sensors and insect attractants in GrainSafe rice storage.

The acoustic detection system for rice storage pests will also be set-up for remote access and applications by adapting an open-source remote sensing technology and ICT solutions such as the HIVE Monitoring System developed by the Smart Apiculture Management Services (SAMS) project. The system will be integrated in a handheld device for remote applications. Field testing will be conducted at IRRI-Philippines and at various project sites of Closing Rice Yield Gaps in Asia with Reduced Environmental Footprint project (CORIGAP).

A. Materials

The materials to be used in the conduct of this research are summarized in the matrix below.

Table 1. Necessary supplies and materials to be used in the study.

| Item No. | Quantity | Description | Purpose/Reference |
|---|---|---|---|
| 1 | 1 | GrainSafe, commercial 1 ton capacity storage system from GrainPro, Inc. | For rice storage |
| 2 | 1 | Air blower/heater tube | To establish a spot of favorable temperature environment for insects in the grain storage as attractant, e.g., at 35°C (Arthur and Casada, 2005) |

| | | | |
|---|---|---|---|
| 3 | 1 | Set of Red LED lights | To be used as insect attractant (Park and Lee, 2017) |
| 4 | 1 | Wheat/Coconut oil | To be used as odor attractant for insect (Dooley et al., 2018) |
| 5 | 1 | Vibration exciter/electro-magnetic shaker | For initiating vibratory communication signal as insect attractant (Polajnar et al., 2014; Zgonik, 2013) |
| 6 | 4 | InsecTap (using MEMS microphones) | For acoustic detection of insect pests in rice |
| 7 | 1 | Mobile GSM WiFi router | For sending data to the internet for remote monitoring |
| 8 | | F1 culture of storage insect pests of rice (e.g., lesser grain borer, red flour beetle and rice weevil) | Subject for determining/establishing acoustic signature of storage insects in rice (during movement, eating, etc.) |
| 9 | 1 | Acoustic shielding chamber | A portable chamber for measuring acoustic signals of insect samples (Njoroge, 2017) |
| 10 | | Assorted software packages and devices for signal analyses (e.g., MATHLAB, DAVIS, oscilloscope, etc.) | For analyzing acoustic signals obtained from the insects |

B. Methods

The experiment will be replicated three times, when measuring acoustic signals of rice insect pests in storage. Statistical analysis on the data will be conducted using statistical software (e.g., MATHLAB, IRRI's STAR software).

The evaluation of the four different types of insect attractant for stored rice will be conducted in two replicates during the same season at IRRI-Philippines.

Detection algorithms will be adapted at University of Kassel based on the data collected at IRRI on the acoustical properties and sound patterns. The algorithms are mandatory inputs for the detection system to be developed that is applicable for storage pests of rice. The latest machine learning techniques will be used for the recognition of signals and development of algorithms and integration into a handheld device for remote monitoring applications.

The developed prototype will be tested at IRRI in a controlled laboratory and will be further tested in the field for stored rice in bags with mixture of different insect species. The system to be developed can be connected to a wi-fi-router or GSM phone to transfer data from a monitoring unit to a data warehouse that is integrated with a handheld device to conduct automated measurement of rice insect pests even in remote storage facilities. This will enable farmers and industries to be alerted at the onset of infestations and implement appropriate and early measures of controlling insect infestations of rice crop in farmers' storages and in strategic rice warehouses, hence, preventing huge losses and help reduce food shortages in the future.

## Expected Results

The study will adapt the current insect acoustic detection system developed at University of Kassel and develop a hand-held acoustic measurement system that is able to distinguish several adult insect pests to species level and potentially species composites through an algorithm that enables reliable detection of acoustical properties of storage insect pests. The use of suitable attractants for insect pests in stored rice will also be evaluated under the premise of optimizing the use of acoustic sensors in the grain bulk. The established working prototype of acoustic sensors will be further developed into systems for small and large-scale applications and test the sensors and interfaces that will allow the use of the system with mobile phones.

## Work Plan (with Gantt Chart)

The first year of study will be devoted to the collection and culturing of most important storage pests in rice, recording and analysis of insect sound pattern in rice and background noises, determination of acoustical properties of rice and evaluation of suitable attractants for insect storage pests of rice.

On the second year, the work will focus on the adaption and classification of algorithms and the conduct of controlled tests with prototype and integration with a handheld device. Field testing of the prototype will be done on this year and the test with different insect pest species. The analysis of initial data gathered will be done once the data are available.

The final year of study will be dedicated to completion of data analysis and writing of the manuscript and InsecTap with a handheld version prototype for remote monitoring insect pests of rice in storage. The Gantt chart indicate the timelines and milestones of the PhD study as shown in Table 2.

| ACTIVITIES | 2021 | | | 2022 | | | | | | | | | | | | 2023 | | | | | | | | | | | | 2024 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S |
| 1. Collection and culturing of most important storage pests in rice at IRRI-Philippines. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2. Determination of acoustical properties of rice and evaluation of four types of attractants. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3. Recording and analysis of insect sound pattern in rice. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4. Detection of common background noise. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5. Adaption and classification of algorithms. Development and initial testing of prototype of InsecTap handheld version. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6. Controlled tests with prototype. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7. Field tests with prototype. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 8. Tests with species mixtures. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 9. Analysis of data gathered. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 10. Writing of manuscript. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

**References:**

Anukiruthika,T.; Jian, F.; and Jayas, S. Movement and behavioral response of stored product insects under stored grain environments - A review. Journal of Stored Products Research. Volume 90, January 2021, 101752. https://doi.org/10.1016/j.jspr.2020.101752

Arthur, F.H.; and Casada, M.E. Feasibility of Summer Aeration to Control Insects in Stored Wheat. Applied Engineering in Agriculture, Vol. 21(6): 1027-1038. 2005 American Society of Agricultural Engineers ISSN 0883-8542.

Banga, S.; Kotwaliwale, N.; Mohapatra, D.; Babu, V.B.; Giri, S.K.; and Bargale, P.C. Assessment of bruchnids density through bio-acoustic detection and artificial neural network (ANN) in bluk stored chickpea and green gram. Journal of Stored Products Research, Volume 88, September 2020, 101667. https://doi.org/10.1016/j.jspr.2020.101667

Boyer, S.; Zhang, H.; and Lempérière, G. A review of control methods and resistance mechanisms in stored-product insects. Bulletin of Entomological Research, Volume 102, Issue, April 2012, p. 213–229. https://doi.10.1017/S0007485311000654

Campbell, J.F. Attraction of waling *Tribolium castaneum* adults to traps. Journal of Stored Products Research 51 (2012) 11-22.

Campbell, J.F., and Hagstrum, D.W. Patch exploitation by *Tribolium castaneum*: movement patterns, distribution, and oviposition. Journal of Stored Products Research 38 (2002) 55-68.

Dooley, M.; Peel, A.D.; and Wakefield, M. The response of *Tribolium castaneum* to wheat germ oil and fungal produced volatiles. 12th International Working Conference on Stored Product Protection (IWCSPP) in Berlin, Germany, October 7-11, 2018. DOI 10.5073/jka.2018.463.033

Fiedler, S.; Kirchner, S.; and Eckey, A. High-fidelity HIVE Prototype Design Report. Project No. 780755, International Partnership on Innovation, Smart Apiculture Measurement Services (SAMS), University of Kassel, Faculty of Organic Agricultural Sciences, Agricultural and Biosystems Engineering. Prof. Dr. Oliver Hensel, Head of Department and Project Lead, 05 August 2019.

Hagstrum, D.W.; Webb, J.C., and Vick, K.W. Acoustical detection and estimation of *Rhyzopertha dominica* (F.) larval populations in stored wheat. The Florida Entomologist, Vol. 71, No. 4 (Dec., 1988), pp. 441-447. Stable URL: http://www.jstor.org/stable/3495003

Hagstrum, D.W.; Vick, K.W, and Webb, J.C. Acoustical monitoring of *Rhyzopertha dominica* (Coleoptera: Bostrichidae) Populations in Stored Wheat. Journal of Economic Entomology, Vol. 83, No. 2 (April, 1990), pp. 625-628.

Hodges, R.J.; Buzby, J.C.; and Bennett, B. Postharvest losses and waste in developed and less developed countries: opportunities to improve resource use. Journal of Agricultural Science, 149 (S1), February 2011, pp. 37-45. doi:10.1017/S0021859610000936

Kirchner, S.M.; Müller-Blenkle, C.; Adler, C.; and Hensel, O. Early detection of insect pests in silos by acoustics methods (InsectTap). Presented at the Proceedings of the BLE Innovationstage 2016 (Germany), Bonn (pp. 160-163). Bundesanstalt für Landwirtschaft und Ernährung (BLE)

Kirchner, S.M.; Müller-Blenkle, C.; Adler, C.; and Hensel, O. Robuste Klassifizierung von Lagerschädlingen anhand ihrer Geräuschsignatur - Grundlage für die Umsetzung eines akustischen Detektionsverfahrens. 60. Deutsche Pflanzenschutztagung, Halle, 20-23 September 2016.

Lima, M.C.F.; de Almeida Leandro, M.E.D.; Valero, C.; Coronel, L.C.P.; Bazzo, C.O.G. Automatic Detection and Monitoring of Insect Pests – A Review. Agriculture 2020, 10, 161; doi:10.3390/agriculture10050161

Mankin, R.W.; Jetter, E.; Rohde, B.; and Yasir, M. Performance of a low-cost acoustic insect detector system with *Sitophilus oryzae* (Coleoptera: Curculinidae) in stored grain and *Tribolium castaneum* (Coleoptera: Tenebrionidae) in flour. Journal of Economic Entomology, 113(6), September 2020, pp. 3004-3010. doi: 10.1093/jee/toaa203

Miles, C.I.; Allison, B.E.; Losinger, M.J.; Su, Q.T.; and Miles, R.N. Motor and mechanical bases of the courtship call of the male treehopper *Umbonia crassicornis*. Journal of Experimental Biology (2017) 220, 1915-1924. DOI:10.1242/jeb.147819

Ni, X.; Gunawan, G.; Brwon, S. L.; Sumner, P.E.; Ruberson, J.R.: Buntin, D.G.; Holbrook, C.C.; Lee, D.R.; Streett, D.A.; Throne, J.E.; and Campbell, J.F. Insect-Attracting and Antimicrobial Properties of Antifreeze for Monitoring Insect Pests and Natural Enemies in Stored Corn. Journal of Economic Entomology, April 2008, Vol. 101, n0.2, pp. 631-636. https://www.researchgate.net/publication/5394422

Njoroge, A.W. Acoustic detection of insect pests of stored grains in Kenya. Dissertation. Witzenhausen 2017. University of Kassel. Available online:

http://34.250.91.188:8080/xmlui/bitstream/handle/123456789/660/DissertationAnastasiaNjoroge%281%29.pdf?sequence=1&isAllowed=y

Njoroge, A.W.; Affognon, H.; Mutungi, C.; Rohde, B.; Richter, U.; Hensel, O.; and Mankin, R.W. Frequency and time pattern differences in acoustic signals produced by Prostephanus truncatus (Horn) (Coleoptera: Bostrichidae) and Sitophilus zeamais (Motschulsky) (Coleoptera: Curculionidae) in stored maize. Journal of Stored Products Research 69, October 2016, pp. 31-40. http://dx.doi.org/10.1016/j.jspr.2016.06.005

Park, J.H.; and Lee, H.S. Phototactic behavioral response of agricultural insects and stored-product insects to light-emitting diodes (LEDs). Appl Biol Chem (2017) 60(2): 137-144. DOI 10.1007/s13765-017-0263-2

Polajnar J.; Eriksson, A.; Lucchi, A.; Anfora, G.; Virant-Doberlet, M.; and Mazzoni, V. Manipulating behaviour with substrate-borne vibrations – potential for insect pest control. Wiley Online Library, 16 July 2014. DOI 10.1002/ps.3848

Prešern, J.; Polajnar, J.; de Groot, M.; Zorovic, M.; Virant-Doberlet, M. On the spot: utilization of directional cues in vibrational communication of a stink bug. Scientific Reports (2018)8:5418. DOI:10.1038/s41598-018-23710-x

Reimer, A.; Wiebe, K.; Rao, J.; Yao, B.; Gui, Y.; Jian, F.; Fields, P.; Jayas, S.; and Hu, C.M. A compact microwave device for monitoring insect activity in grain samples. Biosystems Engineering. Volume 175, November 2018, Pages 27-35. https://doi.org/10.1016/j.biosystemseng.2018.08.010

Reynolds, D.R.; and Riley, J.R. Remote-sensing, telemetric and computer-based technologies for investigating insect movement: a survey of existing and potential techniques. Computers and Electronics in Agriculture 35 (2002) 271-307.

Riaz, T.; Shakoori, F.R.; and Ali, S.S. Effect of Temperature on the Development, Survival, Fecundity and Longevity of Stored Grain Pest, *Trogoderma granarium*. Pakistan Journal of Zoology, vol. 46(6), pp. 1485-1489, 2014.

Sheikh, A.F.; Thomas, M.; Bhandari, R.; and Bunkar, K. Light trap and insect sampling: An Overview. International Journal of Current Research, Vol. 8, Issue 11, pp. 40868-40873, November 2016.

Weinzierl, R.; Henn, T.; Koehler, P.G.; and Tucker, C.L. Insect Attractants and Traps.University of Florida IFAS Extension, ENY277. Available at http://ufdcimages.uflib.ufl.edu/IR/00/00/27/94/00001/IN08000.pdf

Zgonik V.; and Cokl, A. The role of signals of different modalities in initiating vibratory communication in *Nezara viridula*. Central European Journal of Biology 9(2), 2014, 200-211. DOI: 10.2478/s11535-013-0253-2