

## Portable acoustic device for detection of coconut palms infested by *Rynchophorus ferrugineus* (Coleoptera: Curculionidae)

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### ABSTRACT

Acoustic methods have been developed and used to detect insects in concealed habitats. The larvae of red palm weevil, *Rynchophorus ferrugineus* (Olivier), a serious pest of the coconut palm, *Cocos nucifera* L. feed on the soft tissues inside the stem and bud region. Detection of infested coconut palms in the early stages by the conventional method of checking for external symptoms is time consuming, labour intensive and costly. This paper describes the development of a portable and efficient acoustic device and its potential in detection of infested palms in the field. The device comprises a sensor to mount on the palm and to acquire the sounds of red palm weevil larvae, an electronic unit that processes the acquired sounds and a set of headphones to receive the output sound by the listener. It is light weight, user-friendly and powered by batteries. The highest accuracy of identifying infested palms was obtained when the palm was checked at four positions; either side of palm base and bases of the two lowermost leaves. The infested palms were detected with over 97% accuracy, while the probability of not detecting uninfested palms was over 92%. A second check increased the rate of accuracy. Many difficulties encountered with conventional methods could be overcome by the use of this device.

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### 1. Introduction

Red palm weevil, *Rynchophorus ferrugineus* Olivier (Coleoptera: Curculionidae), is a widespread pest of palms in Asia, the Middle East and the Mediterranean region. In Sri Lanka, it is the most serious pest causing fatal damage to young coconut palms (*Cocos nucifera* L.) of 3–10 years of age (Brand, 1917; Kirthisinghe, 1960). It has been estimated that 10% of young coconut palms in the country are lost annually due to its attack (R. Mahindapala pers comm.). Accordingly, during the period of 2000–2005, nearly 200,000 young palms have been killed by red palm weevil resulting in a financial loss of about US \$ 1,800,000. Such a significant loss is unaffordable for an important food plant providing 22% of daily caloric intake of the diet, a commercial plantation crop contributing 13.4% to the Gross National Product of total Agriculture and a multipurpose plant providing inputs to many coconut-based industries in the country (Anonymous, 2007).

Red palm weevil larvae hatching out from eggs deposited on fresh wounds of palms, burrow into and feed on the soft tissues causing their destruction and leading to obstruction of water and nutrient flow. The external symptoms of the infestation are rarely visible at the very early stages, when smaller numbers of larvae are present. Often, the symptoms become obvious in the advanced stage of infestation, when the leaves become yellowed and bud withers, damage from which the palm cannot recover. Nevertheless, one or few symptoms such as small holes on the stem, protrusion of chewed up fibers from the holes, oozing out of a brownish liquid and presence of cocoons on the leaf axils or near the base of the palm may be noted at the moderate stage, if careful examination is made by an experienced person. In most instances, by removing dead leaves and other dry materials to observe these symptoms. But, if the infestation is at the crown region none of the above symptoms may be visible before the palm is killed. Due to severe shortage of labour to carry out routine inspections on each and every individual palm and the time consuming nature of this practice, implementation of control methods are not being carried out at all or are delayed.

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When the larvae are present in the palm they produce sounds, which are due to chewing of palm tissue, crawling, emission and quick oscillation (Pinhas et al., 2008). If a considerable number of larvae are present these sounds can be heard by placing the ear on the stem of the palm. However, at this stage palm may be moderately to extensively damaged. Hence, detection of infestations at an early stage is important to save the palms with less damage.

Acoustic methods have been developed and used to detect insects in concealed habitats; larvae in plant stems (Mankin et al., 1996, 2004), termites in wood (Scheffrahn et al., 1993; Mankin et al., 2002), adults and larvae of stored grains (Vick et al., 1988; Hagstrum et al., 1996) and insects in soil (Mankin et al., 2000; Zhang et al., 2003). Utilization of sound methodology to detect red palm weevil infested date palms has been attempted (Soroker et al., 2004; Al-Manie and Alkanhal, 2005; Pinhas et al., 2008). An electronic device to detect infested coconut palms, although with less reliability and efficiently, has been developed in Sri Lanka (Fernando pers. comm.). Pinhas et al. (2008) developed a prototype that could detect larvae of red palm weevil in offshoots of date palms, which could be used in inspection of horticultural and ornamental palms traded between countries, but this device is not portable, hence it could not be used in field inspections. Although, Al-Manie and Alkanhal (2005) have developed a hand held instrument to detect red palm weevil larvae in date palm trees, it needs to be connected to a portable PC which has to be carried in the field for data acquisition and is practically impossible to use in large fields.

This study aimed to develop and test an efficient and portable acoustic device that could be used to detect red palm weevil infested palms reliably, in field conditions.

## 2. Materials and methods

### 2.1. Acoustic recording and analysis

As the first step of the recording process a simple electronic device with considerable amplification, but without any filtering was developed to capture the acoustic sounds of the red palm weevil larvae inside palm stems. A magnetic cartridge head was used as the sensor for this device. The cartridge was pressed on to the palm stem and held in place by laying a strip of hard paper over it with 2 pins pushed on to the stem at either sides of the strip. The output was directed to a computer installed with a digital audio editing and sound utilization software, Cool Edit Pro 2000. Recordings were made from each of 5 palms of 5-years of age at different test conditions; three artificially infested palms with a known number of red palm weevil larvae, one naturally infested palm with unknown number of larvae and one uninfested palm in the coconut plantation at the Coconut Research Institute of Sri Lanka. The artificially infested palms were introduced with each of 5, 10 and 15 of medium-sized red palm weevil larvae, 3 days before the recording. Infestation was done by making 3 holes of 3 cm diameter and 5 cm depth in the palm stem 45 cm above ground level and inserting the larvae into the holes after which they move inside. After all larvae were inside the stem, the holes were covered with a fine metal mesh and later with a mixture of cement and sand mortar. Sound waves were recorded at 30 cm above the point of infestation. A total of 5 wave files of 50–60s, were recorded from each category of palms. The recording was carried out in an early morning when other environmental noises were minimal.

Sound profiles were subjected to time-frequency wavelet analysis to relate the spectral frequencies available in the unique acoustic signature of red palm weevil larvae to its time of occurrence. A personal computer installed with MATLAB 6 (Release 13) software was used for the analysis. The samples of the signals were

stored in a format based mainly on coefficients, which gives a better understanding about the digital signature of the red palm weevil sound.

### 2.2. Development of the acoustic detector

The acoustic device essentially consisted of a sensor to acquire the sound signals from an infested palm, a signal processing unit to capture and amplify the sound acquired by the sensor while filtering out the environment noise signals and an output device that allowed the user to determine whether the palm was infested or not. Also, as a portable field device it needed to be compact, light weight and convenient to use. After several pre-tests and modifications, a detector with these features was developed. Additionally, it featured a play back of a pre-recorded sound clip of red palm weevil larvae, which can be used to self-train users.

#### 2.2.1. Sensor

The sensor used to collect sound recordings from the trees was difficult to mount on the stem. Therefore, in this study a new sensor made of a piezoelectric transducer sandwiched together with two circular stainless steel discs of 4 cm diameter was developed. One side of the disc was welded with a 1 cm long pin and the other side with a ring. The sensor was moulded using locally available material.

#### 2.2.2. Signal processing unit

Based on the sound profiles obtained from the acoustic recordings and subsequent identification of the unique acoustic signature of red palm weevil larvae, an embedded signal processing circuit to filter out the sounds of red palm weevil larvae from other sounds such as twisting of the leaves due to wind, activities of other insects on the palm and environmental noises, and to amplify the filtered signal was developed (Fig. 1).

In the first stage, sounds emitted from the sensing unit were amplified and reconditioned as required by the band pass filter stage. A high gain low noise amplifier was selected to assure the quality of the output. The signal from the input amplifier was then band limited to remove unwanted sounds using a cascaded band pass filter. An eighth order band pass filter was implemented with an effective pass band of 800–2500 Hz, which has been identified as the effective frequency range of the red palm weevil acoustic emissions. The circuit was a continuous time active filter consisting of independent cascaded 2nd order sections. Each section can be implemented to achieve any filter characteristic and programmed by four external resistors, providing low noise operation and superior dynamic performance due to the continuous time design. The sound extracted by the unit was amplified to drive a 32 ohm headphone set.

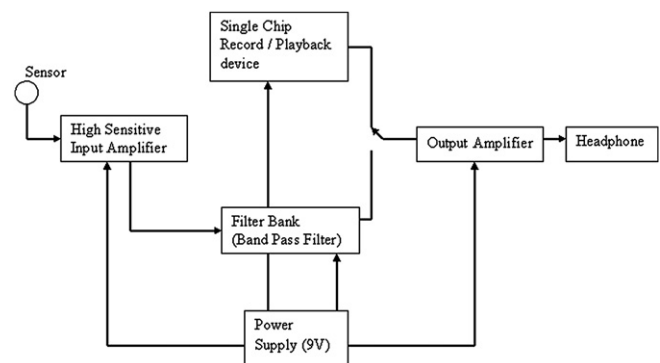


Fig. 1. Functional block diagram of the signal processing system.

The signal processing unit was also integrated with a pre-recorded sound clip of the acoustic sound. The sound recordings used for the development of the device was used for the sound clip also. The information storage chip recorder provides high quality single chip record/playback solution for 60s messaging applications.

### 2.3. Field studies

Field studies were carried out in plantations infested by red palm weevil to determine a suitable position for the placement of the sensor on the infested palms that would effectively detect the presence of larvae and maximize the accuracy of the device in detecting infested palms.

#### 2.3.1. Determination of a suitable position for placement of the sensor

The study was carried out in two estates at Badalgama (Gampaha District, Western Province, Sri Lanka) and Pimburettewa (Polonnaruwa District, North-central Province, Sri Lanka). In each estate, red palm weevil infested blocks comprising of young palms were selected and all palms were checked using the device. Generally, the palms vulnerable to red palm weevil attack are between ages 3 and 8 years of age, hence heights of the palm stems were up to about 2.4 m. On each palm, the sensor was mounted on 4 positions; either side of the base of the stem (positions A and B) and on the leaf bases of the two lowermost fronds (positions C and D) because a previous study had indicated that placing the sensor on these 4 positions would enable detection of infested palms. The sensor was mounted on the palm by pressing the needle of the sensor on each position. On each palm, the sensor was mounted on each of the above-mentioned positions for about 30s and the presence or absence of larvae was determined by the sound heard from the earphones. The main sounds produced by the larvae resemble the sounds of breaking dry twigs or disturbing a heap of twigs. A total of 549 palms were checked in this manner. Afterwards, each palm was cleaned by removing dry fronds and other debris and presence of any red palm weevil damage symptoms on the stem or canopy was recorded. Generally, infested palms show external symptoms if thoroughly examined except, at the very early stage of infestation. Hence, for this study it was assumed that only palms with at least a slight damage symptom were infested by red palm weevil.

#### 2.3.2. Determination of accuracy of the device

Two studies were carried out to determine the accuracy of the device. For Study 1, the data collected from the 549 palms for determining the suitable position of the sensor was used. In those palms, if the sound of red palm weevil was detected at any of the positions, but the symptoms were absent, then the palm was marked for subsequent checking. Those palms were rechecked in the same manner 3–4 weeks later, allowing a period for development of symptoms if the pest was present.

In study 2, the device was tested in heavily infested blocks at Nagahawatte estate (Puttalam District; North-western Province, Sri Lanka) and Mahaweli Coconut Plantation (Polonnaruwa, North-central Province, Sri Lanka). One hundred and fifty nine palms were each checked as described for the previous experiment. Symptoms present on the palms were recorded as 'clearly visible' and 'hardly visible' to the grower.

### 2.4. Statistical analysis

It was assumed that all infested palms show at least a slight external damage symptom at the time of testing, although this may

not always be the case, especially at the very early stages of infestation. The reliability of the device was assessed by the following two statistical indicators;

- (a) Index 1 = 100 \* [Probability of detecting the presence of the pest by the device when the damage symptoms were present]
- (b) Index 2 = 100 \* [Probability of not detecting the presence of the pest by the device when the symptoms were not present]

Thus, if both indices were high it confirmed that the device was effective. The data was analysed using 2-way frequency tables and based on those tables the above indices were computed. For determining the suitable position, the probabilities at each position (A, B, C, D), two positions (A&B, B&C) and all 4 positions (A&B&C&D) were calculated. For determining the accuracy of the device only data on all 4 positions was considered.

## 3. Results

### 3.1. Sound recordings and analysis

A sample sound profile of each test condition is given in Fig. 2. Irrespective of the number of larvae present in the infested palms the highest amplitude of the acoustic sound was found in the frequency band of 500–1000 Hz. The uninfested palm did not yield any significant noise.

Data coefficients extracted from time-frequency wavelet analysis also showed a clear difference in the coefficient values of infested (0.3451 and 0.6588) and uninfested (0.0062) trees and it was possible to distinguish sounds of red palm weevil larvae from the rest of the signals. Since, signal processing by this method requires a high powered personal computer, the results of this analysis was not utilized in developing the device, which is intended to be light weight, portable and provide instant output of the red palm weevil sound.

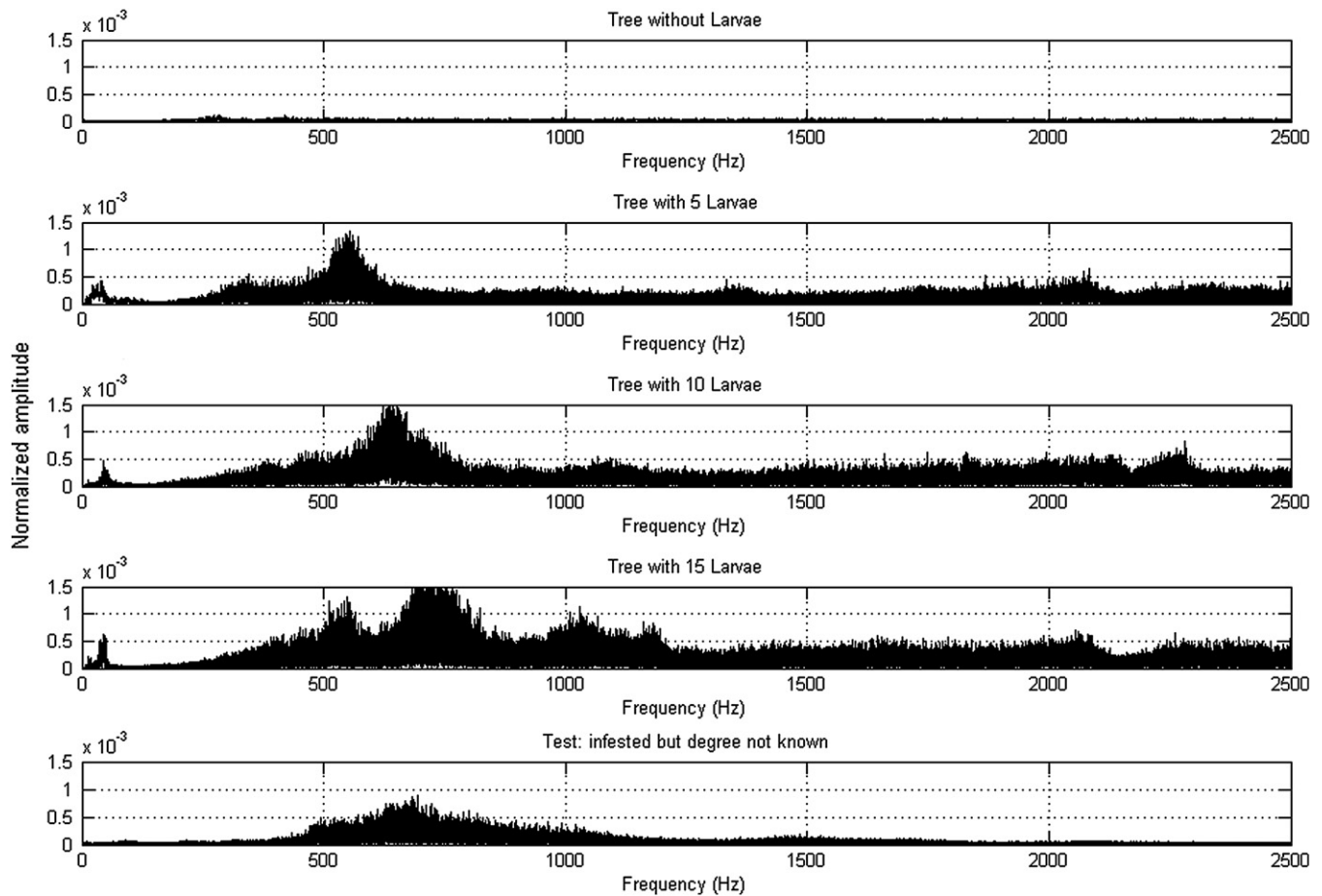
### 3.2. Acoustic device

The device comprising of the sensor, main unit and the set of headphones is shown in Fig. 3. The sensor could be easily mounted on the palm by pressing the needle on to the required position of the stem. The main unit is compact, 11 × 6.5 × 2.5 cm in size and 120 g in weight and powered by two 9 V batteries, which could be easily replaced from the back casing. There are separate knobs with indicators to turn on/off the device and to play the pre-recorded sound clip. The pre-recorded sound clip is playable at any time by the user. It can be used for self-training activities of the farmers, so that decisions can be made by comparing the sounds listened from the unit and the pre-recorded sound.

### 3.3. Field studies

#### 3.3.1. Determination of a suitable position for placement of the sensor

Out of the 549 palms checked, 27 palms showed damage symptoms. Those palms were correctly detected (larval sound present) by the device (Index 1) at various probabilities when the sensor was placed at different positions (Table 1). The highest accuracy of 100% was obtained when checked at all 4 positions. The palms without damage symptoms were not detected as pest present (Index 2) at very high probability levels (Table 1). In contrast to the detection of infested palms, the accuracy of not detecting palms without symptom reduced when the sensor was placed on more than one position, with the lowest probability at all 4 positions.



**Fig. 2.** The frequency spectrum of sounds for five different test conditions. From top to bottom, a tree free from weevil infestation, a tree with five red palm weevil larvae, a tree with 10 larvae, a tree with 15 larvae, and a tree with unknown number of larvae.

### 3.3.2. Determination of accuracy of the device

At the first observation of study 1, all the 27 palms that showed symptoms were detected as infested by the device (Index 1 = 100%). But, out of 522 palms without symptoms, only 492 palms were accurately detected as uninfested (Index 2 = 94.2%). Thirty palms without symptoms were misclassified as infested (Table 2). At the second observation, 2 of these palms developed

symptoms and detected as infested indicating the ability of the device to detect infested palms, even before symptoms are visible. Out of the 30 palms without symptoms, 21 were confirmed as not infested increasing the index 2 to 98.6%. However, 9 symptomless palms were still misclassified as infested.

Out of the 159 palms checked in study 2, 103 palms showed symptoms of infestation. Of these, 97.1% palms (Index 1) were accurately detected as infested. Also, out of 56 palms without symptoms, 92.9% (Index 2) were correctly detected as uninfested (Table 3). Out of the 103 palms that showed symptoms of the damage, 28 palms showed only very slight symptoms such as formation of gum from the liquid oozed out from the tissues, which could be easily missed by the grower checking palms by the conventional way.



**Fig. 3.** The acoustic device comprising the sensor, main unit and the set of headphones.

**Table 1**

Probabilities of correctly detecting palms with symptoms and without symptoms of red palm weevil infestation at different positions by the device.

Position	Percentage palms correctly detected	
	Symptoms present (Index 1)	Symptoms absent (Index 2)
A	70.4	97.8
B	66.7	98.2
C	44.4	98.1
D	29.6	97.5
A&B	70.4	97.3
C&D	44.4	96.7

A and B – either side of stem base, C and D – bases of the two lowermost leaves.

**Table 2**

Frequency of detecting palms with and without symptoms of red palm weevil infestation at all four positions at the first observation in study 1.

Status of palms	Detected	Not detected	Total
<i>Symptoms present</i>			
No. of palms	27	0	27
Percentage out of all palms	4.9	0.0	4.9
Percentage out of all palms with symptoms	100	0.0	
Percentage out of all palms detected/not detected	47.3	0.0	
<i>Symptoms absent</i>			
No. of palms	30	492	522
Percentage out of all palms	5.5	89.6	95.1
Percentage out of all palms without symptoms	5.7	94.2	
Percentage out of all palms detected/not detected	52.6	100.0	
Total	57	492	549
	10.4	89.6	100.0

#### 4. Discussion

The acoustic device developed has a very high accuracy (over 97% in this study) in detecting red palm weevil infested palms, when checked on either side of the stem base and bases of the two lowermost leaves. The use of the device has many advantages over the conventional methods currently in use to detect infested palms. Saving of time and cost of labour are the biggest advantages and it is unnecessary to clean the palms to check for symptoms as required currently. Also, a single palm could be checked in about 30s, which is considerably less than the time spent in checking for symptoms by the conventional way. The device can detect infested palms, even before they show external damage symptoms and when slight damage symptoms such as presence of gum, which could be easily missed out by external examination. Hence, early detection by using the device allows early treatment.

However, there was a low probability (<3%) of misidentifications of infested palms as well as uninfested palms (<8%). Generally, red palm weevil larvae do not make sounds continuously and have resting periods. If there are a large number of larvae inside the trees, resting periods of individual larva may not overlap and do not affect the overall sounds produced. If few larvae are present in the palm and if most of the pest is at the pupal stage, there is

**Table 3**

Frequency of detecting palms with symptoms and without symptoms of red palm weevil infestation by the device in study 2.

Status of palms	Detected	Not detected	Total
<i>Symptoms present</i>			
No. of palms	100	3	103
Percentage out of all palms	62.9	1.9	64.8
Percentage out of all palms with symptoms	97.1	2.9	
Percentage out of all palms detected/not detected	96.1	5.5	
<i>Symptoms absent</i>			
No. of palms	4	52	56
Percentage out of all palms	2.5	32.7	35.2
Percentage out of all palms without symptoms	7.1	92.9	
Percentage out of all palms detected/not detected	3.9	94.5	
Total	104	55	159
	65.4	34.6	100.0

a possibility that they will not be producing sounds during the period of checking and will be missed. The sound frequencies produced by movement of small insects, such as ants inhabiting the coconut palms and swaying of coconut leaves due to light breezes may lie in the range of the frequency emitted by the red palm weevil larvae. In such cases, there is a possibility of misidentifying an uninfested palm. It was shown that the rate of misclassification of palms could be reduced if a second round of checking was done 3–4 weeks later. Also, better results could be achieved by carrying out the checking at times when environmental noises are low.

This device is portable and convenient for use in the field. It is a self contained unit in which in-built filters and microprocessors carry out the required signal processing and allowing the farmer to determine whether the palm is infested or not instantly. Hence, it is unique and a further step forward in the development of an acoustic device to detect red palm weevil infested palms compared to other devices already available, which either require carrying a computer with high processing power to provide the output instantly or the output is provided later, after signal processing where the farmer could not determine the status of the palm instantly (Pinhas et al., 2008; Al-Manie and Alkanhal, 2005). This device could be carried in the pocket of the user and easily operated even by an untrained person. The facility of pre-recorded sound clip provides confidence to the user in determining the presence of infestation and provides opportunity to become familiar with the sounds of the red palm weevil whenever required.

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