academicJournals

Vol. 5(6), pp. 77-83, October 2013
DOI: 10.5897/JEN2013.0081
ISSN 2006-9855 ©2013 Academic Journals
http://www.academicjournals.org/JEN

Journal of Entomology and Nematology

Full Length Research Paper

Effect of red palm weevil, *Rhynchophorus ferrugineus* (Olivier) infestation on temperature profiles of date palm tree

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Accepted 24 October, 2013

This study aimed at identifying the impact of red palm weevil (RPW), *Rhynchophorus ferrugineus* Olivier infestation on date palm trees (*Phoenix dactylifera*) in terms of internal temperature changes compared to ambient atmospheric air temperature. Adult weevils as well as sensors of electronic data loggers were introduced inside date palm trees through holes drilled in the tree trunks for measuring internal temperatures at eight levels of infestation period (one to eight weeks). Three levels of forced infestation were used: 1 male: 1 female, 1 male: 2 females, and 2 males: 4 females. A group of date palm trees with only logger's sensors inside were used as a control. Four loggers with their sensors were hung outside on the date palm trees to measure ambient air temperatures during the experiment. Both minimum and maximum temperatures of healthy (uninfested) and infested date palm trees fell within ranges that were always above the minimum and below the maximum ambient temperature for the whole duration of the experiment. The average temperature of infested date palm (32.60°C) was significantly higher than the average temperature recorded at the same time both inside the healthy trees (29.53°C) and in the ambient atmosphere (29.35°C). The average temperature of infested date palm increased slightly with increase in infestation level with the highest being 32.80°C, which was recorded inside date palm infested with 2 males and 4 females, while it was 32.54 and 32.45°C inside trees infested with 1 male and 1 female, and 1 male and 2 females, respectively. It is evident that temperature differences between infested date palm on one side and healthy date palm and ambient atmosphere on the other side could well provide a platform for identifying infested trees. This is a valuable baseline information for further research to develop a real time multi-sensor fusion system for an effective early detection of RPW infestation which is a crucial step in the implementation of successful RPW integrated pest management (RPW-IPM) programs.

Key words: *Rhynchophorus ferrugineus*, date palm, forced infestation, electronic data loggers, temperature profiles, red palm weevil (RPW) early detection.

INTRODUCTION

The red palm weevil (RPW) is one of the worst pests for palms, since it can completely destroy the plant (Abelardo et al., 2010). Globally, the RPW attacks 40 palm species in diverse agro-ecosystems (EL-Sabea et al., 2009). It has its home in South and Southeast Asia where it is a key pest of coconut (*Cocos nucifera*) and is reported from 15% of the coconut growing countries worldwide (Faleiro, 2006). RPW was discovered in Saudi Arabia in mid-1980s and reached the United Arab Emirates in 1985 (Gush, 1997; Abraham et al., 1998;

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Faleiro et al., 1999). It has spread over most of the date palm areas *Phoenix dactylifera* due to the transfer of infested offshoots and palm trees (Bokhari and Abuzuhira 1992; Abraham et al., 1998 Vidyasagar et al., 2000). Currently, RPW is reported from all the continents with ecological niche modeling predicting its spread to new regions (Fiaboe, et al., 2012). The whole larval life cycle of the weevil is concealed within the palm. For *P. dactylifera*, attacks start when females lay eggs on wounds, or cracks and crevices on the trunk around the collar region near the roots or offshoots, or the base of fronds in young date palms, with trees less than 20 years old being most preferred (Dembilio et al., 2012; Faleiro et al., 2012).

Larvae destroy the interior of the palm tree, often without the plant showing signs of deterioration unless damage is severe. Hollowing out of the trunk reduces its mechanical resistance, making the plant susceptible to collapse and a danger to the public (Davis and Moore 2001). The concealed larvae make early detection using traditional methods very difficult until visual symptoms manifest late in the stage of attack. Consequently, infested planting material is often transported for plantation to a new location without the infestation being noticed as the first detectable symptoms of infestation appear later (Mankinet al., 2008).

RPW is managed in several countries using area-wide pheromone based integrated pest management (IPM) programs (Faleiro, 2006). However, the key to the success of any RPW-IPM strategy lies in the early detection of infested palms which respond to treatment with insecticide (stem injection). Besides, elimination of severely infested trees and use of pheromone traps to trap adult weevils has been used to manage the pest with varying degrees of success. The incorporation of the pesticides in irrigation water has also been recommended as a preventive control measure (Soroker et al., 2005). Recent studies from Spain have shown that in the Canary Island palm, the entomo-pathogenic nematode *Steinernema carpocapsae* (Weiser) proved effective against RPW in semi-field trials in both preventive and curative assays (Llácer et al., 2009).

Despite these efforts, infestations due to RPW are on the rise. Early detection plays an important role in the management strategies against RPW and there has been a growing interest in finding and implementing non-destructive methods for detecting insects residing inside plants (Mankin and Fisher, 2002; Mankin et al., 2002; Mankin et al., 2000; Lemaster et al., 1997; Hagstrum et al., 1996; Shuman et al., 1993). Food-baited pheromone traps (FBPTs) are commonly used to detect the red palm weevil, however, this traditional method is labor-intensive, expensive to implement particularly over large areas, and unreliable for early detection (Al-Saqer, 2012). FBPTs require a very high level of servicing, as bait and water need to be replaced regularly (El-Shafie, 2011). FBPTs can trap up to 20% of the weevil population found outside date palm trees and this could provide information about area infestation but not about individual tree infestation, yet it is not a reliable indication of early detection of area infestation, since the captured weevils could have come from a population existing for a long period over so many generations.

Acoustic sensors with special probes are inserted in the palm tree trunk in order to record sounds produced by the insect especially in the early larval stages of its life, where the feeding and other activities of the insect are at their maximum. The acoustic sensors had drawbacks as having low capability of distinguishing sounds produced by larvae from background noise when insects were hidden in stiff, fibrous structures (Mankin et al., 2008). Electronic gas sensors have been used to detect volatile emitted by plants infested by insects. Unfortunately, these sensors are also highly sensitive to the presence of other different compounds such as alcohols, ketones, fatty acids and esters (Magan, 2001). This would negatively interfere with the performance of gas sensors. Therefore, these approaches suffered from limitations that hamper their success in detecting RPW at its early growth stages.

Information on the thermal properties of date palm such as thermal conductivity, thermal diffusivity and specific heat are essential for the development of any sensor intended for automated detection of RPW as an internal feeder of date palm. Studying the interior environment of the infested date palm trees by identifying their temperature profiles and comparing them with those of the non-infested trees and the ambient environment will provide important primary data and information which will enable understanding the internal insect activities, effects, and changes they cause to the date palm internal environment. Moreover, identifying features that allow monitoring of the RPW presence inside date palm trees would pave the way and aid designing and building a multi-sensory electronic system, which would eventually enable early detection of the pest. Consequently, it would help timely pest management to take appropriate measures such as isolating or treating the infected trees. So far, previous research outcomes did not effectively uncover tangible signs and features that confirm the presence of RPW inside date palm trees. Therefore, the present investigation was carried out to quantify the impact of RPW infestation on date palm trees in terms of its internal temperature changes in comparison to those of the uninfested (healthy) trees and of the ambient atmosphere, with the following objectives: 1) to measure the internal environment temperature in infested and healthy date palm trunk and record the ambient atmosphere to get 2-month temperature profiles at fifteen-minute intervals; 2) to find the effects of infestation intensity and time of occurrence on internal tree temperature and ascertain the difference between RPW infested and healthy date palm in relation to the ambient atmosphere and 3) to assess the potentiality of utilizing internal temperature of date palm tree as an indication for detecting RPW infestation at an early stage.

MATERIALS AND METHODS

Adult RPW females and males were captured using insecticide-free pheromone (Ferrolure TM) traps deployed by Directorate of Agriculture in Al-Ahsa, Saudi Arabia. Active weevils were carefully selected from freshly captured collections, placed in perforated plastic containers and brought to the entomology laboratory of the Date Palm Research Center (DPRC). Weevils were sexed based on the presence of a tuff of fine bristles on the dorsal end of the rostrum in males which were absent in females. The collected insects were kept in large plastic containers (40 cm x 27 cm x 25 cm) and were fed *ad libitum* upon sugar cane.

The most popular date palm cultivar (Khalas) in Al-Hasa region was used in this study. Young date palm trees in the age range of 5-10 years were selected, as at this age date palm is most liable to RPW infestation (Abraham et al., 1998; Sallam et al., 2012). The selected date palm trees were transplanted in a well isolated, insect-proof lath house (mesh house), two months prior to the start of the experiment. It was assumed that the date palm in this house were similar to those grown under open environment except for the light shade provided by the mesh. Palms in the trial were forced infested. Adult weevils as well as sensors of data loggers were introduced inside the date palm tree through holes made by an electric drill. Three levels of forced infestation were used: 1 male: 1 female (infection 1), 1 male: 2 females (infection 2), and 2 males: 4 females (infection 3). A group of date palm trees with only loggers' sensors inside were used as a control representing the healthy (uninfected) trees. Four loggers with their sensors were hung on the outside of the date palm trees to measure ambient air temperatures during the experiment. The experiment treatments were replicated four times. Electronic data loggers of type Tinytag made by Gemini of UK were programmed to measure temperatures of infested and non-infested (control) trees and the surrounding atmosphere for a period of two month (Sep. 16 – Nov. 12, 2012) at 15 min intervals.

Statistical analysis

Treatments were arranged in a complete randomized design with two factors (time in weeks having 8 levels, and infestation intensity having 5 level); each treatment was replicated four times. Temperature values for the two month period were tabulated into weekly averages and inputted for statistical analysis. Matlab statistic toolbox was used to subject data to analysis of variance (ANOVA), separation of means using the least significant difference (LSD), performance of a multiple comparison test between treatment means, and looking for interactions between factors.

RESULTS AND DISCUSSION

Compared to the ambient atmospheric temperature, both minimum and maximum temperatures of uninfested (healthy) and infested date palm trees fell within small ranges; 22.40 to 36.59, and 25.03 - 37.39°C, respectively. Moreover, these ranges were always above the minimum and below the maximum ambient temperatures for the whole duration of the experiment, which were 13.83 and 48.66°C (Figures 1 and 2). It is worth mentioning that the temperature profiles recorded for the three different infestation intensities followed the same pattern and almost coincided as illustrated in Figure 2. Daily average temperature profiles of infested, healthy, and ambient atmosphere are shown in Figure 3. There was some sort of a data aggregation at the first ten days after which a clear variation showed up as profiles of infested trees followed almost similar and adjacent paths at higher temperature values on the unlikely profiles of healthy trees and ambient atmosphere followed relatively adjacent paths at considerably lower temperature values (Figure 3).

Many researchers agree that ambient temperatures exert a very strong effect on the oviposition behavior of females and developmental times for all pre-imaginal stages of RPW. This subsequently affects larval survivorship rates and the number of generations expected in any geographic location, which in turn affects infestation severity (Dembilio and Jacas, 2011; Dembilio et al., 2012). However, fermentation processes which occur within RPW infested palms may hinder predictions based on ambient air temperatures because internal temperatures are unlikely to be the same as those recorded outside of the palm (Llácer et al., 2012). The outcomes of this study provided the evidences to confirm the legitimacy of these concerns regarding reliability of predicting RPW life cycles based solely on ambient air temperature profiles. Evidences are materialized in Figures 1 and 2, as it could be noticed that the ambient air temperature profile has remarkable fluctuations with greater amplitudes unlike those of the interior environments of both infected and uninfected date palm trees, which is true for the whole experiment period.

Therefore, it appears that date palm trees have an inherent characteristic of adap-tability to diverse and harsh environmental conditions especially to ambient air temperature. Interestingly, this date palm capacity of adaptability enables healthy trees to damp down the temperature fluctuations of its surroun-ding environment by keeping its internal temperature almost equal to the mean of that of the ambient atmos-phere (Figure 1). This date palm capacity of adaptability seems to be affected noticeably by RPW infestation after the first week, making trees less capable in damping outside temperature fluctuations, which resulted in a significant increase of internal temperature of infested trees above the mean of the ambient atmosphere (Figure 2) and of the healthy trees (Figure 1) as well. This effect continued for the whole period of infestation. This is an important finding indicating the merit of using electronic sensing of temperature difference to achieve early detec-tion of RPW infestation.

Results of statistical analysis of main effects and interactions of forced infestation are shown in Tables 1, 2

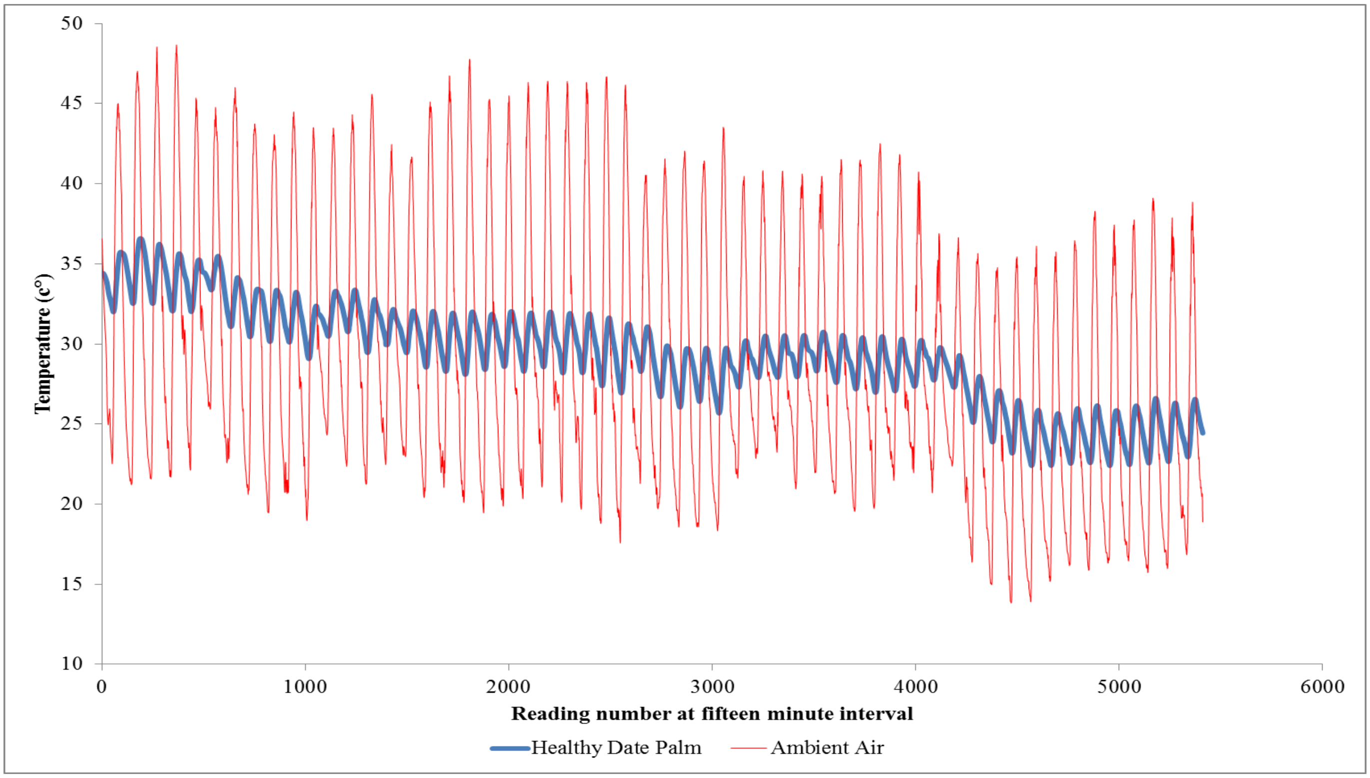

Figure 1. Temperatures recorded inside uninfested (healthy) date palm trees and in the ambient atmosphere.

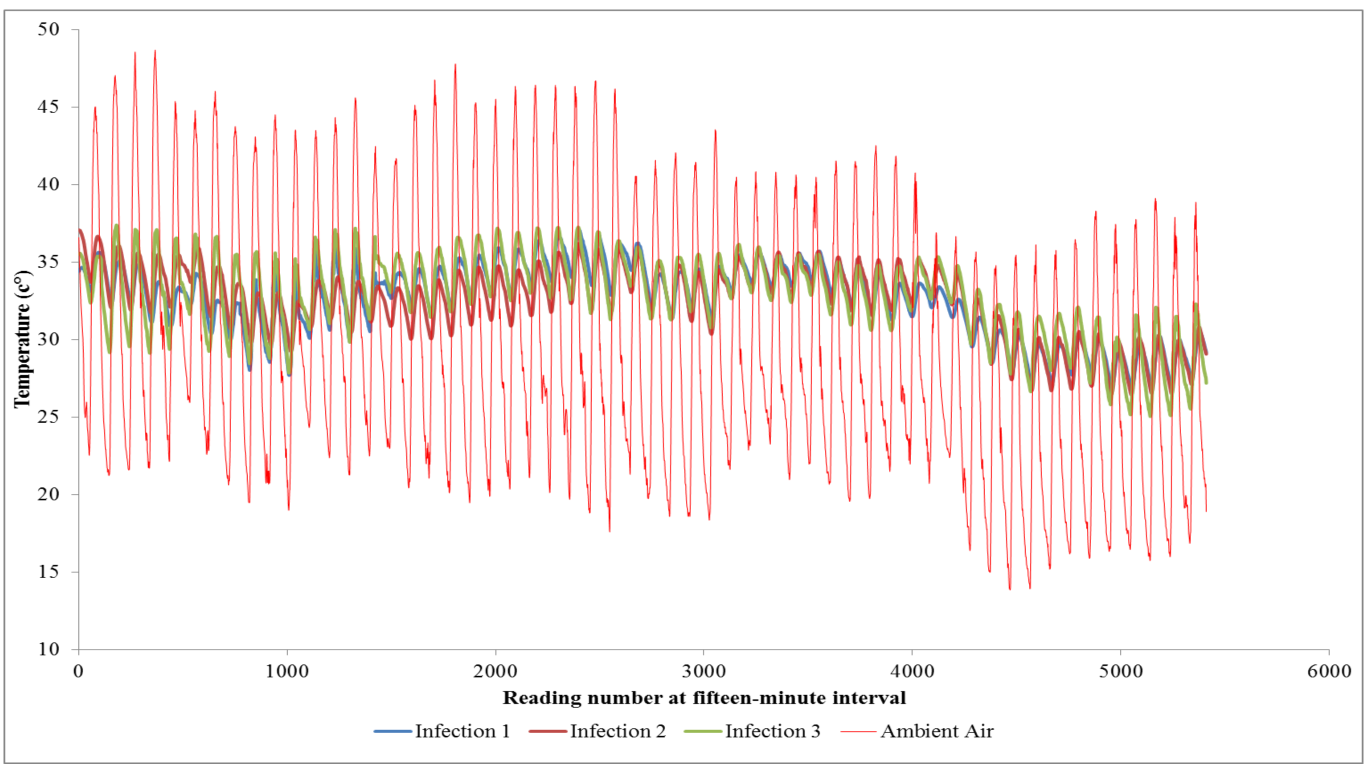

Figure 2. Temperatures recorded inside infested date palm trees and in the ambient atmosphere.

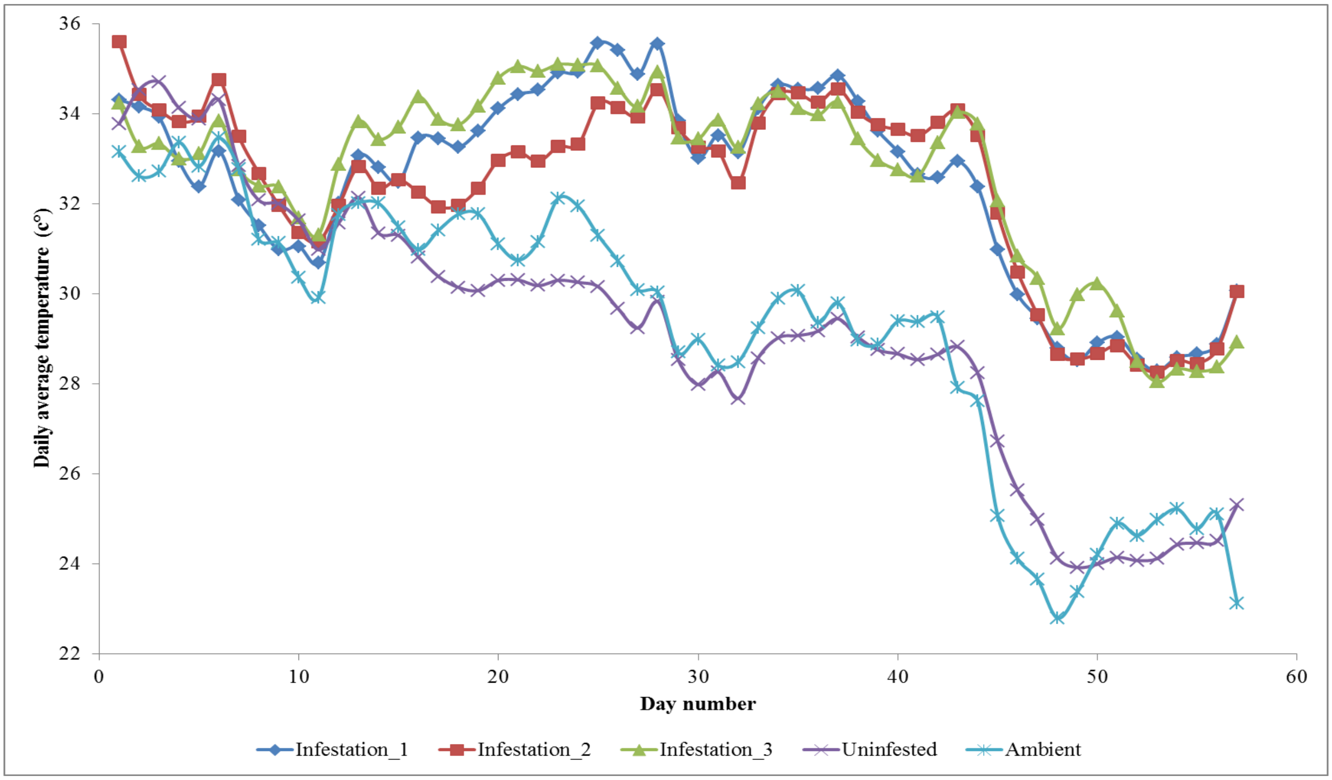

Figure 3. Daily average temperatures of infested date palm trees at three different infestation intensities, of uninfested (healthy) trees, and of the ambient atmosphere.

Table 1. Temperatures inside infested and healthy (uninfested) date palm trees and outside in the ambient atmosphere.

Treatment	Factor B					Means Of A
Factor A	Temperature (°C)					
Time (week)	Infection 1	Infection 2	Infection 3	Healthy	Ambient Atmosphere	
1	33.28	34.30	33.36	34.02	32.99	33.59
2	31.73	32.04	32.56	34.18	31.20	32.34
3	33.54	32.45	34.24	30.47	31.32	32.40
4	35.11	33.77	34.84	29.95	31.05	32.94
5	33.83	33.61	33.84	28.45	29.11	31.77
6	33.67	33.93	33.34	28.90	29.33	31.83
7	30.43	30.94	31.47	26.06	24.94	28.76
8	28.71	28.56	28.77	24.25	24.84	27.02
Means Of B	32.54	32.45	32.80	29.53	29.35	
LSDs at 95% confidence level		A: 0.96 B: 0.76 AB: 2.14				

and 3. It was clear that the forced infestation had a main effect on the internal average temperature of the infested date palm (32.60°C) and it was higher than the temperature recorded at the same time inside healthy trees with a significant difference. Likewise, differences were significant between temperature of infested trees and the surrounding environment (Table 2). For infested trees, the temperature increased slightly with increase in level of infestation but with no significant differences, and the highest was 32.80°C, which was recorded in date palm

Table 2. Significance of mean temperature difference of interaction between factors.

Week number	Significance of Factors Interaction	
	Infected*Healthy	Infected*Ambient air
1	NS	NS
2	NS	NS
3	S	NS
4	S	S
5	S	S
6	S	S
7	S	S
8	S	S

S= Difference is significant; NS= Difference is not significant.

Table 3. Analysis of variance.

Source	Degrees of freedom	Sum of squares	Mean square	F Value	Prob.
Replication	3	31.996	10.665	4.4489	0.0054
Time	7	708.942	101.277	42.2460	0.0000
Infestation	4	385.346	96.337	40.1850	0.0000
Time*Infestation	28	214.666	7.667	3.1980	0.0000
Error	117	280.487	2.397		
Total	159	1621.436			

infested with 2 males and 4 females. Table 2 illustrates the significance of interaction between factors at different levels of time. It can be noticed that the temperature differences between infested and healthy trees started to be significant after the second week of infestation, while the differences between infested trees and the ambient air started to be significant after the third week. This is a clear indication of a good chance to detect RPB infestation at its early stages using electronic sensors sensitive to temperature differences between infested date palm trees on one side and healthy and ambient atmosphere on the other side.

Conclusions

It was evident that the temperature of the infested trees was significantly different from the temperature of both the healthy trees and the surrounding environment. This is a valuable finding which will aid differentiating between infested and healthy date palm trees by detecting such temperature differentials to identify infested trees at early stages of RPW infestation, where, treatment will be timely and effective. Another finding which strengthens the potentiality of early detection of RPW infestation depen-ding on temperature differences, was that all damaging insect activities that significantly affected temperature profiles of date palm trees took place during the first two to three weeks of RPW forced infestation which was the larva stage whereas the damaging effects are at their peak. Basically, this study provides valuable baseline information which is promising in regards to further research pertaining to developing a real time multi-sensor fusion system for an effective early detection of RPW infestations.

ACKNOWLEDGEMENTS

Appreciation and thanks are due to the Deanship of Scientific Research at King Faisal University, Al-Ahsa, Saudi Arabia for supporting this study (project No. 130045) financially.

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