

The Ability of the Invasive Red Palm Weevil, *Rhynchophorus ferrugineus* Infesting Oil Palm in Malaysia

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The red palm weevil of the species Rhynchophorus ferrugineus (RPWf) in this study has shown its capacity to infest oil palm both in laboratory and semi-field settings. Both no choice and choice laboratory experiments showed no significant differences ($p>0.05$) for the number of individuals and time of RPWf adults to reach both coconut palm and oil palm cabbages. Semi-field studies showed that there was a record of infestation of RPWf larvae in the oil palm host for the no choice experiment, while there was no infestation for the choice experiment. Aromatic Pandan coconut showed significant difference ($p<0.05$) in terms of RPWf larval abundances between no choice and choice experiments, where number of RPWf larval individuals were significantly higher in choice experiment. Overall, this study showed the capability of the RPWf to infest oil palm when there were no other suitable palm hosts. Aromatic Pandan and MATAG coconut varieties were proposed to be the most suitable 'trap-crops' in reducing the risks of RPWf infestations on oil palm on plantation scales.

Keywords: *Rhynchophorus ferrugineus*, pest, oil palm, coconut, laboratory, semi-field, infestation, trap-crop.

The red palm weevil (RPW), comprises of two common species, *Rhynchophorus vulneratus* (RPWv) Panzer (Figure 1a), and *Rhynchophorus ferrugineus* (RPWf) Olivier (Figure 1b) (Coleoptera: Dryophthoridae). RPWf is the most notorious polyphagous insect pests that feed and breed on cultivated palms in many parts of the world (Kaakeh *et al.*, 2001; Faleiro, 2006), thus RPWf is known to be more invasive and destructive than RPWv

(Idris *et al.*, 2014; Wahizatul *et al.*, 2013). Damage to the palms by RPW pest is due to the grubs, which are equipped with well-developed and heavily chitinated mouth-parts, usually found in a mass, developing within the tree trunk or cabbage, or even soft tissues near the base of the petioles. The grubs are capable of destroying the palms' vascular system, feeding in the crown region of the infested palms, leading to the collapse of the crown

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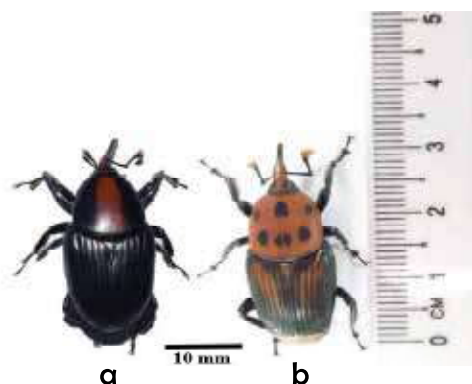


Figure 1 Two distinct species of the red palm weevils, viz. a) the native striped red palm weevil (*Rhynchophorus vulneratus*) and b) the invasive spotted red palm weevil (*Rhynchophorus ferrugineus*)

(Wahizatul *et al.*, 2013). One of the severe signs of infested coconut palms is the drooping of the dried fronds into an umbrella-shape, a sign of irreversible damage and immediate death to the palms (Murphy & Briscoe, 1999). Other symptoms include the presence of holes around the petioles of the fronds as well as the appearance of chewed plant tissues that emanate foul fermented odour and thick brown liquid oozing out from the holes (Kaakeh, 2005).

Early studies showed that RPWv infested economically important palms such as coconut palms (*Cocos nucifera*) and sago palms (*Metroxylon sagu*) (Sivapragasam *et al.*, 1990). However, recent studies found that RPWf's infestation has reached to the extent of causing death of the crown of four common coconut varieties in Malaysia, namely the Malayan Tall, MAWA, MATAG, and the aromatic dwarf or 'kelapa pandan' (Wahizatul *et al.*, 2013). This pest attack was first detected back in 2007 by the Plant Protection Unit of the Malaysian Department of Agriculture (DOA), whereby the damage had

spread to 58 localities in all seven districts of the Terengganu state, stretching from Besut district in the north, bordering the state of Kelantan, to the district of Kemaman in the south, bordering the state of Pahang, though the presence of this pest in both Kelantan and Terengganu could be as early as in 2005 (Wahizatul *et al.*, 2013). The devastating effect of RPWf's infestations were only realised when many dwarf varieties of coconut palms at the Department of Agriculture (DOA) station at Rhu Tapai, Setiu, were losing their crowns.

The number of infestation sites has increased significantly to 858 localities in 2011 (DOA, 2011; Wahizatul *et al.*, 2013). In recent years, RPWf's infestations have been detected in nearly all states of Peninsular Malaysia, except for Selangor, Negeri Sembilan, and Melaka, with only RPWv's infestations detected (Norman, 2017, pers. comm.), further demonstrating the rapid and destructive spreading of RPWf pest in Malaysia, where only five states were initially affected during 2011 to 2013. RPWf was believed to have been introduced by infested date palms with no visible external symptoms which were imported from Egypt as ornamental palms in Malaysia without proper quarantine a few years back (Wahizatul *et al.*, 2013), Rugman-Jones *et al.* (2013) suggested that RPW was already present in Thailand, and it is not surprising that its attack has been reported in Terengganu. Whether or not both methods of RPWf's introduction into Malaysia could be accurate, RPWf has already existed in Malaysia and the combination of these introduction methods made the status of RPWf's infestations levels worsen over time.

Malaysia houses a broad range of palm species other than coconut and sago palms, and more importantly the golden crop i.e. oil palm, as Malaysia is the second largest global

palm oil producer after Indonesia (MPOB, 2015). There have been several reports where RPWf has been recorded to be present within oil palm plantations, detected by implemented pheromone bucket traps (Haris *et al.*, 2014; Idris *et al.*, 2014). Hence, adaptation to previously least preferred and new palm host is possible as is occurring among different coconut cultivars now (Wahizatul *et al.*, 2013). The native RPW of the species *R. schach*, has been known to be present in most oil palm estates in Malaysia, becoming secondary pest of oil palm, infesting oil palm individuals that were previously attacked heavily by *Oryctes rhinoceros* (Wood, 1968). However, the ability of the invasive RPWf to infest oil palm is still unknown, although several observations showed that RPWf has the ability to infest and kill several palm species including nibong (*Oncosperma tigillarium*), nipah (*Nypa fruticans*), sago palm (*Metroxylon sagu*), and the Royal palms (*Roystonea* sp.) (Yong *et al.*, 2015).

RPWf is an introduced pest species with an invasive behaviour i.e. actively mating and feeding especially as this pest has ample-enemy free space. It is also able to shift easily from one host plant to another i.e. coconut to other palms which includes the oil palm, and this has been observed to be true from other known invasive insect pest species (Idris *et al.*, 2014). In recent years, oil palm plantations have contributed approximately RM70 billion to the national revenue, and if these plantations are infested by RPWf, then this will result in negative intolerable drawback to the nation's economy (Norman, 2014). The possibility of RPWf shifting host between different palm species in Malaysia has resulted in this study being conducted to determine the potential of RPWf's ability to infest oil palm under both laboratory and semi-field conditions.

MATERIALS AND METHODS

Laboratory experiment

Choice and no choice experiment

RPWf (*R. ferrugineus*) samples used were reared according to Kaakeh (2005) with slight modifications. The inner growing bud part of both coconut and oil palm was chosen as the diet medium. Two different laboratory experiments were carried out, the choice and no choice experiments. Each replicate (with a total of five replicates) containing three pairs of adult RPWf were released into aquarium-like plastic container (40 cm x 24.5 cm x 30 cm) and were left for a minimum of 12 hours. For choice experiment, both coconut and oil palm cabbage were separately placed into a plastic jar. The plastic jars containing coconut and oil palm cabbages were placed into similar plastic containers. Small spaces (3 cm) were horizontally provided at the container's edge to enable movement, each separated by polystyrene board (4 cm x 21.5 cm x 30 cm) (Figure 2), while the plastic jars were placed into separate plastic containers for no choice experiment (Figure 3). Number of adult RPWf individuals and the minimum time required to reach both coconut and oil palm cabbage media were recorded and compared. Independent *t* – test was used to compare the data between the two experiments employing SPSS software v.24.

Effects of different palm cabbage media on RPWf population sizes

Each replicate (a total of five replicates) containing six pairs of RPWf adults was released into a plastic container (40 cm x 24.5 cm x 30 cm) containing either separated coconut and oil palm cabbages (no choice) or

both coconut and oil palm cabbages (choice) and were left for 60 days. After 60 days, both coconut and oil palm cabbages were examined. RPWf population sizes (number of larvae + pupae + adults) of both cabbages for choice and no choice experiments were recorded. Independent t – test was used to assess the difference of RPWf population sizes for both experiments employing SPSS software v.24.

Semi-field experiment

Three coconut varieties (treatments) namely the MATAG, MAWA, and Aromatic Pandan were tested in this study plus oil palm as control. The experiment was designed as choice and no choice where the number of RPWf that survived was recorded. To do this, wild RPWf larvae were collected from randomly chosen



Figure 2 Choice laboratory experiment of adult RPWf showing both plastic jars containing coconut and oil palm cabbages placed into similar plastic container bordered by polystyrene board



Figure 3 No choice laboratory experiment of adult RPWf showing both plastic jars containing coconut and oil palm cabbages placed into different plastic containers

infested coconut, brought back to laboratory and reared until adult stage. Adult beetles were sexed, paired, and placed within small round plastic containers (7.5 cm in diameter), left for four to six hours as to ensure mating process occurred (Kaakeh, 2005). Selection of mated adult RPWf females were based on behavioural categorisation, where most mated females were more aggressive in finding food sources compared to virgin females.

Choice experiment

All three coconut varieties (MAWA, MATAG, and Aromatic Pandan), and oil palm were placed in a screen cage (4 m x 4 m x 4 m), following Latin Square Design, with four replicates, with 4 x 4 arrangements were employed for all four palm hosts per replicate. Different palm hosts were distanced 1 m from each other. At least five mated RPWf females were released into the screen cages, initially placing them within a round plastic container. Wooden poles were set between different palm hosts and the five mated RPWf females were released on the central pole between all four palm hosts (*Figure 4*). Common damage

symptoms including the presence of holes on the petioles or crown, accumulated frasses, oozed thick liquid with rotting-odour, dying shoots (browning or yellowing), or collapsing fronds were observed each day, appositely marked the day for counting the number of larvae per palm host. One-Way ANOVA was used to compare the number of RPWf larvae that survived on different palm hosts employing SPSS software v.24.

No choice experiment

No choice experiment involved similar coconut palm host varieties and oil palm. The screen cages (1 m x 1 m x 1 m) were used separately for each different palm host (*Figure 5*), with a distance of 2 m from each other and following Latin Square Design, replicated four times, and with 4 x 4 arrangements per replicate. Three mated RPWf females were released separately for each palm host per screen cage and placed into round plastic containers that were hung at the top centre of each screen cage. Common damage symptoms including the presence of holes on the petioles or crown, accumulated frasses, oozed thick liquid with rotting-odour,



Figure 4 Choice semi-field experiment showing five RPWf adults were placed in the round plastic container above the central wooden pole where all four palm hosts were arranged within the screen cage

dying shoots (browning or yellowing), or collapsing fronds were observed each day. The number of larvae per palm host is then counted on marked days. One-Way ANOVA was used to compare the number of RPWf larvae surviving on different palm hosts employing SPSS software v.24.

Comparison between choice and no choice semi-field experiments

Independent *t* – test was used to evaluate any significant difference of RPWf's number of larval individuals surviving on different palm hosts between choice and no choice experiments. This was done employing the SPSS software v.24, with the raw data transformed following fourth-root transformation ($^{0.25}\sqrt{}$), to ensure variances' homoscedasticity.

RESULTS

Laboratory no choice experiments recorded

higher adult RPWf individuals feeding on coconut cabbages (4.78 ± 0.18) compared to oil palm cabbages (4.72 ± 0.23), but not significantly different ($t = 0.22$, d.f. = 7, $p > 0.05$) (Figure 6). The minimum mean time required to reach coconut cabbages' container was quicker (6.60 ± 1.17 minutes), but again not significantly different compared to oil palm cabbages (7.40 ± 1.36 minutes) (Figure 7).

Laboratory choice experiments showed significant difference ($t = -3.58$, d.f. = 7, $p < 0.05$) for the number of RPWf adults feeding on coconut cabbages (1.96 ± 0.051) and oil palm cabbages (1.68 ± 0.058) (Figure 8). The minimum mean time required to reach coconut cabbages' container also was quicker (17.60 ± 2.42 minutes), however was not significantly different compared to oil palm cabbages (23.40 ± 4.63 minutes) (Figure 9).

Higher RPWf population sizes of different life stages were recorded on coconut palms' cabbage media, but not significantly different



Figure 5 No choice semi-field experiment showing separated screen cage for each different coconut palm variety and oil palm at a distance of 2 m from each other

($p > 0.05$) from oil palms' cabbage media for both no choice and choice experiments, including final pooled populations recorded on the sixtieth day of the experiment (Table 1).

In semi-field study, results of no choice experiments showed the number of RPWf larvae amongst different coconut varieties did not differ significantly ($F = 164.08$, d.f. = 3,

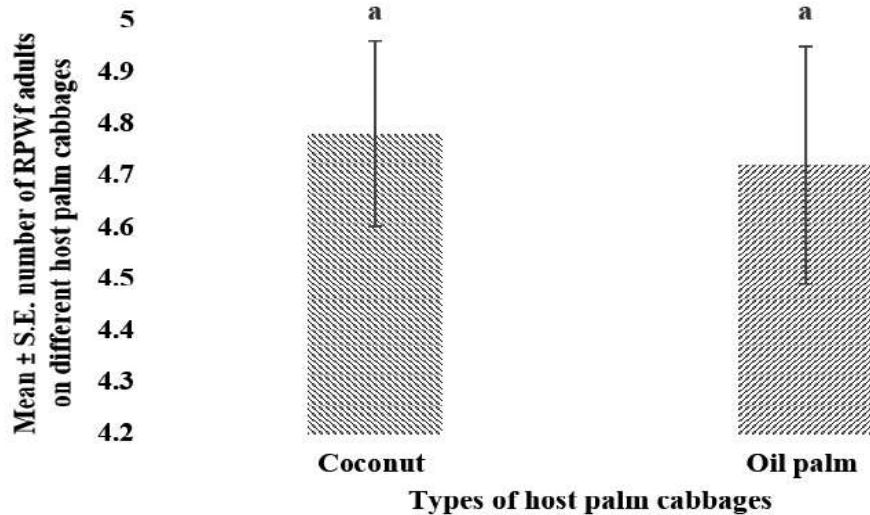


Figure 6 Mean ± S.E. number of adult RPWf individuals on both coconut and oil palm cabbages in laboratory no choice experiment

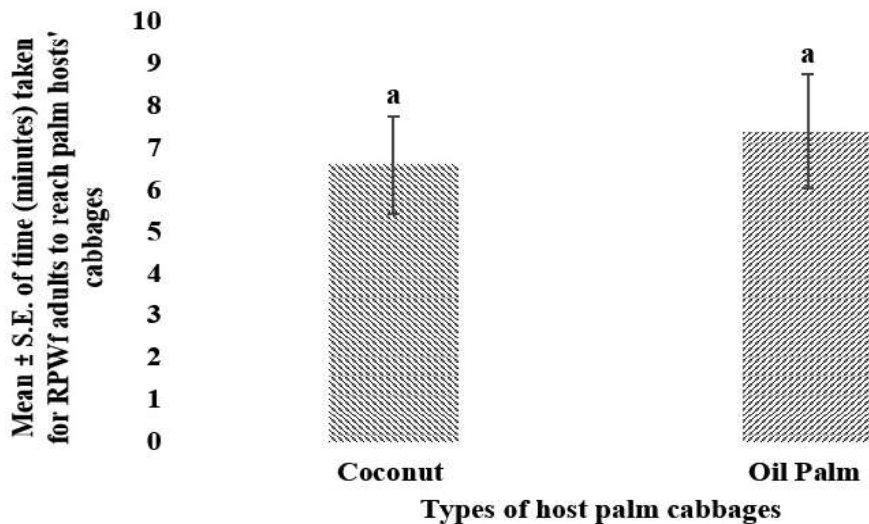


Figure 7 Mean ± S.E. time taken (minutes) for adult RPWf to reach both coconut and oil palm cabbages in laboratory no choice experiment

$p < 0.05$), with Aromatic Pandan variety having recorded the highest larval individuals (33.76 ± 0.49), but was significantly higher than that of oil palm ($F = 164.08$, d.f. = 3, $p < 0.05$), which recorded the lowest larval abundance ($3.75 \pm$

1.14) (Figure 10). On the other hand, choice experiments showed the number of RPW larvae amongst different coconut varieties differed significantly ($F = 760.16$, d.f. = 3, $p < 0.05$), with Aromatic Pandan variety

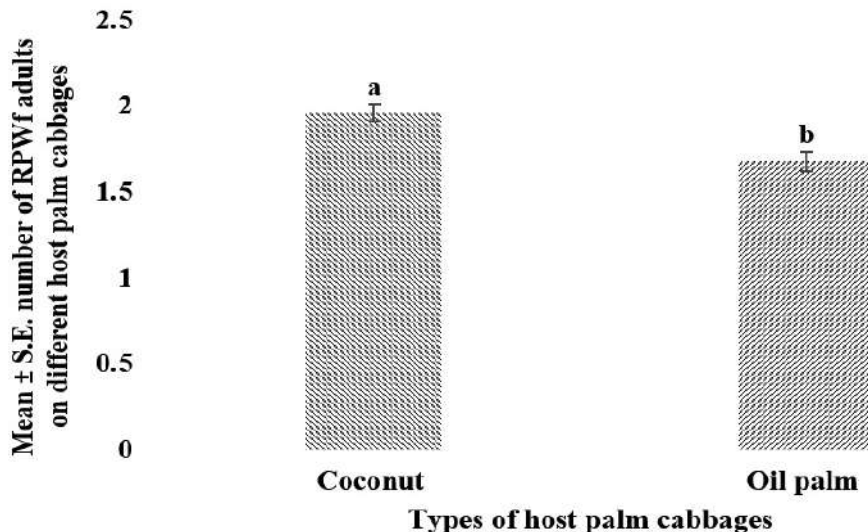


Figure 8 Mean ± S.E. number of adult RPWf individuals on both coconut and oil palm cabbages in laboratory choice experiment

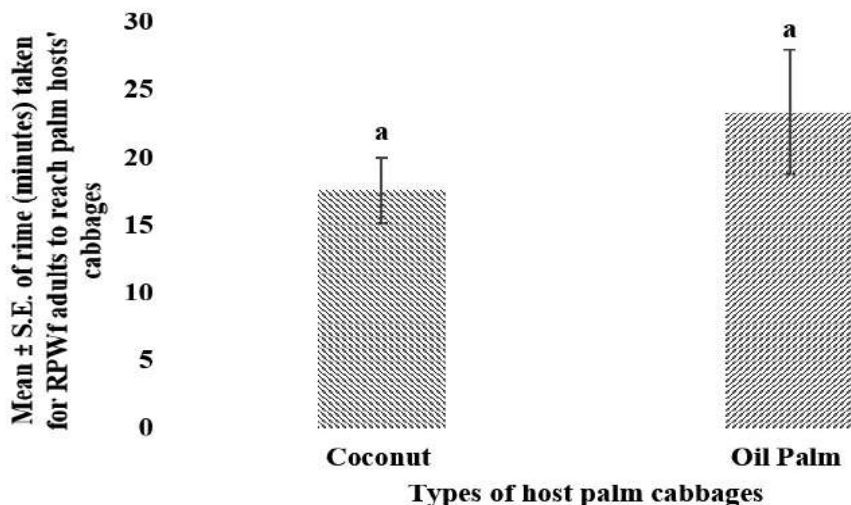


Figure 9 Mean ± S.E. time taken (minutes) for adult RPWf to reach both coconut and oil palm cabbages in laboratory choice experiment

recording the highest larval individuals (95.94 ± 1.71), higher than the no choice experiments, and no record of RPWF larvae on oil palm host (Figure 11).

No choice and choice semi-field experiments showed no significant difference for the number of RPWF larvae on MATAG ($t = -0.97$, d.f. = 6, $p > 0.05$) and MAWA ($t = -$

9.43 , d.f. = 6, $p > 0.05$) varieties. However, number of RPWF larvae were significantly different for Aromatic Pandan variety between no choice and choice experiments ($t = -30.30$, d.f. = 6, $p < 0.05$). The oil palm also showed significant difference between the no choice and choice experiments ($t = 2.85$, d.f. = 6, $p < 0.05$) (Table 2).

TABLE 1
MEAN $\pm$ S.E. NO. OF RPWF INDIVIDUALS OF DIFFERENT LIFE STAGES RECORDED ON BOTH COCONUT PALM AND OIL PALM MEDIA OF WITH CHOICE AND NO CHOICE EXPERIMENTS FOR 60 DAYS[†]

Experiment type	Diet	Larvae	Pupae	Adults	Pooled populations
With choice	Coconut palm	$18.20 \pm 1.96_a$	$4.40 \pm 0.60_a$	$2.40 \pm 0.25_a$	$25.00 \pm 1.97_a$
	Oil palm	$14.80 \pm 1.85_a$	$3.20 \pm 0.66_a$	$2.00 \pm 0.55_a$	$20.00 \pm 1.30_a$
No choice	Coconut palm	$27.00 \pm 1.76_b$	$4.00 \pm 0.45_b$	$2.40 \pm 0.25_b$	$33.40 \pm 1.57_b$
	Oil palm	$25.80 \pm 1.46_b$	$3.40 \pm 0.40_b$	$2.20 \pm 0.20_b$	$31.40 \pm 1.25_b$

[†] Mean with similar subscript alphabet among different palm cabbages and experiment types are not significantly different, $p = 0.05$.

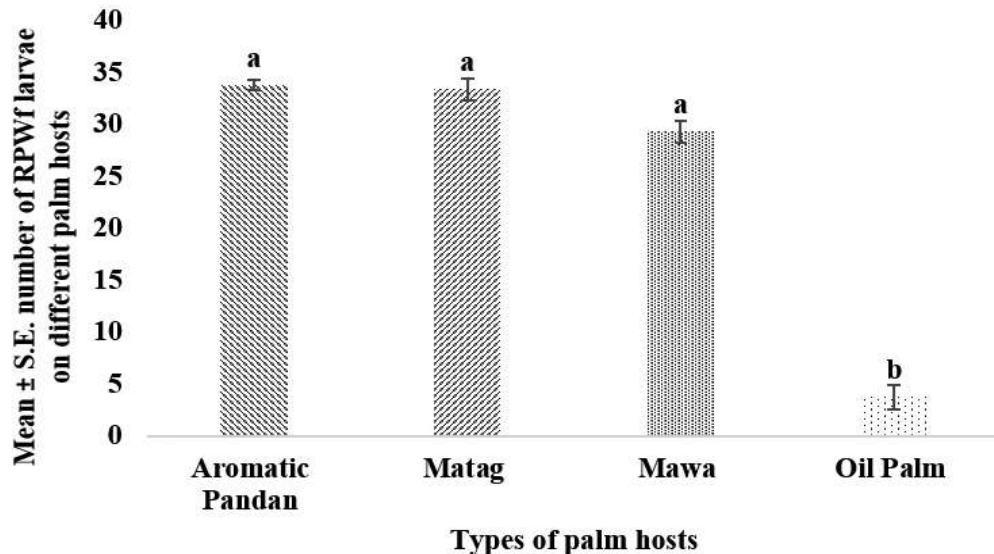


Figure 10 Mean $\pm$ S.E. number of RPWF larvae on Aromatic Pandan, MATAG, MAWA, and oil palm hosts in semi-field no choice experiment

DISCUSSION

Previous research suggested that coconut palms were more susceptible to RPWv's and RPWf's infestations compared to the oil palm (Giblin-Davis *et al.*, 1996). Results of our study showed that there was significant difference on the number of RPWf adult individuals feeding on coconut and oil palm cabbages in

laboratory choice experiment, however, the number of RPWf adults and the minimum time to reach both coconut and oil palm cabbages in laboratory no choice experiment showed that the differences were not significant, yet there was occurrence of RPWf larvae on oil palm host for semi-field no choice experiment, and these RPWf larvae seemed to have the capacity to feed and survive on oil palm

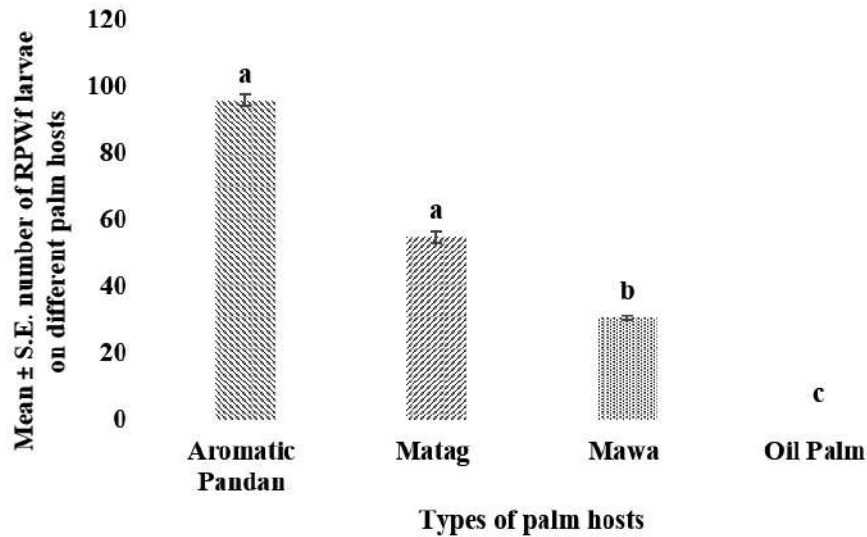


Figure 11 Mean ± S.E. number of RPWf larvae on Aromatic Pandan, MATAG, MAWA, and oil palm hosts in semi-field choice experiment

TABLE 2

MEAN ± S.E. NUMBER OF LARVAL RPWF INDIVIDUAL DIFFERENCES BETWEEN SEMI-FIELD OF NO CHOICE AND CHOICE EXPERIMENTS FOR AROMATIC PANDAN, MATAG, MAWA AND OIL PALM HOSTS†

Palm hosts	No choice experiment	Choice experiment	No choice vs Choice experiments
Aromatic Pandan	33.76 ± 0.56 _a	95.94 ± 1.97 _a	$t = -30.30, p = 0.000, d.f. = 6, p < 0.05$
MATAG	33.40 ± 1.23 _a	55.05 ± 1.94 _a	$t = -0.97, p = 0.868, d.f. = 6, p > 0.05$
MAWA	29.31 ± 1.25 _a	30.76 ± 0.82 _b	$t = -9.43, p = 0.119, d.f. = 6, p > 0.05$
Oil palm	3.75 ± 1.32 _b	0.00 ± 0.00 _c	$t = 2.85, p = 0.046, d.f. = 6, p < 0.05$

† Mean with similar subscript alphabet among different palm hosts and experiment types of semi-field experiment are not significantly different according to two sample independent *t* – test, *p* = 0.05.

(Figure 12). It is surprising that according to common notion, the odour from damaged tissue in feeding holes by the pest *Oryctes rhinoceros* as the primary palm pest, is proposed to attract RPWv or RPWf for oviposition (Wattanapongsiri, 1966). Oehlschlager (2007) on the other hand had suggested that the attack by RPWf mostly resulted from freshly cut, injured, or damaged palm tissues, after several frond pruning activities. In this study, both the coconut and oil palms in semi-field setting were not injured, hence no exposed tissue site for immediate attraction and oviposition by the adult RPWfs. Alarmingly, these findings generally showed that RPWf has the ability to infest oil palm, even without any damage caused by either the primary pest *O. rhinoceros*, or anthropogenic physical injury to the palms, as Wood (1968) proposed that RPW is the secondary pest of oil palm, in addition to the



Figure 12 RPWf larvae found within the oil palm basal trunk for the semi-field no choice experiment

condition where coconut palms as the current and main palm hosts, are becoming less common or low in abundance (Idris *et al.*, 2014).

The choice of RPWf for different coconut palm varieties compared to oil palm in semi-field choice experiment tend to agree with the findings by Ainatun Nadrah *et al.* (2018), who reported that RPWf larvae highly preferred coconut, followed by oil palm and sago. They concluded that coconut was more attractive than oil palm or sago, as coconut may have additional nutrients such as fibre, proteins and vitamins (USDA, 2014). Furthermore, fibre made up to 29 per cent from the total composition of coconut meat (USDA, 2014), which is important as basic material for the exoskeleton development in adult RPWs in the form of chitin (Fabritious *et al.*, 2011), as well as crucial for the cocoon building processes in late instars during the pupal stage (Wahizatul *et al.*, 2013). However, clarification of the less attractive of oil palm cabbage or tissues compared to coconut needs further study.

Choo *et al.* (2009) and Howard *et al.* (2001) suggested that although most RPW were polyphagous, in most cases, they were very selective in choosing specific host palms, particularly dependent on the nutritional quality that will affect larval sizes during development, as well as the hardness of host palm tissues accessible for the larvae. This justifies the very low infestation of RPWf larvae in oil palm in semi-field experiment, as well as significant difference between oil palm cabbage and coconut cabbage in choice laboratory experiment. In addition to the fact that oil palm was less preferred compared to coconut palm as indicated in this study, the life cycle of RPW was relatively shorter on oil palm compared to coconut and sago palms, which reached the sixth instar before turning into pupae, while the seventh instar was needed for coconut and

sago palms, in addition to shorter developmental growth as well (Ainatun Nadrah *et al.*, 2018).

Although oil palm seemed to be less attractive to RPWf than coconut palm in both the laboratory and semi-field studies, the host shift phenomena may occur in a matter of time as a result of the reduction in coconut palm's abundance as the current host (Idris *et al.*, 2014). The host shift could be enhanced as RPWf is able to change its biology and behaviour as suggested by Ju *et al.* (2011) that RPW larvae may have fewer instar larval stages, in addition to developmental time that can be shortened when it reaches suitable host palm species. They claimed that the Vitamin E (alpha-tocopherol) and K were highly available in oil palm compared to coconut (USDA, 2014), where these two vitamins could enhance RPW larval growth and development, further affecting the reproductive performance of RPW by producing more viable offspring (Parra, 2012). This coincides with the results of this study where pooled RPWf populations of all life stages showed no significant difference between coconut palm and oil palm.

It is possible for oil palm to become the second most attractive host palm after coconut in large scale plantations, although Haris *et al.* (2014) proved that oil palm has the least attractive rotting sweet aroma compared to pineapple or sugarcane when applied as food bait in bucket traps for the purpose of mass-trapping, correlated with high concentration of ethylene glycol and ethyl acetate, comparable to carbohydrate or sugar levels in the tissues (Abdel-Moniem *et al.*, 2014) as the main attractant factor. The possibility of more RPW adults attracted into a large scale oil palm plantation is higher if nearly half of the plantation had already been infested by RPW larvae. This is due to the accumulation of volatile chemicals from the rotting fermented oil palm exudate of

infested oil palm. Similarly in previous studies, RPW showed higher preference to the additive host palms' kairomone levels that came from wound sites (Faleiro *et al.*, 2002; Giblin-Davis & Howard, 1989; Giblin-Davis *et al.*, 1996; Hagley, 1965; Murphy & Briscoe, 1999; Wattanapongsiri, 1966; Weissling & Giblin-Davis, 1994).

Therefore, in an area-wide point of view to manage possible RPW infestations into oil palm plantations, coconut palms can either be important 'trap-crop' or further attracting more RPW into the oil palm plantations. Hence differential abundance of various coconut palm varieties must be quantified and marked with specified threshold levels as well as damage ratings (Idris *et al.*, 2014; Wahizatul *et al.*, 2013). In this study, Aromatic Pandan coconut variety was the most attractive coconut palm variety compared to MATAG and MAWA. According to Haris *et al.* (2014), sweet-scented host palms were correlated with higher sugar tissue contents, and attracted more RPW adults. Similarly this study also showed that the Aromatic Pandan was the most attractive coconut palm to RPW adults, in respect to the highest larval abundance.

In confined semi-field cages where water was scarce and relative humidity was unstable, RPW adults preferred host palms with higher water content for water conservation and to ensure larval survival (Weissling & Giblin-Davis, 1994). Sweet-scented and high water content were both the attributes of Aromatic Pandan coconut palms (Abd Razak *et al.*, 2009; Wan Khairul & Idris, 2013). Bioassay studied on coconut samples showed that both RPWv and RPWf were very sensitive to the coconut volatile organic compounds, and have the innate ability to detect host coconut palms in a very wide area (Guo, 2007; Juan & Antonia, 2015). MATAG is the second most

attractive coconut palm variety after Aromatic Pandan because it is a highly abundant coconut palm, mostly planted in many coconut plantations along with Aromatic Pandan (Wan Khairul & Idris, 2013), showing additive adaptation process of RPW where multiple abundant palm hosts exist (Anisul *et al.*, 2015). Landscape management of arranging more and less attractive palm hosts is highly crucial in reducing the risks of wide scale infestations, especially in oil palm plantations. In a practical sense, it can be concluded that both Aromatic Pandan and MATAG coconut palm varieties are the two most important 'trap-crop' to alleviate the attack of RPW on oil palm in the near future.

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