REVIEW ARTICLE

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ADVANCES IN THE CONTROL OF RHINOCEROS BEETLE, *Oryctes rhinoceros* IN OIL PALM

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ABSTRACT

Oryctes rhinoceros *is an important pest attacking young oil palms in South-east Asia. In Malaysia, in addition to well-known breeding sites it is able to multiply in shredded chipped old oil palm trunk material in replant areas, also in empty fruit bunches. The aggregation pheromone ethyl 4-methyloctanoate is produced by males of* O. rhinoceros *(also by the similar pest* O. monoceros *in Africa), and is used in traps as an important component of Integrated Pest Management (IPM) and in ecological studies. In Malaysia, the incidence of endemic entomopathogens can be increased. The fungus* Metarhizium anisopliae *is available for use as a biopesticide against immature stages in breeding sites and may be distributed by adults. The molecular and ultrastructure of* Oryctes *Nudivirus (OrNV) has been extensively studied. It kills larvae and is disseminated by adults. New PCR techniques may enable reliable estimates of the quantity of virions in experimental dosages ingested and hence of the virulence of different isolates. It is possible one isolate when released may out compete another.*

Keywords: *Oryctes rhinoceros*, Nudivirus, *Metarhizium anisopliae,* oil palms, pheromone ethyl 4-methyloctanoate, *Oryctes monoceros*.

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INTRODUCTION

Oryctes rhinoceros (L.) (Coleoptera: Scarabaeidae: Dynastinae) (*Figure 1*) is a serious pest of young oil palms in South-east Asia, boring into the base of the cluster of unopened leaves (the spear or spindle) (Wood, 1968). Attacked palms show damaged fronds with wedge-shaped gaps or cuts, broken or truncated fronds, holes in petioles, and snapped-off spears. Fronds towards the centre may be crumpled and malformed (*Figures 2, 3* and *4*). This damage to the heart can allow the entry of bacteria and fungi which cause secondary rotting. Replant palms less than a year old are often killed by *Oryctes* attack but the likelihood of damage proving lethal declines rapidly as the palms mature (Wood, 1968). It also attacks female inflorescences by boring into the stalk so up to 26% of the fruits of a bunch may be lost (Ponnamma *et al.*, 2001b). In Malaysia, for the past two decades trunks of old felled oil palms in replant areas are shredded (pulverised or chipped) which avoids burning, and this material is spread as a layer or in heaps or windrows between the replants (Ooi *et al.*, 2001; 2004; 2005; Samsudin *et al.*, 1993). Encouraging rapid overgrowth of this material by a cover crop has long been accepted as a component of Integrated Pest Management (IPM) as the cover crop, acting as a vegetative barrier, contributes to concealing the material from the beetle as a potential breeding site, and it also hinders beetles from locating young palms to attack (Wood, 1968). However, *O. rhinoceros* is still able to take advantage

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Figure 1. Oryctes rhinoceros – *male on the left, female on the right.*

Source: Courtesy of Ramle Moslim (MPOB).

Figure 2. Young oil palm attacked by Oryctes rhinoceros.

of this material as a breeding site which may shelter abundant immature stages (*Figure 5*) (Norman *et al.*, 2005). These also occur in empty oil palm fruit bunches (Wan Zaki *et al.*, 2009), fruit mesocarp waste (Ponnamma *et al.*, 2001a) and other types of adjacent breeding material (Norman and Basri, 1997). *O. monoceros* (Olivier) attacks oil palms in Africa

Source: Courtesy of Ramle Moslim (MPOB).

Figure 3. Young oil palm dying due to attack by Oryctes rhinoceros.

Figure 4. Young oil palm attacked by Oryctes rhinoceros – *note crumpled malformed central fronds.*

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Figure 5. Oryctes rhinoceros - *immature stages - upper from left, egg, first-, second-, third-instar larvae; lower from left, prepupa, pupa.*

(Ukeh, 2007). Both species also attack coconut palm. While this review refers mainly to oil palm, much of the data gathered in the coconut palm environment has relevance to the oil palm context (Bedford, 2013). Readers will find references to earlier work in Wood (1968), which gives further illustrations of damage, and Bedford (1980). The history of the introduction of the oil palm into Malaysia and the development of the *O. rhinoceros* beetle problem in relation to coconut then oil palm there, is summarised by Manjeri *et al.* (2014).

In Malaysia, the endemic entomopathogens affecting immature stages are: *Oryctes* Nudivirus (OrNV), the bacteria *Bacillus thuringiensis* (Berliner) and *Bacillus popilliae* (Dutky), and the fungus *Metarhizium anisopliae* [Metsch. (Sorokin)] (Norman *et al.*, 2001; 2007). Adults are affected by OrNV (Ramle *et al.*, 2005) and *M. anisopliae* (Ramle *et al.*, 2011). Here, and in India, application of insecticide such as carbofuran granules to the axils of young oil palms may form a component of IPM (Hoong and Ho, 1992; Kalidas, 2004; Kumar and Ahmad, 2008; Norman and Basri, 1997; Norman *et al.*, 2007).

Odour from damaged tissue in feeding holes of *O. rhinoceros* may attract the Asian red palm weevil *Rhynchophorus ferrugineus* Olivier (= *R schach* Olivier = *R. vulneratus* Panzer (Hallett *et al.*, 2004; Wattanapongsiri, 1966) for oviposition, and the resulting larvae cause the death of the young oil palm. However, to date such attacks seem to be only occasional and secondary (Wood, 1968), as infestation is reported to occur only via oviposition in freshly cut, injured or damaged palm tissue (Oehlschlager, 2007). In India, oviposition can occur in *O. rhinoceros* feeding holes made in fruit bunches and stalks causing loss of yield (Ponnamma *et al.*, 2001b).

PHEROMONE

As pheromone trapping has become an important component of IPM for control of rhinoceros beetle, as well as a tool for ecological studies, and possible dissemination of pathogens, it seems appropriate to address this topic early in this review.

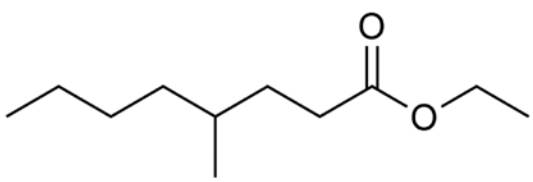

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Figure 6. Ethyl 4-methyloctanoate (E4-MO).

Ethyl 4–methyloctanoate (abbreviated to E4-MO) (*Figure 6*) was found to be the main male-produced aggregation pheromone in *O. rhinoceros* (Hallett *et al.*, 1995; Morin *et al.*, 1996) and *O. monoceros* (Gries *et al.*, 1994). Methods of synthesis were developed (Munoz *et al.*, 2009; Ragoussis *et al.*, 2007) and it is now available in a slow-release sachet dispenser. Various types of traps have been tested (listed in Bedford, 2013), ranging from the cheaper plastic bucket type (a plastic bucket placed on a support with the concave cover upside down and perforated with five beetle-sized holes) to the more expensive barrier type with double metal vanes with the dispenser in the centre, standing in a funnel inserted into a plastic bucket (pail) (Chung, 1997; Desmier de Chenon *et al.*, 2001). The double vane type (*Figure 7*) was found to be the most effective and economical at one trap per 2 ha, particularly if the pest is at low population levels (Chung, 1997). It is best placed 3 m above ground, 1-2 m above the young oil palm canopy (*Figure 8*), and can lower damage by more than 90% (Oehlschlager, 2007). A synergist is freshly rotting empty oil palm fruit bunches, where available, which increased catch by four times that of pheromone alone, thus reducing dose and cost (Sudharto *et al.*, 2001), but its weight may make the elevated trap unstable and so may be omitted (Oehlschlager, 2007). In India, pheromone traps at 3.7 m above ground level, with oil palm petiole cuttings in the bucket, caught more beetles than those at the standard height of 3 m. These higher traps apparently attracted more beetles which were migrating in. Also, catches were higher in traps near likely breeding sites (Ponnamma and Lalitha, 2005).

There is a possibility the pheromone is produced in male *O. rhinoceros* only at certain times in its adult life (Morin *et al.*, 1996), in particular to attract females with maturing eggs. In Indonesia, the pheromone traps attracted 81% females, one-half having developed ovaries but an empty bursa

Source: Courtesy of Ramle Moslim (MPOB).

Figure 7. Double-vane pheromone trap.

Source: Courtesy of Ramle Moslim (MPOB).

Figure 8. Double-vane pheromone trap above young oil palm canopy.

copulatrix suggesting they were seeking a mate or oviposition site occupied by males (Morin *et al*., 1996). In Malaysia, the average pheromone trap catch was 60% females of which 92% were gravid with 16 eggs/female and deemed to be looking for breeding sites (Norman and Basri, 2004), while in India of 12 700 beetles trapped in coconut plantations, 68% were females, of which 54% were virgin and 34% gravid (Jayanth *et al*., 2009). There is evidence in *O. monoceros* in the Ivory Coast that the pheromone, whether emitted naturally by males or from traps, catches at that time only the proportion of the population seeking breeding sites rather than those seeking to feed on palms (Allou *et al*., 2008). It is not known if this also applies to *O. rhinoceros*.

In Malaysia, traps were used to monitor immigration of *O. rhinoceros* from adjacent mature plantings into a 4.5 ha block beginning five months after replanting (Norman and Basri, 2004). Infestation of breeding sites reached the centre of the block four to seven months after they were chipped. Females were trapped more consistently at the edges than the centre, and there was a reduction in the number of second-instar larvae found in the breeding heaps 40 – 60 days later. Trap captures showed an increase in flight activity during wet weather and by males during full moon, and reduced damage to adjacent palms. Traps are beneficial in reducing the build-up of populations in oil palm breeding sites (Norman *et al*., 2001; 2007). With one trap per 2 ha, infestation stayed below 10 individuals (mainly larvae) per m^2 of breeding material, until breeding ceased after 24 months. With a very high trap density, 11 traps per 1 ha (reduced to 5 per ha after the first six months), larvae dwindled away in the breeding sites by 16 months. Without traps, immature stages soon built up to 25 – 50 insects per m^2 and persisted after 26 months, but at 11 – 14 months suffered high mortality due to pathogens (particularly OrNV and bacteria), possibly a density-dependent effect.

In India, mass-trapping using bucket traps in coconut plantations caught a high percentage of females, so was considered beneficial in reducing beetle populations (Jayanth *et al*., 2009). A study in an oil palm plantation using one trap per 2 ha gave a good catch (10 traps caught 1338 beetles over 25 months) and a considerable reduction in the beetle population and damage. Sachets were effective for an average of five months. So, mass-trapping could well be incorporated into an IPM programme (Ponnamma *et al*., 2002). However, in Andhra Pradesh a trial using double-vane traps in an oil palm plantation found the pheromone evaporated quickly when day temperatures were above 33.5^0C, reducing its longevity. Also, some attracted beetles 'skipped', *i.e.* did not fall into the trap. So, under these conditions the traps were not considered economical (Kalidas, 2004). These differing results in India suggest that the economic advantage of trapping could vary with different ecological situations.

Metarhizium anisopliae

Pathogenicity

Metarhizium anisopliae fungus occurs in long *(major)*, or short-spored varieties affecting *O. rhinoceros* larvae or adults, with a long-spored isolate being more virulent and causing higher mortality in laboratory trials (Ramle *et al*., 1999), and four such isolates from Malaysia killing all third-instar larvae after 14 days (Ramle *et al*., 2006). Earlier work had shown that larvae of *Oryctes* spp. are susceptible only to strains of *M. anisopliae* isolated from *Oryctes* spp. (Ferron *et al*., 1972; Sivapragasam and Tey, 1994), and only *major* strains isolated from *Oryctes* spp. seemed pathogenic to *O. rhinoceros* adults (Ferron *et al*., 1975). An important condition for infection is the ability of conidia (spores) of a particular pathotype to adhere to the hosts' surface at sites such as integumental folds and germinate there to penetrate the cuticle (Vey *et al*., 1982).

Incidence

In shredded oil palm material in Malaysia, only 1% – 2% of third-instar larvae (*Figure 9*) were found

Figure 9. Oryctes rhinoceros *third-instar larva killed by* Metarhizium anisopliae *fungus – note coating of spores on exterior.*

infected, but in one case it killed 12% of pupae (Norman *et al.*, 2007). In an oil palm replant area, heaps of shredded coconut trunk debris after two years of cover crop overgrowth had less than 2% *M. anisopliae* infections and could contain substantial numbers of larvae (Tey and Ho, 1995).

Biopesticide

The low natural incidence of *M. anisopliae* prompted development of methods for mass-producing spores and trials of its use as a biopesticide. Mycelium was cultured in liquid medium then transferred to maize to sporulate. Spores were then separated and dried at low temperature to powder form, and remained approximately 60% viable after 15 months when stored at an optimum temperature of 5^0C – 15^0C. When the spores were mixed with water and applied to breeding sites, close to 70% of the third-instar larvae were infected by 12 months after treatment with the total larval population reduced by up to 80% (Ramle *et al.*, 2006). In another trial (Ramle *et al.*, 2007), two different dosages of spores were sprayed onto rotting oil palm residue heaps 15 months after felling and now under cover crops. Eight months later, the treatments had reduced the number of second- and third-instar larvae, prepupae and pupae to 31 – 41 insects per treatment sampling plot (30% – 33% infection level) as compared to 132 insects per control sampling plot (13% infection). The third-instar being of longer life-span is more likely to catch the infection. By 12 months, the control heaps had caught up to the treatment heaps (52% – 73% infection levels). The results indicated that *M. anisopliae* is best applied early, *i.e.* six to eight months after chipping of the trunks to cause earlier infection before the leguminous cover crop has fully overgrown the heaps. The further growth of the cover crop protects the spores below. There was no reduction in adults caught in pheromone traps in the study areas because they apparently immigrated from surrounding untreated replant areas. Populations of non-target beetle species in the treated areas were unaffected.

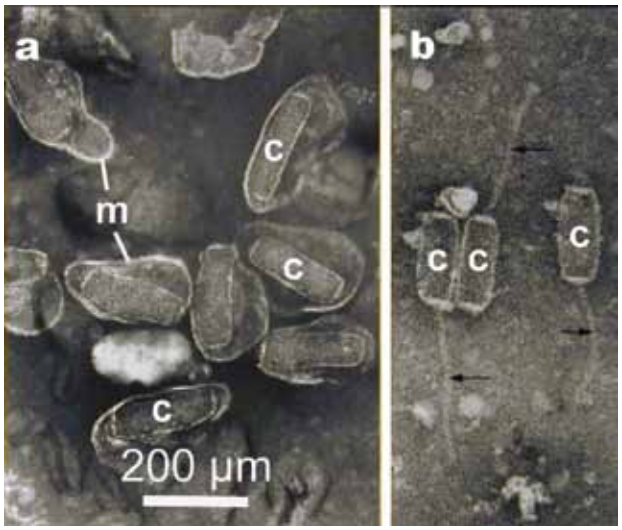
As granules may be easier to apply in the field in the future, different granule formulations based on kaolin and rice bran were tested in the laboratory in rotting oil palm material (Ramle *et al.*, 2009). The granules were: mycelium plus its growth medium (M + GM), mycelium only (M), and spores only (S), and were compared with application of spores only in a suspension. The (M + GM) granules gave a lower yield in production due to their higher weight but gave 100% fungal growth, 87% sporulation and quick production of spores as the fungus could use the nutrients in the granules. There was 93% mortality of third-instar larvae at 18 days after treatment. The S granules caused a similar mortality. The M granules gave a higher yield in production due to their lower weight, with 62% fungal growth and 48% sporulation. The spore suspension gave 96% mortality and killed in 12 – 14 days. Application of a spore suspension (prepared from a powder formulation) by spraying onto breeding sites in the field caused high mortality (80%-100%) of larvae by four to eight months after treatment, even where the breeding sites had been overgrown by leguminous cover crop (Ramle *et al.*, 2013). Application of spores to the crowns of young oil palms in India gave a beneficial result in reducing damage (Kalidas, 2004).

In order to explore other ways of boosting the incidence of *M. anisopliae* var. *major* in natural breeding sites, a pheromone trap to capture adults, automatically infect then release them has been trialled (Ramle *et al.*, 2011). Some 85% – 95% of such trapped and inoculated beetles left the trap and so could disseminate the fungus, and when placed in boxes of breeding material 92% of third-instar larvae were killed by cross-infection. Artificial breeding sites are also being trialled, in which beetles are attracted by pheromone to decomposing trunk chip material which is frequently treated with *Metarhizium*. Crawling through this the beetles become infected, and contaminated with spores, and they then disperse to spread the infection (Ramle *et al.*, 2013).

Oryctes NUDIVIRUS (OrNV)

History and Overview

Huger (2005) described his original discovery in 1963 of this endemic virus affecting *O. rhinoceros* larvae in rotting oil palm breeding sites in Malaysia. It has since been found in the Philippines (Zelazny, 1979), Indonesia (Zelazny *et al.*, 1989) and Kerala in India (Zelazny, 1981). Previously considered to be a Baculovirus, OrNV is now classified as a member of the Nudivirus group (Burand, 1998; Wang and Jehle,



Source: With permission from A M Huger, *J. Invertebrate Pathology Vol. 89* (2005): 78-84.

Figure 10. Virions of Oryctes *Nudivirus (OrNV) - (a) showing capsids [c] and viral membrane [m], (b) showing capsids [c].*

2009; Wang *et al.*, 2007a, b; 2008). The rod-shaped virion has an outer coat or capsid surrounded by a viral membrane (Huger, 2005) (*Figure 10*) and is the infective unit in which OrNV must persist in the environment, and be transmitted. Its genome is a double-stranded DNA molecule with a sequence of 127.615 kilobases (kb) determined for a Malaysian isolate Ma07 (= type B) (Wang *et al.*, 2008). Several genomic variants may coexist in the same locality (Crawford *et al.*, 1986) while the same isolate (Malaysian type A = PV505) can be found both on the Malaysian Peninsula and in the Philippines (Ramle *et al.*, 2005) about 2300 km apart. Infection is peroral. It multiplies in the midgut and fat body of larvae, and in the midguts of adults which defaecate the virus and so are 'flying virus factories' (Huger, 1972; 2005) responsible for its dispersal.

Larvae die from the infection (*Figure 11*) and their cadavers release new OrNV into the breeding sites, where adults are infected by ingesting it there or during mating. The adult life-span is shortened, and females cease oviposition. Safety testing showed it to be harmless to vertebrates (Food and Agricultural Organisation of the United Nations, 1978; Gourreau *et al.*, 1979; 1981; 1982). OrNV is readily propagated by infecting larvae or adults, or in insect tissue culture, but is rapidly inactivated in the environment, possibly by bacterial or fungal decomposition (Bedford, 2013). Various methods of detection have been developed and the current method uses PCR techniques to detect OrNV DNA in midgut tissue from larvae or adults (Ramle *et al.*, 2001). Possible differences in virulence of different geographic isolates have been suggested (Zelazny, 1979), but in the past there has been no way to measure doses of virions administered.

Figure 11. Oryctes rhinoceros *– healthy third-instar larva on left, OrNV- infected on right with prolapsed rectum.*

Significant reductions in *O. rhinoceros* populations and damage have been achieved when OrNV isolates have been released into coconut palm environments in locations in the western South Pacific and Indian Oceans, and West Asia, where the virus did not previously exist. Readers are referred to reviews such as Bedford (1980; 2013), Gopal *et al.* (2001), Jackson (2009) and Jackson *et al.* (2005) which provide an entry to the extensive literature on the use of OrNV in the coconut palm context over past decades, and on the details provided in the above overview.

Malaysia

There has been only one study of OrNV in the oil palm environment. This was in Malaysia where 33%-65% of pheromone-trapped adults, and 0%-52% of adults from breeding sites were found infected (Ramle *et al.*, 2005). In an oil palm plantation on the west coast, 38% of trapped adults were found infected with isolate A (= Philippines isolate PV505). An isolate B (= Ma07) was extracted from adult midguts and considered more virulent as it caused higher mortality in larvae and adults after standardising doses by comparative PCR of its DNA (though the number of virions in a dose is unknown). Adults were trapped, infected with isolate B and released, and small samples of the population were tested. Eleven months later, more than 90% of trapped adults were found infected and B dominated, having spread from release sites and apparently out competed isolate A. Five months after release, 11% of larvae were infected but this level soon fell, suggesting little transmission occurred among immature stages. So at locations where breeding sites are abundant, there is a high probability of many new healthy adults emerging to cause damage, even when the incidence of OrNV among adults is relatively high.

DISCUSSION

It is of interest that in coconut palm-growing areas where OrNV is not endemic [*i.e.* not autochthonous (Huger, 2005)] it has proved to be an important component of IPM against *O. rhinoceros* (Bedford, 1980; 2013) when introduced, whereas where it is endemic, *e.g*. Malaysia, it is not relied on as a chief control agent in oil palm replanting areas where large amounts of shredded old trunk material temporarily provide abundant breeding sites despite high incidence among adults (Norman and Basri, 2007). Hence the use in Malaysia of pheromone traps, and *M. anisopliae*. In South Pacific coconut areas, there have been no peer-reviewed accounts of the ongoing effect of OrNV on damage for decades apart from Viti Levu, Fiji, where damage was still low about 35 years after OrNV was established at certain sites (Bedford, 2013).

The possibility of an upsurge of damage has been mentioned if there is an increase in breeding sites (Jackson *et al*., 2005). However, this would require ongoing monitoring both of the damage levels and occurrence of breeding sites within and in the vicinity of study areas. Hochberg and Waage (1991) suggested that if *M. anisopliae* were used as a biopesticide, it might reduce *O. rhinoceros* to a level where OrNV might die out, but it seems likely (Bedford, 2013) to be replenished, especially on larger islands or continental landmasses, by infected adults flying in from outside the treated areas. Wherever temporarily abundant breeding sites occur, such as in oil palm replant areas, any reduction in immature stages, or older adults visiting breeding sites, is likely to lead to a beneficial reduction in adult attacks to palms at that location, unless significant immigration occurs. This is because in both partially burned and zero-burnt chipped oil palm trunk material, *O. rhinoceros* stages, predominantly third-instar larvae, appeared three months after felling and chipping, and were abundant after 13 months (Cik Mohd Rizuan Zainal Abidin *et al*., 2014).

The bacterial pathogens *B. thuringiensis* and *B. popilliae* in breeding sites in Malaysia (Norman *et al*., 2007) and *Acinetobacter calcoaceticus* in India (Kannan *et al*., 1980) and *Pseudomonas* alcaligenes in Kerala, India (Gopal and Gupta, 2002; Gopal *et al*., 2002) may conflict with OrNV for hosts. Wherever different pathogens co-exist in breeding sites, it is possible there may be competition or conflict between them for hosts unless there are seasonal differences in the abundance of each, in which case they may complement each other in regulating *O. rhinoceros* numbers.

In any country where OrNV is endemic, or introduced, any spontaneous change in its DNA sequence creates a new isolate. If such a new variant were to be considered beneficial to release, this would entail trapping of adults, testing to ensure they were virus-free, then infecting and releasing them (Ramle *et al*., 2005) and accepting the associated costs. And, an unknown proportion of these adults might then disperse from the area being observed (Marshall and Ioane, 1982).

Hochberg and Waage (1991) proposed a model in which OrNV is transmitted from infected feeding adult to susceptible feeding adult, occurring predominantly in palm crowns. While copulation has been noted in split coconut log breeding site traps (Cumber, 1957), mating by *O. rhinoceros* in crowns of coconut palms or at the entry to feeding holes in young oil palms has not been observed. Is the aggregation pheromone released there, or in breeding sites, or in both?

While it is possible that infected adults may defaecate OrNV at or in their feeding holes, there is no published evidence of OrNV having been found there, or how long it would persist, or the likelihood of a second adult attacking the same palm (whether coconut or oil palm) and visiting the same hole and becoming infected, before the deposited OrNV becomes inactivated and disappears. [In experiments with feeding treated or stored OrNV samples to third-instar larvae (L3) in attempts to cause infection, variable results have been found – Paulose and Abraham (2002) found samples held for 4½ hr at 37°C had lost all infectivity, while Mohan (1991) found all infectivity was gone after eight days when the OrNV samples had been mixed with cow dung.]

In the past discussion of virulence of geographic isolates of OrNV has been problematic as the doses and resulting LD_{50} were expressed as amounts of suspended OrNV-infected tissue (ground-up infected larvae fed to larvae or haemolymph from infected larvae injected into adults), so the number of infective virions in doses is always unknown (Bedford, 1980). Also, 'virulence' can vary among authors, meaning time taken to die, or % mortality, or LD_{50}. While such dosages can be sufficient for field releases (as summarised in Bedford, 2013), exploring 'virulence' in the laboratory requires accurate doses in number of virions per millilitre (Jackson *et al*., 2005), although this may be difficult to achieve. A solution might be comparative PCR (Ramle *et al*., 2005) which may be developed to become a reproducible index of the number of virions in a dose (Bedford, 2013). A further problem with the LD_{50} measure is that it implies 50% of a test batch of larvae or adults receiving the dose (presumably a large number of virions) survive in the experiment, a survival for which there is currently no explanation.

If virulence is defined as causing more rapid kill, selecting more virulent strains for release leading to earlier death, could be detrimental to transmission of OrNV (Young, 1974) as it would lead to more rapid death of larvae and subsequent decomposition

and inactivation of OrNV in breeding sites, and a shorter life-span for adults during which they could act as 'mobile virus factories' (Huger, 2005) for virus dissemination. So, less-virulent strains may evolve and come to be more widespread in the wild (Alfiler, 1992), such as isolate A from the Malaysian Peninsula or isolate C from Sabah (Ramle *et al.*, 2005). In the oil palm environment, whether immature stages take a longer or shorter time to succumb to pathogens such as OrNV (due to having ingested smaller or larger numbers of virions of more- or less-virulent genotypes respectively) or *M. anisopliae*, in breeding sites seems of little or no significance from an IPM perspective – the important thing is they die eventually resulting in reduction in the number of adults emerging from breeding sites to attack palms in the replant areas. For this reason, factors involved in transmissibility (which might be difficult to identify) of different OrNV isolates, leading to eventual death, could be more important than solely percentage mortality or time taken for larvae to die.

The considerable investment and commitment to pheromone trap deployment and maintenance as a component of IPM against *O. rhinoceros* is widely accepted by oil palm plantations in South-east Asia, bearing in mind it may be difficult to estimate what proportion of the wild population originating in, or immigrating into, the trap deployment area, is caught. This might vary with location. And, they might perhaps catch only a portion of the component of the population that is in a physiological state to go to traps at that time, as found for *O. monoceros* (Allou *et al.*, 2008). And, traps baited with E4-MO are competing with wild males emitting the pheromone. One may speculate that, presumably, beetles follow a pheromone gradient 'trail' to reach an emitting male or a trap, and this gradient is disturbed by any wind occurring (during which time attractant emitted is ineffective and thus wasted). Further information on how beetles move to a trap would be of interest and from what distances they come. Data indicate they may travel an average of 19 m per day or about 140 m per week towards traps in areas where there are abundant feeding and breeding sites, but possibly much longer distances where these resources are scarcer (Norman and Basri, 2004). Also, what happens on approaching the trap would be of interest – what proportion might 'skip' and not fall in (Kalidas, 2004)? If a beetle hits the vanes but happens to fall outside, does it remain in the vicinity and keep trying to get into the trap, or does it divert to nearby palms? While interesting, these inquiries could be difficult as beetle flight activity is nocturnal, and unpredictable to any particular trap being observed. In Malaysia, beetles from various populations were morphologically indistinguishable, and DNA studies showed high gene flow between closely and distantly located populations on the Peninsula. This seems to exclude, for now, the possible existence of cryptic species complexes in *O. rhinoceros* having differing attraction to E4-MO pheromone traps Manjeri *et al*. (2014).

Volatiles emitted by palms appear important in the life of rhinoceros beetles, and would be of interest for further investigation. Emitted volatiles are presumably involved in the attraction of *O. rhinoceros* to layers of shredded oil palm trunk chips, heaps of empty fruit bunches and mesocarp waste, and to the tops of dead standing coconut palms and decaying coconut logs, for oviposition, and possibly mating there beforehand. These materials when added to pheromone traps boosted catches. Empty fruit bunches or decaying coconut wood when added to pheromone traps increased catches of *O. monoceros* (Allou *et al.*, 2006). Catches of the date palm pest *O. elegans* Prell are boosted by adding fresh date palm tissue to the 4-methyloctanoic acid pheromone traps (Rochat *et al.*, 2004). Volatiles emitted by living palms presumably attract beetles for feeding, so might perhaps act in concert with the male aggregation pheromone in attracting beetles to feeding or mating sites, and volatiles emitted by decomposing palm tissue may perhaps attract beetles to breeding sites for mating or oviposition or both.

In Malaysia, *Bacillus* spp. cause mortality of immature stages in breeding sites (Norman *et al.*, 2001; 2007) but have not been proposed for propagation and release. With *M. anisopliae* already present, and available for release to boost its level, OrNV strains present and also available for possible release, and *Bacillus* spp. present, there is three-way competition between these pathogens. Where possible, the necessary expertise and facilities being available, monitoring of these pathogens in immature stages in breeding sites, and of *Metarhizium* and OrNV in adults from pheromone traps, would be desirable, with a view to maximising the contribution to IPM of each in oil palm plantations of all sizes. Similarly, in the use of pheromone traps, are the trapped beetles to be removed from the population, or used to disseminate strains of OrNV, or *M. anisopliae*? Developments in IPM against *O. rhinoceros*, which may evolve in the future, seem likely to be based on existing methods.

Following replanting, pulverisation of old trunks, and use of cover crops, the decision as to which components of IPM against *O. rhinoceros* to implement, may well be fluid and depend on the ecological situation each oil palm plantation confronts at that time, based on accumulated experience.

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