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Comparison of the Breeding Performance of the Barn Owl *Tyto alba javanica* under Chemical and Bio-based Rodenticide Baiting in Immature Oil Palms in Malaysia

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ABSTRACT

The breeding performance of barn owl, *Tyto alba javanica*, in areas treated with rodenticides in immature oil palms in Malaysia was investigated. Four plots were established, each at least 100 ha in size and treated with warfarin, brodifacoum, a biorodenticide (*Sarcocystis singaporensis*) and a non-baited control plot. Three rat baiting campaigns, which coincided with the barn owl breeding season, were carried out in October 2008, February and March 2009, and in October 2009. The nest boxes were distributed at a mean density of one unit per 25 ± 3.83 ha. The clutch size, hatching and fledging rates of barn owls in each plot was monitored monthly from September 2008 to January 2010. There was no significant difference in mean clutch size for all four treatments. The lowest percentage of hatching success was recorded in the brodifacoum-treated plot in all three breeding seasons. Fledging success was highest in the control plot, followed by the *S. singaporensis*-, warfarin- and brodifacoum-treated plots. The mean clutch size and mean hatching success was not significantly correlated with mean rat damage (clutch size, $r = 0.754$, $p > 0.05$; mean hatching success, $r = 0.832$; $p > 0.05$). The mean fledging success was significantly correlated with mean rat damage ($r = 0.969$; $p < 0.05$). Brodifacoum achieved the lowest level of rat damage but not significantly lower than warfarin and *S. singaporensis*. This indicates that *S. singaporensis* is a better rodenticide than warfarin and brodifacoum in controlling rats and yet achieved the highest reproductive rates in the baited areas as reflected by the rate of fledging success.

Keywords: brodifacoum, *Sarcocystis singaporensis*, secondary poisoning, warfarin, rodent control

INTRODUCTION

The barn owl *Tyto alba* occupies a wide variety of habitats with almost a worldwide distribution (Stangl and Shipley 2005). They primarily hunt rodents, and the choice of prey is influenced by the relative abundance of the species present (Heubschman *et al.* 2000; Cameron 2003). In Malaysia, *T. alba javanica* has been encouraged to breed naturally to control rat problems and boosting their numbers through provision of nest boxes in several crops, such as in oil palm plantations (Chia and Lim 1995), cocoa (Lee and Ho 1999) and ricefields (Hafidzi and Naim 2003).

Rat damage can be a serious problem to immature oil palms, where losses caused by rats has been estimated at 5% and can reach up to 30% of reasonable yield if no action is taken (Wood and Chung 2003). In Malaysia the barn owl *T. a. javanica* primarily preys on rats but will only be effective in controlling the latter in combination with rodenticides (Smal *et al.* 1990; Chia and Lim 1995). Rodenticide residues on the other hand can have harmful cumulative effects on *T. a. javanica* through the food chain in the long term (Lenton 1984).

Here, we look at three different rodenticides. Warfarin is a first generation anticoagulant that has been widely used in biological control in conjunction with *T. a. javanica* without any marked deleterious results being recorded in adult birds of barn owl (Duckett 1984) and tawny owl (Townsend *et al.* 1981). However, it is possible that this rodenticide may have some negative effects on egg and chick survival, although this has yet to be discerned (Smal 1989). The use of the second generation anticoagulant, brodifacoum, has proven to be toxic to birds and mammals (Lambert *et al.* 2007; Walker *et al.* 2008; Dowding *et al.* 2010) and to *T. alba* in particular, as demonstrated in the laboratory (Mendenhall and Pank 1980). Besides chemical rodenticides, we also look at a parasite that has recently been used as a biorodenticide. *Sarcocystis singaporensis* is a protozoan which develops in the gut of the reticulated python *Python reticulatus* and trials have proven that rats of the genera *Rattus* and *Bandicota* can be alternative hosts (Jakel *et al.* 1999). This parasite causes a debilitating muscle infection in the host and the weakened rats become easier prey for raptors and other potential predators (Wood 2001).

The objective of this study was to evaluate and compare the effects of warfarin, as a first generation rodenticide, brodifacoum, as a second generation rodenticide, and *S. singaporensis*, as a protozoan-based biorodenticide on the reproductive performance of *T. a. javanica* and the subsequent impact upon rat control in an immature oil palm area.

MATERIALS AND METHODS

Location and period of the study

The study was conducted in immature oil palm at FELCRA oil palm plantation scheme in Seberang Perak (4° 02′ N, 100° 53′ E), Perak, Malaysia from September 2008 to December 2010. The study sites constitute part of the replanting area started in mid 2007.

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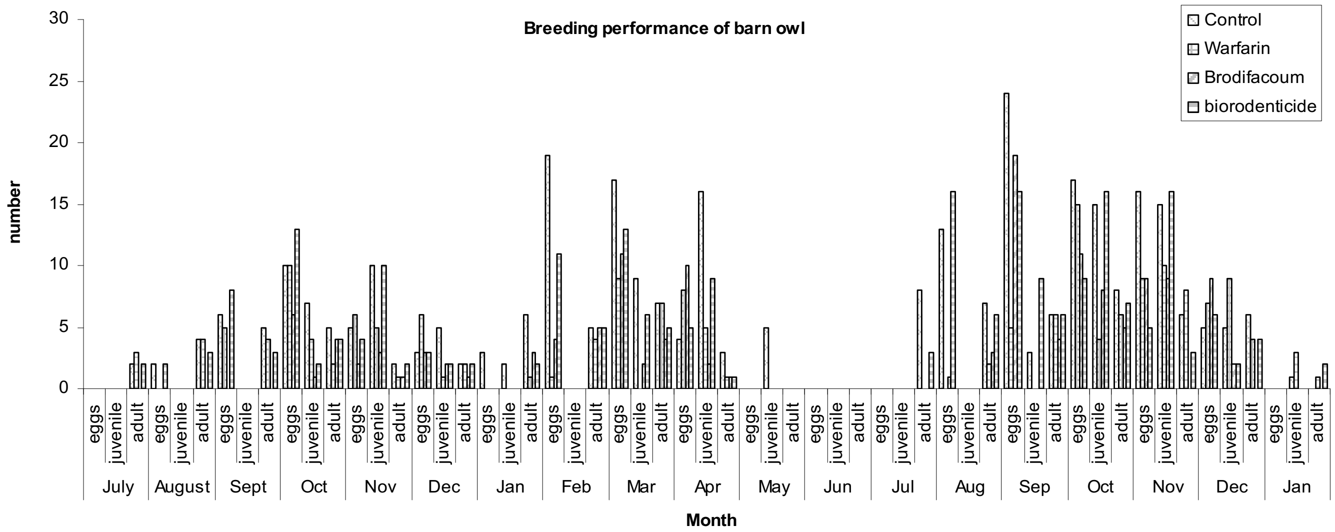

Fig. 1 Mean clutch size, hatching success and fledging success of *Tyto alba javanica* in untreated control plot and rodenticide-treated plots in immature oil palm plantation in Seberang Perak.

Baiting and treatment

Twenty two artificial nest boxes, constructed out of wood, were erected between April and June 2008 in the immature palm by Felcra management. Four treatment plots were established, and the distance from one treatment to another was around 8-10 km apart. The area for each plot was no less than 100 ha. Three plots were separately baited with warfarin, brodifacoum and the biorodenticide *S. singaporensis*. The fourth plot was left untreated and served as the rodenticide-free control plot. The average nest box density was 1 box for 25 ± 3.83 (S.D) ha. The first baiting campaign for all three rodenticides was carried out on 20-25th October 2008. The second baiting campaign for warfarin and brodifacoum on 10-12th March 2009, while second baiting campaign for biorodenticide was carried out on 25-27th January 2009. The third baiting campaign was carried out on 28 September to 3rd October 2009 for all three rodenticides. The baits were placed at the base of the palm tree. In the first campaign, a single round of baiting was carried out while two baiting rounds were conducted in the second and third baiting campaigns.

Breeding performance of *Tyto alba javanica*

The number of eggs laid and hatched and the number of owlets fledged was recorded regularly by inspecting and counting all nest boxes. Owlet considered successfully fledged if not found in the nest box anymore. Data was collected until the third breeding season ended.

Rat damage

Rat damage assessment was conducted every month during the study. Assessment of rat damage was carried out on four selected blocks for each treatment. For each block, one row from every ten rows of palms (10%) was inspected to determine percentage of rat damage. Percentage of fresh damage was used to quantify the severity of damage on all plots.

$$\%\ \text{Fresh damage} = \frac{\text{No. of palms damaged}}{\text{Total No. of palms assessed}} \times 100\%$$

Data analysis

Mean clutch size, mean hatching success and mean fledging success from three breeding seasons was calculated and compared for significant difference at the 0.5% level using one-way analysis of variance (ANOVA) since data was normally distributed. To detect significant differences between means, the least significant difference (LSD) test was used.

The percentage of rat damage was square-root transformed to make data distributed normally and analyzed by one-way ANOVA. To detect significant differences between means the LSD test was used.

Pearson correlation analysis was carried out to investigate whether rat damage levels were correlated with the mean clutch size, mean hatching success and mean fledging success.

All analyses were carried out using statistical package SAS Program Version 9.2.

RESULTS AND DISCUSSION

Breeding performance of *Tyto alba javanica*

One of the main advantages of using *T. a. javanica* as a biological control agent against rats in oil palm plantations is that they readily occupy artificial nest boxes provided for them and thus can be easily monitored. In mature oil palms, *T. a. javanica* breeds throughout the year, although two distinct breeding peaks can be distinguished: from July to October and from November to February (Smal 1989). However, in immature oil palm plantations the peak breeding periods tend to be from July to October and from January to May (**Fig. 1**).

The average clutch size of *T. a. javanica* in oil palm plantations is 6.6 (Lenton 1984), with the mean dimensions of the eggs being 41.9 mm × 33.1 mm, and a mean weight of 26.1 g. The weight of the clutch is generally closely related to the female body weight, with the eggs weighing approximately 4.9% of the weights of female (Taylor 1994). Incubation begins with the first egg and continues for a period of 31 to 35 days for each egg, where the mean is 32.6 days. Total incubation periods of the clutch varies from 40 to 52 days from the first egg laid to the last hatched (Lenton 1984). The hatching success rate of *T. a. javanica* in oil palm plantations is 79.8%. Mean hatching weight is 18.46 g. The mean weight changes with the growth of the chicks, where the greatest weight is normally achieved by the largest individual in the brood, and varies according to brood size. The recorded fledgling success in Malaysia is 81.2% (Lenton 1984).

Mean clutch size of *Tyto alba javanica*

Based on the three breeding seasons of *T. a. javanica* assessed, no significant difference for mean clutch size was found for all four treatments (ANOVA; $p > 0.05$) (**Table 1**). Pearson correlation analysis showed that the mean clutch size of *T. a. javanica* in immature oil palm was not significantly correlated to mean rat damage ($r = 0.754$; $p = 0.242$) (**Fig. 2**). Mean rat damage at the time when owls were laying their eggs tended to be comparable across all treatments, i.e.; 5.36, 4.32, 5.07 and 5.99% in the warfarin-, brodifa-

Table 1 Mean clutch size of *Tyto alba javanica* in all plots. Values represent mean ± standard deviation (SD).

Treatment	**Clutch size**			**Mean**
	1st breeding season	**2nd breeding season**	**3rd breeding season**	
Control	4.50 ± 0.58	5.20 ± 0.45	6.60 ± 1.67	5.43 ± 1.07 a
Warfarin	4.60 ± 1.15	3.25 ± 2.06	4.00 ± 1.22	3.95 ± 0.68 a
Brodifacoum	3.50 ± 2.12	4.33 ± 1.15	6.67 ± 0.58	4.83 ± 1.64 a
Biorodenticide	4.50 ± 2.52	4.75 ± 0.50	5.60 ± 2.19	4.95 ± 0.58 a

Means with the same letter in a column are not significantly different ($p > 0.05$) according to LSD.

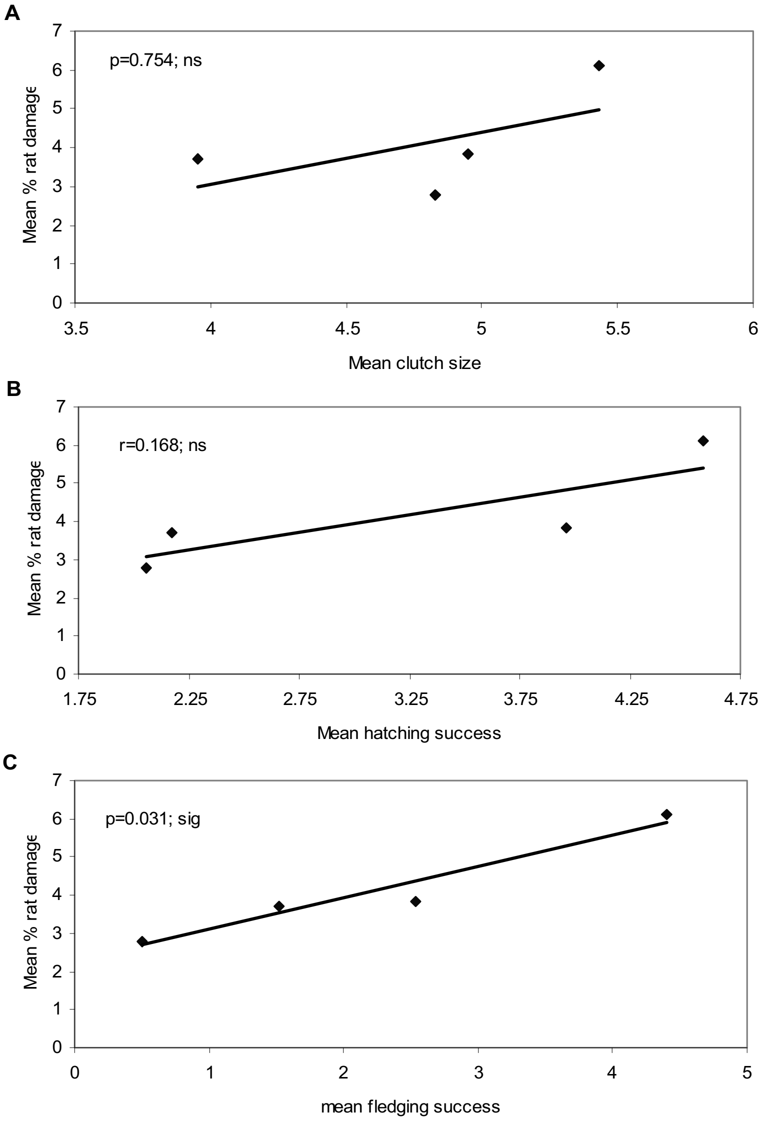

Fig. 2 Relationship between mean rat damage and mean clutch size (**A**), mean hatching success (**B**) and mean hatching success (**C**) of *T. alba javanica* in immature oil palm area.

coum-, and biorodenticide-treated plots and the control plot, respectively. This means the rat populations at the start of the experiment was similar across the plots as baitings were carried after most of the eggs have been laid. This explains why there was no difference in the mean clutch size among treatments. Taylor (1994) found that the clutch size of *T. alba* was correlated to the food supply, producing bigger clutch sizes if food is abundant and smaller clutch sizes if food is scarce. Wood and Liau (1984) showed that rat populations range from 200 to 600 per ha if no control measures were taken. Lenton (1984) stated that if a barn owl consumes rats that have ingested bait, the rodenticides will be transferred to the eggs while not disrupting actual egg production. This would indicate that the rodenticides are being metabolized and the rodenticide load is presumably removed in the form of addled eggs. Barn owls are indeterminate egg layers and would thus keep laying until a clutch of rodenticide-free eggs is produced (Duckett 1984; Lenton 1984). Therefore even if the baitings were carried out before eggs were laid, a similar scenario could have arisen.

The mean clutch size in this study was lower than that reported by Lenton (1984) i.e. 6.6 in mature oil palm area. This could be attributed to the higher rat populations found by Lenton in mature palm compared to the numbers found in the immature palm in this study. Another possible reason is that mature palm has a number of advantages over immature palm, such as much more suitable fronds for perching. Direct observation in the field has shown that *T. a. javanica* in immature palm often perch and wait for prey in the much higher placed fronds of an adjacent mature palm area. This suggests that the fronds of immature palm are too low to provide a suitable vantage point for the bird to scan for prey. Also, the denser canopy of mature palm provides more shade, rendering a much cooler habitat than that found in an immature area (Lenton 1984; Smal 1989).

Table 2 Mean hatching success of *Tyto alba javanica* in all plots. Values represent mean ± standard deviation (SD).

Treatment	**Clutch size**			**Mean**	**Percentage of hatching success**
	1st breeding season	**2nd breeding season**	**3rd breeding season**		
Control	3.75 ± 0.95	4.40 ± 0.55	5.60 ± 1.14	4.58 ± 1.07 a	84.42 %
Warfarin	2.67 ± 1.16	1.25 ± 0.96	2.60 ± 0.55	2.17 ± 0.80 c	55.32 %
Brodifacoum	1.50 ± 2.12	1.00 ± 1.73	3.67 ± 1.53	2.06 ± 1.42 d	42.50 %
Biorodenticide	3.25 ± 1.26	3.50 ± 0.58	4.40 ± 1.95	3.96 ± 1.52 b	75.38 %

Means with the same letter in a column are not significantly different ($p > 0.05$) according to LSD.

Table 3 Mean fledging success of *Tyto alba javanica* in all plots. Values represent mean ± standard deviation (SD).

Treatment	**Clutch size**			**Mean**	**Percentage of hatching success**
	1st breeding season	**2nd breeding season**	**3rd breeding season**		
Control	3.50 ± 1.29	4.20 ± 0.45	5.50 ± 1.00	4.40 ± 1.01 a	77.92%
Warfarin	2.20 ± 1.00	0.75 ± 0.50	1.60 ± 1.55	1.52 ± 0.73 c	36.17%
Brodifacoum	0.50 ± 0.70	0.33 ± 0.58	0.67 ± 1.15	0.50 ± 0.17 d	10.00%
Biorodenticide	2.75 ± 0.50	2.60 ± 1.14	2.25 ± 0.50	2.53 ± 0.26 b	50.76%

Means with the same letter in a column are not significantly different ($p > 0.05$) according to LSD.

Mean hatching success of *Tyto alba javanica*

The study also indicated that *T. a. javanica* in the control plot showed a consistently and significantly higher mean hatching success compared to rodenticides treated plots. The brodifacoum treated plot showed significantly lower hatching success compared to biorodenticide and warfarin treated plots, while the warfarin treated plot also showed significantly lower hatching success compared to the biorodenticide treated plot (**Table 2**). The percentage of hatching success was also influenced by the availability of rat prey as the main source of food for *T. a. javanica* and during the brooding period, breeding females depend fully on males for food (Taylor 1994; Vandenbroucke *et al.* 2008). If males can bring sufficient food it will increase the hatching success. In the untreated control plot, the rat population is more stable because there was no rodenticide application to suppress numbers. A stable rat population will provide sufficient food, thereby increasing the hunting success of *T. a. javanica* which in turn will lead to greater hatching success.

The lowest percentage of hatching success was recorded in the brodifacoum-treated plot in all three breeding seasons (**Table 2**). Another interesting observation from nest inspection was that brooding females in the control and the biorodenticide-treated plots were always found on the nest throughout the incubation period; no breeding pairs in those areas were found to abandon their eggs. In contrast, a breeding pair in the brodifacoum-treated plot left their nest box in the first breeding season, abandoning two eggs just five days following baiting. The eggs were left abandoned until the end of the breeding season. A similar situation was recorded in the second breeding season where two out of three breeding pairs abandoned their nest boxes and eggs (with five and three eggs, respectively) following baiting with brodifacoum. There is a possibility that these breeding pairs may have succumbed to secondary poisoning from consuming rats that had fed upon the brodifacoum baits. However, attempts to recover the carcasses of the presumed dead owls were unsuccessful. Similarly in the warfarin-treated area, no breeding pairs abandoned their eggs in the first breeding season but one of the four breeding pairs abandoned their five eggs in the second breeding season. If warfarin bioaccumulates in eggs then this indicates it is metabolized and the warfarin load would presumably be removed in the form of one batch of addled eggs (Duckett 1984; Lenton 1984).

The mean rat damage during incubation periods in the warfarin-, brodifacoum- and the biorodenticide-treated plots and the untreated control plot was 3.04, 1.78, 3.24 and 6.37%, respectively. The correlation between mean rat damage and hatching success was not significant (Pearson correlation, $r = 0.832$; $p = 0.168$) (**Fig. 2**).

Mean fledging success of *Tyto alba javanica*

Tyto alba javanica in the control plot consistently showed the highest mean fledging success compared to the rodenticides treated plots in all three breeding seasons. The biorodenticide-treated plot showed higher mean fledging success compared to the chemical rodenticides treated plots. The brodifacoum-treated plot had a significantly lower fledging success compared to the warfarin-treated plot (**Table 3**). There was a significant, positive correlation between mean rat damage and mean fledging success (Pearson correlation $r = 0.969$; $p = 0.031$) (**Fig. 2**). Mean rat damage in the warfarin-, brodifacoum- and biorodenticide-treated plots and the untreated control plot was 3.07, 2.34, 3.47 and 6.19%, respectively. Fledging success of juveniles was also apparently influenced by the availability of prey, as chicks seemed to be fully dependent on adult males to deliver the prey.

This study indicates that *T. a. javanica* in the untreated control plot showed the highest percentage of fledging success compared to the treated plots; followed by the biorodenticide-, warfarin- and brodifacoum-treated plots (**Table 3**). The higher recruitment in the control plot indicated a stable rat population as shown by rat damage census over the 16 months study period in that area (**Fig. 4**). In the rodenticide-treated areas, especially the warfarin and brodifacoum area, rats, as the main prey, fluctuated in numbers and decreased drastically after the baiting campaign as shown in rat damage census. A similar finding was also reported by Wood and Liau (1977) and Wood (2001) where the rat population decreased shortly after the rat baiting campaign. This decrease in rat prey will reduce hunting success, especially during the breeding season, leading to less prey delivered to females and chicks. As chicks grow asynchronously in barn owls, less food means that only the older chicks will get fed and the younger chicks will die from starvation. Casual observation indicates that younger chicks seem to loose weight when compared to the weeks before and after the latter were found dead in their nest boxes.

Chicks in the warfarin- and brodifacoum-treated plots also face the risk of secondary poisoning by feeding on rats brought to the nest which have ingested the baits. Usually, there is a time lapse before the rats succumb to the chemical rodenticide consumed (Hadler 1984; Buckle 1994). While the consumed anticoagulant rodenticides are taking effect, poisoned rodents remain active and become more exposed to predation (Wood and Chung 2003).

In general, the percentage of fledging success of *T. a. javanica* in immature oil palm, especially in the untreated control plot (77.92%), was comparable to 81.2% as reported by Lenton (1984) in mature palm. This finding again indicates that higher rat damage in the untreated control plot that was also associated with higher rat populations are more stable and that *T. a. javanica* secured enough food throughout the breeding season and in turn produced more

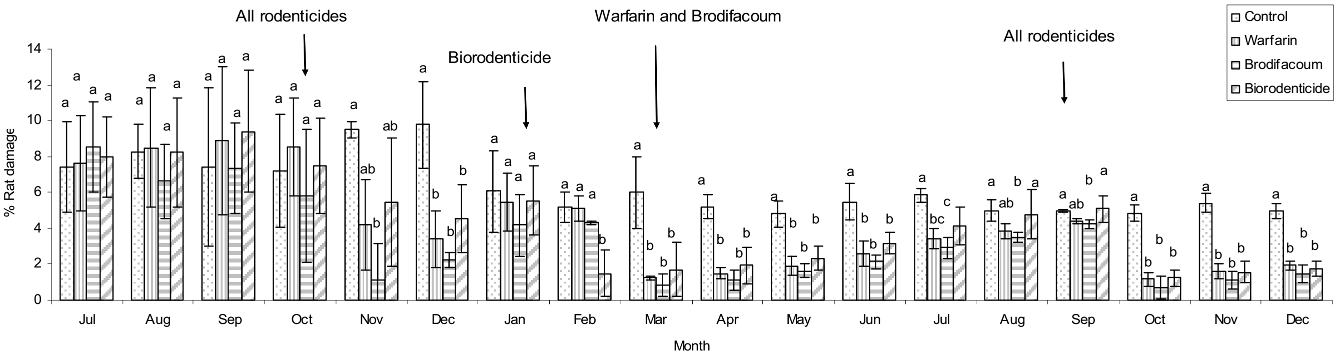

Fig. 3 Mean percentage of rat damage in all plots from September 2008 to December 2009. Arrows indicate rodenticide application. *Different letters for each month indicate significant differences according to the LSD test ($p < 0.05$).

young compared to the rodenticides treated plots. *T. a. javanica* in the brodifacoum treated plot produced very few young, although their clutch sizes were comparable to the untreated control plot.

Although *S. singaporensis* is reportedly not harmful to non-target animals other than rats from genera *Rattus* and *Bandicota* (Jakel *et al.* 1996), this study showed that baiting with *Sarcocytis singaporensis* did indeed have a direct effect on the breeding performance of *T. a. javanica*. The plausible explanation for this is that the rat population, as the main food item for the birds, decreased drastically following the baiting campaign as shown in rat damage census, and this, in turn, caused a marked reduction in the hunting success and food delivery to the female and the chicks (Taylor 1994).

Rat damage in rodenticide-treated plots fluctuated during the study, low after the baiting campaign and increased gradually after baiting; while rat damage in the untreated control plot tended to be much more stable, although there was some indication that rat damage was lower at the end compared to the beginning of the study. Based on the correlation made between rat damage and breeding performance, only the mean fledging success showed a positive correlation to rat damage. This finding indicates that adequate rat population density is very crucial during that stage because the nestlings need more rat prey for their optimum growth. When males fail to deliver sufficient food, chicks will starve and die if food continues to be scarce (Lenton 1984; Taylor 1994). Smal (1989) postulated that a residual rat population is needed to support the breeding of *T. a. javanica.* The presence of rats must be tolerated, and he calculated that the rat populations of around 15–50 rats per ha (rat damage around 5%) is sufficient to support optimum growth of chicks. In practical terms, a criterion of 5% fresh damage has been suggested before a campaign baiting commences (Highland Research Unit 1987). This finding can be combined with baiting with harmless rodenticides such as biorodenticide to minimize the secondary poisoning effects on birds.

Rat damage in immature oil palm

Rat damage analysis shows that rats can cause serious problems in immature oil palms if there is no rat control program. In the untreated control plot, rat control was solely by predation of *T. a. javanica* and rat damage analysis suggested that *T. a. javanica* contributed moderate control 24 months after the nest boxes were installed (**Fig. 3**). Rat damage fluctuated in the untreated control plot, from as low as 4.81% (May 2009) to as high as 9.78% (December 2008). Nonetheless, rat damage at the end of the study was lower compared to the damage incurred at the start of the census.

The ability of *T. a. javanica* to deal with rat infestation has been acknowledged by several authors (Smal 1989; Lenton 1984; Hafidzi *et al.* 2007). However, this study shows that rat damage, as an indication of control success, fluctuates from month to month in untreated control plots, despite nest boxes having been in place for almost two years. Only in four instances from 16 months of assessment did the rat damage drop below the economic threshold level for rat damage in oil palm area (5%). This was probably attributed to the low density of nest boxes in the area i.e., an average of 1 box per 25 ha. A sustainable control can be achieved with a higher density of nest boxes i.e. 1 box for every 10 ha, as suggested by Ho and Teh (1997) and Anon (2004). Duckett and Karuppiah (1990), Smal (1989) and Anon (2004) suggested that control using *T. a. javanica* does not bring immediate effects and may need time before reaching a new predator-prey equilibrium.

In this study, *S. singaporensis* was effective against rodents from the genus *Rattus* as indicated by Jakel *et al.* (1999). However, correct application is necessary to achieve the desired result. A single round of baiting decreased rat damage in biorodenticide-treated plot slightly from 7.46 to 5.47%, and from 8.55 to 4.18% in the warfarin-treated area, but the reduction was not significantly different to the untreated control plot (9.49%) ($F = 4.65$; $p = 0.052$). Unlike biorodenticide and warfarin, brodifacoum can achieve control with only one baiting round (level of rat damage decreased to 1.11 from 5.80%); significantly lower than the untreated control plot, although not significantly different with the warfarin- and biorodenticide-treated plots ($F = 4.65$; $p = 0.052$) (**Fig. 3**).

When the baiting campaign was carried out in two rounds, it successfully lowered the rat damage further in the biorodenticide-treated plot to 1.48 from 5.56%, in the second baiting campaign to 1.24 from 5.09%, and in the third baiting campaign; significantly lower compared to the untreated control plot (5.20 and 4.85%, respectively) ($F = 14.84$; $p < 0.01$ and $F = 34.12$; $p < 0.01$, respectively*)*. Rat damage increased gradually after baiting but remained low (4.13%); and still significantly lower compared to the control plot (5.86%) ($F = 15.46$; $p < 0.01$) six months after baiting in the second baiting campaign. This suggests baiting with biorodenticide in combination with *T. a. javanica* can be effective in dealing with rat infestation.

The efficiency of *S. singaporensis* to suppress rat damage is comparable with that of warfarin based on the similar levels of mean rat damage achieved (**Fig. 4**), suggesting that this pathogen can be an effective substitute to chemical rodenticides; especially brodifacoum, which is harmful to non-target organisms (Mendenhall and Pank 1980; Eason *et al.* 2002). Two rounds of baiting with biorodenticide rather than a single round gave the desired result. In a single round of baiting, rats possibly took a sub-lethal dose of the infectious unit, thereby not causing mortality (Jakel *et al.* 1996; Boonsong *et al.* 1999).

Warfarin, like the biorodenticide, gave satisfying results only when a baiting campaign was carried out for at least two rounds. Two rounds of baiting brought about a drastic decrease in rat damage i.e. to 1.24 from 5.11% in the second baiting campaign and to 1.16 from 4.41% in the third baiting campaign, significantly lower than the untreated control plot (6.02%. $F = 19.79$; $p < 0.01$ and 4.85%, $F = 34.12$; $p <$

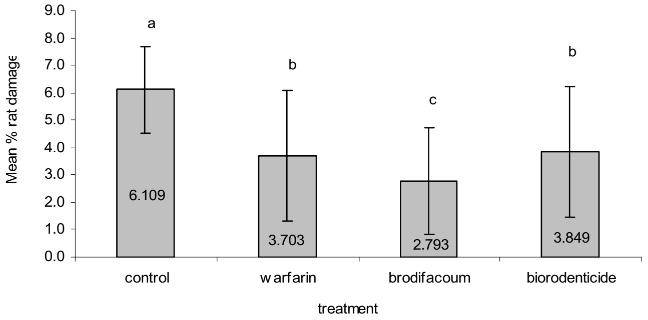

Fig. 4 Mean percentage of rat damage during the study. Bars represent standard deviation (SD).

0.01, respectively). Similar to the biorodenticide, rat damage in the warfarin-treated plot increased gradually after baiting. However, in contrast to the biorodenticide-treated plot that showed significantly less rat damage than the control area six months after baiting, the damage level in the warfarin-treated plot was 4.41% over the same period, which was not significantly different than the control plot (4.97%).

Warfarin is still effective against rats in the Felcra immature oil palm plantation of Seberang Perak. Records show that the plantation had not been baited with warfarin in the previous years. The resistance of rats to warfarin took place after systematic control began for 6 or 7 years and that the resistance of populations toward warfarin appeared after about 15 to 20 years (Wood and Liau 1977; Lam 1986; Wood *et al.* 1989; Wood 2001). This probably explains why warfarin is still effective against rats in that area. Nevertheless, two rounds of baiting are required before the desired result is achieved. Wood (2001) and Wood and Chung (2003) recommended the "replacement round system" campaign when employing warfarin to reach satisfying results. This is done by placing baits all around the base of the palm trees and replacing missing baits at 4-days intervals until bait acceptance dropped below 20%. This would give increased exposure of the bait to the more cautious or subordinate individuals, and allow more rats to take a higher dose "chronically" and minimize sub-lethal consumption of baits.

Brodifacoum was most effective compared to the other rodenticides; the level of damage decreased to 0.84% from 4.32% in the second baiting campaign and to 0.69% from 4.25% in the third baiting campaign. The damage level was significantly lower in the untreated control plot (6.02%, F = 19.79; $p < 0.01$; 4.85%, F = 34.12; $p < 0.01$), but not significantly different compared to warfarin- and biorodenticide-treated plot (F = 19.79; $p < 0.01$). Rat damage six months after baiting in brodifacoum-treated areas was significantly lower (4.25%) compared to the untreated control plot, but not significantly different to the warfarin-treated area (F = 4.15; p = 0.042).

Brodifacoum, a second generation anticoagulant, was introduced to deal with resistance against warfarin (Buckle 1994). It is more potent but also has a greater risk to non-target organisms (Newton *et al.* 1990; Shore *et al.* 1999). Brodifacoum has a similar mode of action to warfarin, i.e. inhibiting the normal synthesis of vitamin K-dependent clotting factor in the liver (Hadler and Shadbolt 1975; Buckle 1994), but effective at much smaller doses and does not require multiple feeding (Hadler 1984; Buckle 1994). This explains why a single round of baiting is sufficient to bring about effective control. However, care must be taken with the side effects of brodifacoum on non-target animals, particularly *T. a. javanica.* Brodifacoum is known to have a longer half-life in the blood and tissues of animals than warfarin, which is metabolized and excreted much more readily (Vandenbroucke *et al.* 2008). There are many reports around the world on secondary poisoning effects of brodifacoum to *T. alba*. Duckett (1984) reported that *T. a. javanica* was common in oil palm plantations in Malaysia during the late 1970's, but when brodifacoum was introduced to replace warfarin in order to deal with resistant rats in 1982, the numbers of *T. a. javanica* declined drastically only one year after its application, with owl carcasses frequently being found amongst palms. A secondary poisoning effect of brodifacoum was also reported by Newton *et al.* (1990). In a trial using captive birds in Britain, four out of six *T. alba* died 6–17 days after each consumed three mice fed with brodifacoum baits.

CONCLUSION

Biorodenticide, based on *S. singaporensis*, and warfarin are comparable to brodifacoum in suppressing rat populations if baiting is carried out in two rounds. However, unlike chemical rodenticides that pose great risk to non-target organisms, including *T. a. javanica*, through secondary poisoning, biorodenticide has no toxic effects if ingested by animals other than rats from the genus *Rattus.* Its high host specificity makes it safe to the environment and inert to non-target animals. This is a promising prospect for rat control in oil palm. Biorodenticide should be seriously considered as a substitute to chemical rodenticide which has been the mainstay in dealing with rat infestation, especially in cases of sudden outbreaks.

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