Effect of Coconut Mite-induced Changes in Coconuts on the Searching Behaviour of Predatory Mite, *Neoseiulus Baraki*

N. S. Aratchige*#, M. W. Sabelis** and I. Lesna**
*Crop Protection Division, Coconut Research Institute, Lunuwila, Sri Lanka
**Section Population Biology, Institute for Biodiversity and Ecosystem Dynamics (IBED), University of Amsterdam, Amsterdam, the Netherlands
#Author for correspondence (cpd@cri.lk)

ABSTRACT

The coconut mite, *Aceria guerreronis* is small enough to reach the meristematic surface under the perianth of coconuts where it is safeguarded from attack by many predators. However, recent experimental evidence shows that the coconuts respond to the coconut mite damage by changing the structure of the perianth to promote the access to predatory mites. This study investigates whether the coconut mite-induced changes in nuts attract predators and allow the predators into the site where the coconut mite feeds. Experiments with a T-tube olfactometer showed that the female predators of *Neoseiulus baraki* can discriminate between air currents carrying odours from coconut mite-infested nuts and uninfested nuts. In a release-recapture set-up under still air conditions, predators did not discriminate between infested nuts over uninfested nuts and between uninfested, perianth-manipulated nuts over uninfested, intact nuts within 1.5 hours.

Of the predators recaptured on the coconuts, per-nut fraction of predatory mites was larger under the perianth of infested nuts and the perianth-manipulated-uninfested nuts than under the perianth of uninfested nuts. There was no significant difference between the per-nut fraction of predatory mites under the perianth of infested nuts and that under the perianth of uninfested, manipulated nuts. The findings suggests that a change in the structure of the perianth, either due to herbivory or due to mechanical manipulation, facilitates predatory mites on the nut to move under the perianth.

Key words: *Coconut mite, Aceria guerreronis, biological control, Neoseiulus baraki, Perianth*

INTRODUCTION

Aceria guerreronis Keifer (Acari: Eriophyidae) is an important pest of coconut (*Cocos nucifera* L.) in different parts of the world (Keifer, 1965; Mariau, 1977; Mariau and Julia, 1970; Fernando *et al.*, 2002). It is the only nut-infesting mite that can cause substantial damage to the crop. The crop loss has been estimated to be 10% in Benin (Mariau and Julia, 1970), 16% in Ivory Coast (Julia and Mariau, 1979), 30% in Mexico (Hernandez Roque, 1977) and 11-28% in St Lucia (Moore, 1986) and 2-3% in Sri Lanka (Wickramananda *et al.*, 2007).

Several methods have been tested to control the coconut mite but most of them are without acceptable results (Ramaraju *et al.*, 2002). The peculiar characteristic of the coconut-coconut mite system is that the pest is in a concealed habitat of the host plant. This makes many chemicals to be less effective as they cannot reach the target pest. Because of the tall nature of the host plant which bears nuts of the susceptible stage throughout the year and the concern over environmental pollution, biological control is preferred over chemical control as a more sustainable, long-term strategy to contain and suppress the pest.

Predatory mites are among the potential biological control agents of coconut mite. Although several predatory mites have been reported to be associated with the coconut mite (Moraes and Zacarias, 2002; Moraes *et al.*, 2004; Lawson-Balagbo *et al.*, 2008), relatively a small number of studies have dealt with the possible use of predators to control coconut mite. Even the limited number of attempts to use predatory mites against the coconut mite has not achieved the results that are acceptable to the biological control scientists or the growers. The insufficiency in controlling the coconut mite using predatory mites is probably not so much due to the fact that the predatory mites not preferring coconut mites or due to the inadequate numerical and functional responses of predatory mites to the density of coconut mite. Observations both in the field and in the laboratory suggest that many potential predatory mites find it difficult to invade the habitat of the coconut mite, i.e. the area under the perianth of the nut (Fernando L.C.P., pers. comm.).

Coconut mite is among the smallest arthropods in the world and this is perhaps the key to its ecological success. The minute size allows it to live on the meristematic area under the perianth of fruits (nuts) of the coconut palm. Here, it finds a refuge from many predators, usually phytoseiids that are at least three times bigger than the coconut mite. When it is safeguarded from the predators, its population grows exponentially and develops into pest status, thereby causing considerable damage to the nut. However, the habitat under the perianth is not totally enemy-free for the coconut mite. There are at least a few predatory mites that are sufficiently equipped with morphological and/or behavioural traits that enable them to enter the area under the perianth. One such mite is *Neoseiulus baraki* Athias-Henriot (Acari: Phytoseiidae). It is the most abundant predatory mite associated with the coconut mite in Sri Lanka (Moraes *et al.*, 2004). It shows a strong temporal relationship with the density of coconut mite (Fernando *et al.*, 2003). Moreover, it has a flat and elongated idiosoma which enables it to reach the meristematic tissue under the perianth of the coconut where their prey feeds on (Moraes *et al.*, 2004). But why do only certain predatory mites do better than the others in this system? How does the palm actively involve in exposing the pest mites that are otherwise not reachable by the predatory mites? Understanding on how nuts respond to the coconut mite and thereby promote the effectiveness of the predatory mites would enhance perspectives for biological control of the coconut mite. Recent experimental evidence has revealed that, in response to coconut mite damage, the structure of the perianth changes and these changes are sufficient to give predatory mites, *N. baraki*, better access to the area under the perianth (Aratchige *et al.*, 2007). It was found that the mean maximum perianth-nut gaps (40-68 μm) at the perianth edge of uninfested nuts of cultivars "Sri Lanka Tall" (SLT), Dwarf Green (DG) and the hybrid DG x SLT (DGT) is large enough for the coconut mite (36-52 μm thick) to enter the area under the perianth, but too small for *N. baraki* (>100 μm thick). Interestingly, when the nuts are infested, the perianth-nut gap is increased to such an extent that even *N. baraki* can enter the area under the perianth (Aratchige *et al.*, 2007). The result of this study which analyses the statistical relations between plant cultivar, plant state (infested, uninfested), perianth-nut gap and the density of coconut mites and *N. baraki* has prompted mechanistic studies to reveal how the structural changes of the nut affect the searching-behaviour of *N. baraki*.

The objective of the study reported in this paper is to investigate how the coconut mite-induced structural changes in the perianth help the predatory mite, *N. baraki* to reach the area under the perianth.

MATERIALS AND METHODS

Predatory mites

Neoseiulus baraki, collected from infested nuts in the field, was reared on black plastic sheets

placed on plastic foam pads saturated with water in a plastic box. Wet tissue papers placed along the periphery of the plastic sheet prevented the escape of the predators and provided them with drinking water. Three such boxes were maintained in a tray with water and covered with another tray to provide high humidity and shade. Cultures were maintained in an incubator at *ca.* 25^{0}C. Coconut mites were provided as the food on every second day.

Odour sources

Young nuts (3 months old after fertilization) of the cultivar SLT were used as the odour source. Nuts that were 3 months old were specifically selected because they usually contain a substantial number of coconut mites, and either no or few predatory mites (Fernando *et al.*, 2003).

Olfactometer experiments

Response of predatory mites to volatiles released from selected nuts was studied in a T-shaped olfactometer which consisted of two glass tubes (each 12 cm long) connected by a plastic tube (Fig. 1). A glass capillary tube held inside the glass tubes enabled the predatory mites to walk on it and served as a 'railroad'. The base of the plastic tube was connected to a vacuum pump, causing air to move through the glass tubes to the base of the T-shaped plastic tube. Two identical glass jars that contained odour sources (3 months old nuts) were connected to two small plastic containers *via* plastic tubes. The air that entered the glass jars was filtered through charcoal. The plastic containers had wet filter paper on cotton wool at the bottom and they were connected to the glass tubes. At the end of each glass tube, an insect pin (bent at *ca.* 90^0) was connected to the capillary tubes. The insect pin helped to hold the capillary tube in position as well as to direct the predatory mites from the capillary tube to the center of the wet filter paper. The air speed inside the olfactometer was approximately 0.5 m/s as measured by a hot-wire anemometer inserted in-between the plastic containers and glass jars (Fig.1). Prior to use in the experiment, the predatory mites were starved in a pipette tip for 4 hours. When they were introduced by connecting the pipette tip to the center of the T-shaped plastic tube that connected the two glass tubes, they started to move on the capillary tube towards the end of a glass tube and entered the wet filter paper in the plastic container via the insect pin. Thirty minutes after the introduction of the predatory mites into the set up, the plastic containers

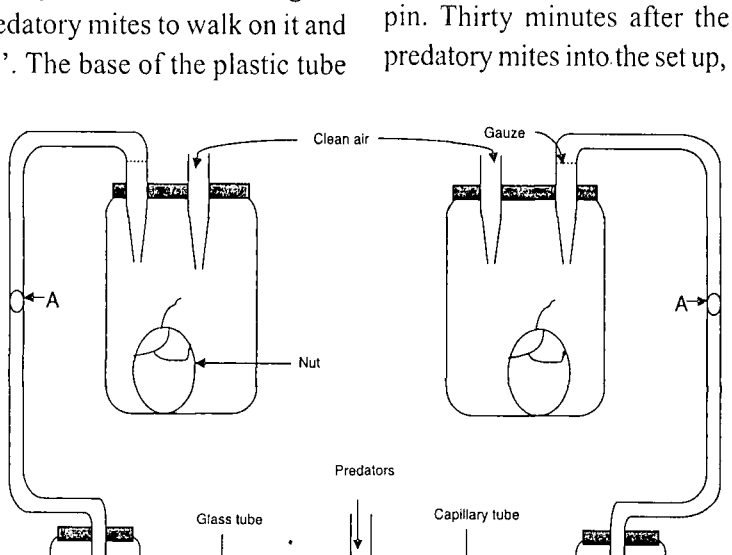

Fig. 1. *Arrangement of the T-tube olfactometer. A: Holes for hot wire anemometers in plastic tubes are covered with parafilm during the experiment.*

were disconnected from the glass tubes and the number of mites on the wet filter paper in each plastic container was counted. One infested nut placed inside one glass jar and one uninfested nut placed inside the other glass jar served as the odour sources in each replicate experiment. Collecting predatory mites was laborious in this setup. Therefore, in total, 3 replicate experiments (on 3 consecutive days) were carried out, each with 30 predatory mites. Different sets of predatory mites and odour sources were used in each replicate experiment. At the start of each replicate experiment, odour sources were interchanged between the left and right arms of the T-tube. This was to minimize the overall response of the predatory mites towards the odours by unforeseen directionality in the environment outside the T-tube.

Release-recapture experiments

Four nuts (three-months old) of cultivar SLT were arranged at the four corners of an arena consisting of 30 x 30 cm black plastic sheet placed on plastic foam. The arena was positioned in a plastic tray and wet tissue paper strips that were in contact with the water surrounding the arena were laid along the periphery of the plastic sheets to prevent the predatory mites from escaping. Sixty female predatory mites of 3-7 days old, starved for 6 hours prior to the experiments and held in a Petri dish (ø. 3.5 cm) were introduced at the centre of the arena. Nuts exposed to the mites were destructively sampled 1.5 hours after the introduction of predatory mites. The number of predatory mites on each nut, under and outside the perianth was counted. Presence of predatory mites on the nuts prior to the experiments would lead to overestimation of the response and should therefore be avoided. This could be solved by marking the released, adult female predators, but this appeared far too laborious. A practically feasible solution to this problem was to inspect the nuts destructively after the experiment and to discard replicates from further analysis in case they contained nuts with any juvenile stages or males of predatory mites. In addition, replicates with less than 100 coconut mites per nut were excluded from the analysis in all tests. To exclude the possibility that the introduced predatory mites move under the perianth of the nuts to avoid light, the tray with the arena was covered with another tray to create darkness inside. The number of mites on each nut was counted after a fixed time period after the introduction of the mite but not by continuous observation as this would require a light source.

Following the above procedure, three experiments were conducted with different odour sources: (1) Infested nuts versus uninfested nuts, (2) Uninfested, manipulated nuts versus intact, uninfested nuts, and (3) Uninfested, manipulated nuts versus infested nuts. Nuts were termed 'manipulated' when the gap between the perianth and the surface of the nut (perianth-nut gap) was increased by carefully inserting 3 insect pins at 3 different places in between the perianth and the surface of each nut. Care was taken not to damage the meristematic tissue under the perianth while inserting the pins.

Each experiment was replicated 4 times with a different set of nuts and group of mites on different days. In each replicate experiment, the two types of nuts were arranged alternately at the four corners of the arena. The position of the two types of nuts used in the experiments was interchanged in each replicate experiment to prevent effects of any unforeseen asymmetry in the set-up. For example, infested nuts were positioned at the top-left and bottom-right positions in the first 2 replicate experiments and at the top-right and bottom-left positions in the subsequent replicate experiments. All experiments were conducted in a room at *ca.* 20°C.

Statistical analysis

Data from the T-tube olfactometer experiments was analyzed using a replicated goodness-of-fit test (G-statistics) against the null hypothesis of 1:1 (Sokal and Rohlf, 1997). To test whether predatory mites can distinguish between different odour sources in release-recapture experiments, data

were first subjected to a replicated goodness-of-fit test (G-statistics) against the null hypothesis of 1:1 distribution for the total number of mites (under the perianth + outside the perianth) that were recaptured from the exposed nuts. Then a chi-square analysis was used to determine the difference in the distribution of predatory mites under the perianth of nuts that received the different treatments. In addition, a replicated G-test was carried out to test whether the predatory mites distribute themselves randomly over the nut. Under this null hypothesis we expect 30% of the predators to be present under the perianth, since this structure covers *ca.* 30% of the nut surface. Rejection of this null hypothesis indicates a preference to stay under or outside the perianth. The test was carried out on the predators recaptured from the two equally treated nuts together in each replicate experiment.

RESULTS

In the olfactometer experiments, 63% of predatory mites out of the total recovered were collected on the wet filter paper in the plastic container connected to the glass jar with infested nuts (Table 1). None of the replicate experiments was

Table 1. *Results of T-tube olfactometer tests (A) and replicated goodness-of-fit tests (B) for the responses of N. baraki to infested (+) and uninfested (-) nuts [n=number of predators to (+), (-) or none (0); N=n(+)+n(-)+n(0)]*

	Olfactometer tests				Replicated goodness-of-fit test		
	n(+)	*n*(-)	*n*(0)	*N*	df	G-statistics	Critical value
Replicate1	13	7	10	30	1	1.82	0.18(ns)
Replicate 2	11	5	14	30	1	2.30	0.13(ns)
Replicate 3	11	9	10	30	1	0.20	0.65(ns)
Pooled					1	3.54	0.06
Heterogeneity					2	0.77	0.68(ns)
Total	35	21	34	90	3	5.03	0.17(ns)

Table 2: *Results of release-recapture tests (A) and replicated goodness-of-fit tests (B) for the responses of N. baraki to infested (+) and uninfested (-) nuts [n=number of predatory mites* to (+), (-) or none (0); N=n(+)+n(-)+n(0)]*

	Olfactometer tests				Replicated goodness-of-fit test		
	n(+)	*n*(-)	*n*(0)	*N*	df	G-statistics	Critical value
Replicate1	13	7	10	30	1	1.82	0.18(ns)
Replicate 2	11	5	14	30	1	2.30	0.13(ns)
Replicate 3	11	9	10	30	1	0.20	0.65(ns)
Pooled					1	3.54	0.06
Heterogeneity					2	0.77	0.68(ns)
Total	35	21	34	90	3	5.03	0.17(ns)

**Total number of predatory mites under and outside the perianth of the nut*

significantly different from a 1:1 ratio. Heterogeneity was not observed among the replicate experiments which allowed for pooling of the data. The pooled results showed a deviation that was bordering significance (Table 1).

In the release-recapture experiments 69% of mites were recaptured on nuts when they were offered infested and uninfested nuts as the odour source (Table 2). The number of mites recaptured on infested and uninfested nuts was not significantly

Table 3. *Results of the per-nut distribution of predatory mites and replicated goodness-of-fit tests for the distribution of predatory mites under the perianth (+) and outside the perianth (-) of infested (A), uninfested-intact nuts (B) and uninfested-manipulated nuts (C) [n=number of predatory mites to (+) or (-); N=n(+)+n(-)]*

	Olfactometer tests				Replicated goodness-of-fit test	
A) Infested nuts	***n*(+)**	***n*(-)**	***N***	**df**	**G-statistics**	**Critical value**
Replicate1	14	5	19	1	15.1	0.0001
Replicate 2	11	12	23	1	3.0	0.08
Replicate 3	11	14	25	1	1.98	0.16
Replicate 4	10	11	21	1	2.68	0.10
Pooled				1	18.07	<0.0001
Heterogeneity				3	4.71	0.19
Total	46	42	88	4	22.8	0.0001
(B) Uninfested nuts						
Replicate1	0	21	21	1	-	-
Replicate 2	0	16	16	1	-	-
Replicate 3	2	17	19	1	4.15	0.04
Replicate 4	0	23	23	1	-	-
Pooled				1	41.2	<0.0001
Heterogeneity				3	-	-
Total	2	77	79	4	-	-
(C) Uninfested-manipulated nuts						
Replicate1	9	8	17	1	3.71	0.05
Replicate 2	9	13	22	1	1.02	0.31
Replicate 3	12	8	20	1	7.46	0.006
Replicate 4	6	10	16	1	0.31	0.58
Pooled				1	10.0	0.001
Heterogeneity				3	2.49	0.48
Total	36	39	75	4	12.5	0.01

different from a 1:1 ratio; on average 53% of mites were recaptured on infested nuts (Table 2). Of those recaptured on infested nuts, 52% was recaptured under the perianth (Fig. 2) whereas, of those recaptured on uninfested nuts only 3% of predatory mites were collected under the perianth (Fig. 2). Chi-square analysis of the data showed that the fraction of mites recovered under the perianth of infested nuts is significantly different from that of uninfested nuts (χ^2=50.288, df=1, P<0.001). A replicated G-test conducted to assess whether the predatory mites are distributed randomly over the surface of the nut showed that the fraction of predators under the perianth of infested nuts is higher than the 0.3 fraction expected under the null hypothesis (Table 3).

When uninfested nuts with manipulated perianths and uninfested intact nuts were used in the release-recapture experiments, 55% of the released predatory mites were recaptured on the nuts (Table 4). Fifty seven percent of recaptured predatory mites were collected on manipulated nuts, but this did not differ from a 1:1 ratio (Table 4). Of the recaptured mites on manipulated nuts 48% were collected under the perianth while it was only 2% in intact nuts (Fig.3). According to the results of the chi-square analysis, there was a significant difference between the fraction of mites collected under the perianth of manipulated nuts and that of uninfested intact nuts (χ^2=26.3, df=1, P<0.001). Results of the replicated G-test for the distribution of predatory mites over the surface of the nut showed that the fraction of predators under the perianth was significantly higher than the 0.3 fraction expected under the null hypothesis (Table 3). Thus, the predators tend to aggregate under the perianth.

When infested nuts and manipulated nuts were offered as the odour sources in release-recapture experiments, in total 60% of the released mites were recaptured, out of which 46% was from manipulated nuts which was not significantly different from 1:1 (Table 5). Of recaptured mites on manipulated nuts 56% were collected under the perianth while 51% of recaptured mites on infested nuts were collected under the perianth (Fig. 4). Chi-square analysis of these data showed that fraction of mites recaptured under the perianth of manipulated nuts was not significantly different from that of infested nuts (χ^2=0.428, df=1, P=0.5).

Table 4. *Results of release-recapture tests (A) and replicated goodness-of-fit tests (B) for the responses of N. baraki to uninfested, manipulated (+) and uninfested, intact (-) nuts [n=number of predatory mites* to (+), (-) or none (0); N=n(+)+n(-)+n(0)]*

	Olfactometer tests				Replicated goodness-of-fit test		
	n(+)	*n*(-)	*n*(0)	*N*	df	G-statistics	Critical value
Replicate1	17	14	29	60	1	0.29	0.59(ns)
Replicate 2	22	18	20	60	1	0.40	0.53(ns)
Replicate 3	20	16	24	60	1	0.46	0.50(ns)
Replicate 4	16	9	35	60	1	1.99	0.16(ns)
Pooled					2	2.46	0.12(ns)
Heterogeneity					3	0.66	0.88(ns)
Total	75	57	108	240	4	3.12	0.54(ns)

**Total number of predatory mites under and outside the perianth of the nut*

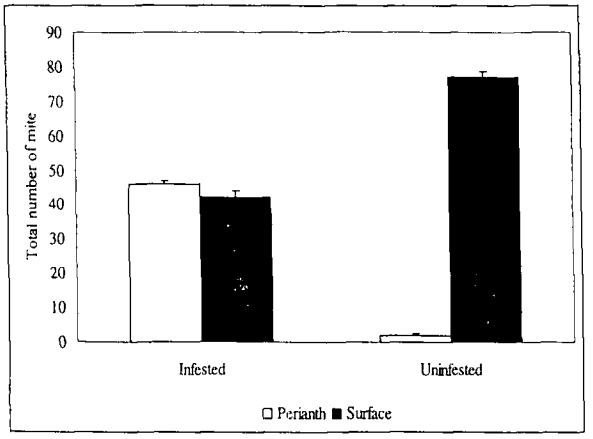

Fig. 2. *Total number (±SE) of recaptured mites under the perianth (open bars) and on the nut surface (solid bars) of infested and intact, uninfested nuts in release-recapture experiments*

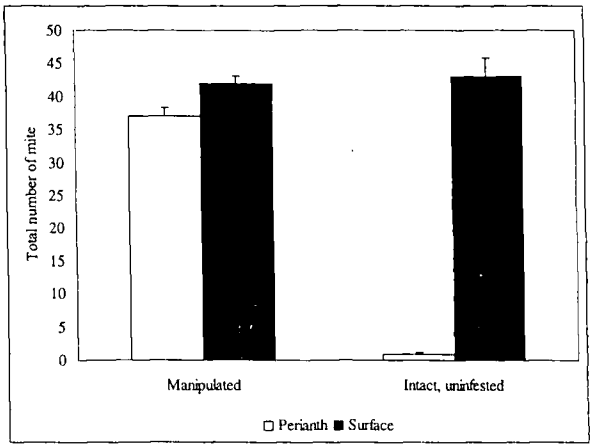

Fig. 3. *Total number (±SE) of recaptured mites under the perianth (open bars) and on the nut surface (solid bars) of manipulated nuts and intact, uninfested nuts*

Table 5. *Results of release-recapture tests (A) and replicated goodness-of-fit tests (B) for the responses of N. baraki to uninfested, manipulated (+) and infested (-) nuts [n=number of predatory mites* to (+), (-) or none (0); N=n(+)+n(-)+n(0)]*

	Olfactometer tests				Replicated goodness-of-fit test		
	n(+)	*n*(-)	*n*(0)	*N*	df	G-statistics	Critical value
Replicate1	18	18	24	60	1	0.0	0.10(ns)
Replicate 2	20	21	19	60	1	0.02	0.88(ns)
Replicate 3	18	14	28	60	1	0.50	0.48(ns)
Replicate 4	12	25	23	60	1	4.67	0.03
Pooled					2	0.69	0.41(ns)
Heterogeneity					3	4.51	0.21(ns)
Total	68	78	94	240	4	5.19	0.27(ns)

**Total number of predatory mites under and outside the perianth of the nut*

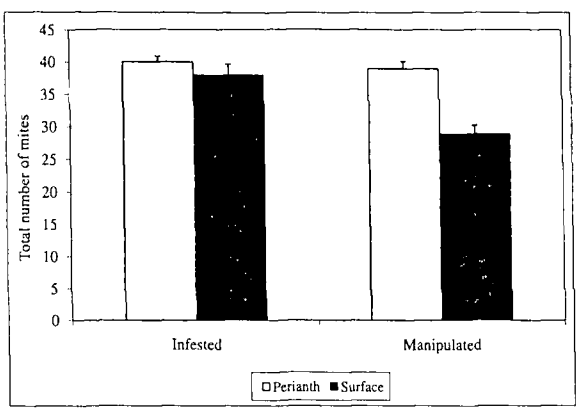

Fig. 4. *Total number (±SE) of recaptured mites under the perianth (open bars) and on the nut surface (solid bars) of infested and uninfested, manipulated nuts*

DISCUSSION

The results of this study indicate that the females of the predatory mite, *N. baraki,* prefer odours from nuts infested by *A. guerreronis* to odours from uninfested nuts. The alternative interpretation that they avoid uninfested nuts and therefore end up moving to odours from infested nuts cannot be rejected based on the experiments presented here, but seems less likely given the predator's need to find prey.

Based on the data obtained from olfactometer experiments conducted, it is not possible to determine whether the attractive odours originate from the pest alone, the host plant alone or due to mechanical and/or physiological interaction between the pest and the host plant. This would have required testing the response to artificially wounded nuts in the T-tube olfactometer. Coconut mites feed on the meristematic tissue under the perianth of the nut. It is not possible to simulate this damage at the site where the mites cause damage to the nut without removing the perianth. However, removal of the perianth itself causes damage to the nut. Hence, one cannot be certain whether the odours result from the removal the perianth or from the mechanical damage inflicted by the treatment. Therefore, during this study experiments were not conducted to elucidate the origin of odours using mechanically wounded nuts.

Contrary to the results from the T-tube experiments, infested nuts were not attractive to the predatory mites in release-recapture experiments with four equidistant nuts under still air conditions. Predatory mites were uniformly distributed over infested and uninfested nuts. Under natural conditions in the coconut palm, nuts are borne close together at the base of the long peduncle of the leaves and this arrangement resembles the release-recapture experiment. Wind-borne mites are more likely to land on leaves than directly on nuts. Once they are on leaves, the volatiles that emanate may make the predatory mites either to leave the palm and become wind-borne again or move towards the cluster of nuts that are either infested or uninfested. This situation is reflected in the release-recapture experiments and may explain why predatory mites do not distinguish between infested and uninfested nuts within clusters, whereas they do discriminate – as in the T-tube – at a larger spatial scale within the palm tree.

The most striking observation in the release-recapture experiments is the per-nut distribution of predatory mites under the perianth of infested and uninfested nuts. The number of predatory mites per unit area was higher under the perianth than outside the perianth in infested and perianth-manipulated nuts. It could be hypothesized that the predatory mites move under the perianth in search of food or shelter. In our experiments search for shade was excluded as a possibility by conducting the experiments under dark conditions. Of the total number of mites recaptured on infested nuts, 52% were recaptured under the perianth of infested nuts, whereas only 3% of the mites recovered from uninfested nuts had moved under the perianth. This prompted us to hypothesize that the coconut, when infested, somehow facilitated the predatory mites to move under the perianth. In a separate study it was observed that the gap between the perianth and the surface of the nut is increased in response to infestation by coconut mites, (Aratchige *et al.*, 2007) thereby giving the predatory mites better access to the space underneath the perianth and promoting the clean up of coconut mites that would otherwise be enemy-free. When this was experimentally simulated by inserting insect needles in between the perianth and the surface of the nut, more predatory mites were recaptured under the perianth of manipulated nuts than under the perianth of uninfested intact nuts. This observation was corroborated in another experiment showing that the coconut mites had a similar abundance under manipulated and infested perianths. Therefore it can be concluded that the space under the perianth plays a major role as a refuge. Also changes in the infested plant exposes coconut mites under the perianth to predatory mites.

Based on the findings of this experiment it is difficult to conclude whether the increase in distance between the perianth and the surface of the nut is brought about directly by the activity of the coconut mite that favours it or whether it is a response of the plant (for its benefit) as a response to pest damage. The average gap between the perianth and the surface of the uninfested nuts of the cultivar SLT was found to be 41 µm (Aratchige *et al.*, 2007), which is just sufficient for the coconut mites to move under the perianth, but too small for *N. baraki*. Therefore, it is unlikely that the increase the perianth-nut gap favours the coconut mite because this would make it more exposed to the predators. The response of the plant to pest damage is more likely to modify the perianth structure. It however, remains to be elucidated whether this effect is purely due to the mechanical (hence unspecific) damage caused by the pest or due to physiological changes resulting from the interaction between the coconut mite and the plant (i.e. the meristematic tissue under the perianth). It appears that plants that harbour coconut mites in refuges produce different indirect defense mechanisms, by releasing volatile signals to attract predators and by structural changes that increase accessibility to the plant-based refuges. Increased perianth-nut gap may allow larger herbivores to enter the space under the perianth, which may cause the meristematic region of the nut to desiccate. However, by allowing the predators to enter under the perianth of infested nuts where the coconut mites are (and by not allowing them under the perianth of uninfested nuts), coconut palms may promote the impact of natural enemies on their herbivores, thus increasing the overall vigour of the plant.

Perspectives and implications for biological control of coconut mite

Preference for herbivores and adequate numerical and functional responses of the phytoseiid mites to their density are usually considered in selecting phytoseiid predatory mites for biological control of plant feeding mites. Apart from these traits, phytoseiid predatory mites of pests that live in concealed habitats should show some other morphological and/or behavioural characteristics to reach their target prey (see also Lesna *et al.*, 2005). In addition, without passively being affected by the pest damage, plants also should be actively involved in changing the structure of the microhabitat of their pests and thereby promote the effectiveness of the phytoseiid mites. Changes in plant structure are usually microscopic in nature (Aratchige *et al.*, 2007; Lesna *et al.*, 2005), but provides an opportunity for predatory mites to reach the prey.

Evidence on plant structural changes in infested nuts partially explains why only certain predatory mites do better than the others in the environment within which they have to forage for prey. For example, despite the diversity of predatory mites on coconuts, only a handful of predatory mites have been reported to attack coconut mite colonies under the perianth (Moraes and Zacarius, 2002; Moraes *et al.*, 2004). This raises the question as to which traits determine the suitability of the predatory mites against the coconut mites. Essentially mites that have a flat idiosoma with short distal setae (such as *N. baraki* and *N. paspalivorus*) will be the ideal candidates for the biological control of coconut mites. Larger predatory mites such as *Proctolaelaps bickleyii* would not perform well under these conditions as they are unable to reach under the perianth (Fernando L.C.P., pers. comm.). Therefore, suitable predatory mites have to be screened against the coconut mites not only in terms of adequate numerical and functional responses but also for their morphological and behavioural traits that allow them to move under the perianth. Moreover, cultivars with adequate pest-induced responses in nuts would better be suited in biological control programmes against coconut mites. These cultivars have to be identified and included in breeding programmes for tolerant cultivars for coconut mite damage.

Increased perianth-nut gap of coconuts may make coconuts more vulnerable to the pests that are somewhat larger than eriophyoid mites. However, being a generalist predatory mite, *N. baraki* would feed on the juvenile stages of other larger

herbivorous mites as well. Therefore, selection of a predatory mite species with a wider food range is a requirement of the biological control of the coconut mites.

A widely recognized problem in augmentative biological control is that the mass-reared natural enemy does not reach the target after release. This is largely because the medium that is used to mass rear them lacks the associated cues relevant to searching in the field (Sabelis *et al.*, 1999). *N. baraki* is reared on *Tyrophagus putrescentiae* Shrank (Acari: Ascidae) in artificial arenas (Fernando *et al.*, 2004). This would also result in reduced preference of *N. baraki* for the coconut mite. A simple solution may be to expose *N. baraki* to the odours associated with the damage to coconuts by the coconut mites before releasing.

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