Recent Advances in Research on Biological Control of the Coconut Mite, *Aceria Guerreronis* Keifer in Sri Lanka

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ABSTRACT

Biological control is considered as the most economical, sustainable and environment-friendly approach for the control of coconut mite, *Aceria guerreronis* Keifer. In Sri Lanka, several research have been done on the local predatory mite, *Neoseiulus baraki* Athias-Henriot and the entomopathogenic fungus, *Hirsutella thompsonii* Fisher to evaluate their effectiveness against the coconut mite in an augmentative biological control approach. This paper reports recent developments in research on *N. baraki* and *H. thompsonii* in Sri Lanka as potential biological control agents of the coconut mite.

Two technologies, "dry culture" arena method and the "sachet" method were developed for mass rearing of *N. baraki*. The effect of a single augmentative release of *N. baraki* in the field to reduce the coconut mite populations was not consistently significant. Release of *N. baraki* at the rate of 5000 mites/palm in two months intervals increases the number of nuts with discontinued damage scars and reduces the number of nuts that are sold at half-price in the harvest. *H. thompsonii* isolate IMI 391722 showed the highest efficacy in reducing the coconut mite populations. Single application of *H. thompsonii* in the field is effective only for a short duration. Application of the fungus both at 2- and 3-month intervals caused similar mortality levels of the coconut mites. Perspectives of these findings in the biological control of coconut mite are discussed.

Key words: *Coconut mite, biological control, Neoseiulus baraki, Neoseiulus paspalivorus, Hirsutella thompsonii*

INTRODUCTION

The coconut mite, *Aceria guerreronis* Keifer (Acari: Eriophyidae) is an important coconut pest that has extended its original distribution from central and south America to Africa and Asia. It was first reported in Sri Lanka in 1997 from the Kalpitiya peninsula (Fernando *et al.*, 2002). Currently it has invaded into 42%, 10% and 3% of the coconut lands in the dry-, intermediate- and wet-zones respectively.

In Sri Lanka, several short-term recommendations, based on insecticides, have been made to manage the pest (Fernando *et al.*, 2002; Chandrasiri and Fernando, 2004). However, due to the small, worm-like body with a small cross-sectional diameter which enables it to reach concealed habitats that are not reachable by many insecticides and the tall nature of the host plant, chemical control is bound to be less effective. In addition, use of chemicals is limited by the need for the repeated application and the concerns over the environmental pollution. Hence, biological control has been recognized as the most sustainable, economical and environment-friendly management strategy for the coconut mite.

Despite the long global history of about four decades, the coconut mite has drawn scant attention

of the biological control scientists. So far in Sri Lanka, biological control using a local and an exotic predatory mites and an entomopathogenic fungus has been attempted. This paper elaborates the recent developments in research using the local predatory mite and the entomopathogenic fungus with respective to the coconut mite control.

USE OF PREDATORY MITES

Of the predatory mites that have been reported to be associated with the coconut mite in Sri Lanka, *Neoseiulus baraki* Athias-Henriot (Acari: Phytoseiidae) is the most common predatory mite (Moraes *et al.*, 2004, Fernando, 2005). In addition, *N. paspalivorus* De Leon and *Amblyseius largoensis* Muma (Acari: Phytoseiidae) have also been reported on coconut mite colonies in Sri Lanka (Moraes *et al.*, 2004). *N. baraki* and *N. paspalivorus* are usually found underneath the perianth of coconut mite-infested nuts, whereas *A. largoensis* is found outside the perianth. Although *N. baraki* and *N. paspalivorus* are morphologically very similar, they show a distinct difference in the pattern of distribution in different agro-climatic zones: *N. baraki* more commonly in the dry and intermediate zones while *N. paspalivorus* is predominantly in the wet-zone and the wet areas in the dry-zone (Fernando and Aratchige, 2006).

Neoseiulus baraki as a prospective natural enemy

Coconut mite lives in a concealed habitat, which is inaccessible to many phytoseiid predators that are usually larger than their prey. However, *N. baraki* has certain morphological and behavioral features that enable it to reach the meristematic area under the perianth. It has a flattened idiosoma (Moraes *et al.*, 2004), which is an ideal feature of a predatory mite whose prey is in a refuge inside a narrow habitat such as underneath the perianth of coconut. The patterns of abundance of *N. baraki* and the coconut mite show a similar trend within the palm: the coconut mite reaches peak population levels in 5 month old nuts and *N. baraki* shows the peak population levels one month later, a typical delay for prey-predator interactions (Fernando *et al.*, 2003). They also show a strong positive seasonal correlation; both reaching the peak population levels during the south-west monsoon and the lowest population levels during the south-east monsoon. They usually do not prefer too much light and stay in sheltered habitats (Moraes and Zacarius, 2002). All these features make *N. baraki* a potential candidate for biological control of the coconut mite.

N. baraki has been reported on coconuts infested by the coconut mite in Puerto Rico (Howard *et al.*, 1990) and in Brazil (Lawson-Balagbo *et al.*, 2008). The possibility of using it in biological control of the coconut mite has not been attempted in the other countries, probably because of the less importance of coconut mite in such countries and the difficulties associated with mass rearing of *N. baraki* for field releases. Hence, as the first step in an attempt to evaluate *N. baraki* as a potential candidate natural enemy of the coconut mite, studies were conducted to develop a suitable mass rearing technique of *N. baraki*.

Mass rearing of *N. baraki*

One major constraint in the method described by Fernando *et al.* (2004) to mass rear *N. baraki* in the laboratory was the frequent contamination of cultures by other mites, particularly *Lasioseius* sp (Acari: Ascidae) that feeds on *N. baraki* and its alternative host, *Tyrophagus putrescentiae* Shrank (Acari: Ascidae). This hampered the perpetual supply of *N. baraki* for field release experiments. Hence, modifications were made to the method described by Fernando *et al.* (2004) and consequently two improved methods were developed.

1. "Dry-culture" arena method

The "dry-culture" arena consists of a black plastic sheet pasted on a plastic tray. Insect glue applied along the periphery of the plastic sheet serves to prevent the escape of the predatory mites and acts as a barrier to safeguard the arena from external

contaminants. A piece of wet plastic foam wrapped with a tissue paper is placed on a glass sheet of the same size on a piece of net, which serves as an egg laying substrate for predatory mites. Rice bran is provided as the food source of *T. putrescentiae*. In this method, approximately 110-fold increase of *N. baraki* is achieved in 3 weeks (Fernando, 2006).

This arena can be used to rear both *N. baraki* and *T. putrescentiae*. The advantages of this method over the method described by Fernando *et al.*, (2004) are that, the cultures can be maintained with less handling and the cultures are relatively free of contaminants (Fernando, 2006).

2. Sachet method

In this method the predatory mites are reared inside a sealed poly propylene sachet. A moistened tissue paper is kept inside a partially separated chamber in one side of the sachet to provide drinking water to the mites and to create a high relative humidity inside the sachet. *T. putrescentiae* reared on rice bran is provided as the alternative food for *N. baraki*. Approximately 110-fold increase of *N. baraki* is achieved by this method in 6 weeks (Fernando, 2006).

This method is far less laborious than the method described by Fernando *et al.*, 2004. It is even better than the "dry-culture" arena method in that it needs no or minimum intervention and is almost totally free of contaminants if the introduction of the mite cultures in to the sachet is done properly, ensuring the prevention of entry of contaminants. It needs less space to maintain the cultures and is cheaper than the "dry-culture" arena method. Moreover, rearing sachets could be directly used to release *N. baraki* in the field (Fernando, 2006).

Field releases of *N. baraki*

Single release of predatory mites

To determine the effect of a single release of laboratory reared *N. baraki* on the coconut mite population in the field, a study was conducted in two coconut mite-infested estates in the Pallama and Battuluoya areas (Fernando, 2005). In each estate approximately, 50,000 predatory mites (10,000 mites per palm) were released on to 5 coconut mite-infested palms in a block of 60 palms in each estate.

The results revealed that a single augmentative release of *N. baraki* increase their numbers on both released and adjoining palms, resulting in a marked reduction in the coconut mite populations. However, the reduction in the coconut mite population varied depending on the site where the releases were carried out. In Battuluoya and Pallama sites, a reduction in the coconut mite population was recorded up to 6 and 3 months respectively. Occasionally the coconut mite numbers in the released palms were significantly lower than that in the untreated palms (Fernando, 2005).

Suitable numbers of predatory mites/palm for release

An experiment was conducted in Bangadeniya and Udappuwa to determine the number of predatory mites required to be released on to a coconut palm to reduce the pest population. Laboratory reared *N. baraki* were released at the rate of about 2500, 5000 or 10,000 mites / palm. In the Bangadeniya site, there were no significant differences in the coconut mite counts with different rates of release of predatory mites ($p=0.17$). But the predatory mite counts were significantly higher in the palms that received 5000 predatory mites per palm compared to the control as well as to the other rates of release ($p<0.001$). In the Udappuwa site, the rates of release of predatory mites did not significantly affect either the coconut mite or the predatory mite populations ($p>0.06$) for the coconut mite and the predatory mites (Fernando, 2006).

Data on harvest records of the bunches on to which predatory mites were released showed that the percentage of nuts with no damage scars and the nuts with discontinued damage scars from the perianth were higher in the palms that received 5000 predatory mites/palm (Table 1). Based on this result, ca. 5000 predatory mites per palm were released in subsequent studies.

Table 1. *Percentage nuts with no scars and nuts with discontinuous patches at harvest in released bunches in the palms that received 2500 predatory mites/palm, 5000 predatory mites/palm, 10000 predatory mites/palm and control palms in Bangadeniya*

No. of predatory mites / palm	Nuts with no scars	Nuts with discontinuous patches
2500	27	0
5000	44	17
10000	28	0
Control	28	8

Suitable frequency of release of predatory mites

Although a single augmentative release of *N. baraki* in the field resulted in a reduction in the pest population, the effects were not consistently significant (Fernando, 2005), prompting to evaluate the effects of multiple releases. Hence, an experiment was conducted to determine the suitable frequency of release of *N. baraki* in the field. The experiment was conducted in two sites and the predatory mites were released for 1 year, either at 2-month or 4-month or 6-month intervals in each of the 1 ac plots.

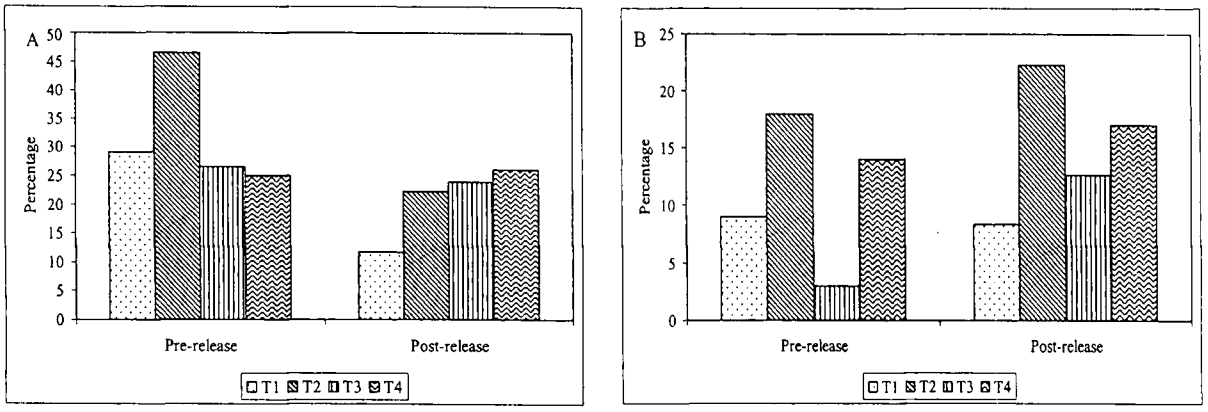

Fig. 1. Percentage of nuts sold at half-price in the harvest, in plots released with predatory mites at 2-months (T1), 4-months (T2), 6-months (T3) intervals and control (T4) in Weragoda estate, Pallama (A) and Typing estate, Mangalaeliya (B) (n=10 palms)

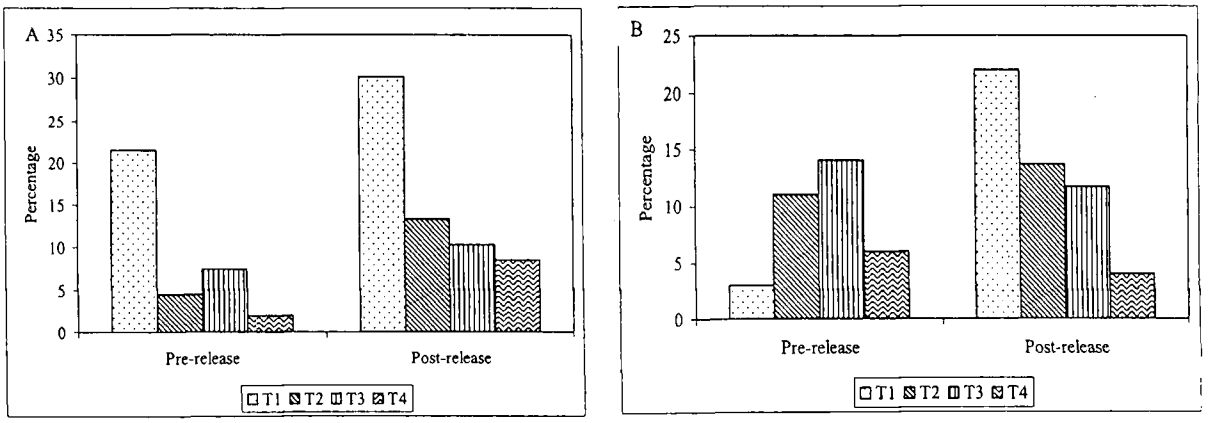

Fig. 2. *Percentage of infested nuts with discontinued damage scars from the perianth in the harvest in plots released with predatory mites at 2-months (T1), 4-months (T2), 6-months (T3) and control (T4) in Weragoda estate, Pallama (A) and Typing estate, Mangalaeliya (B) (n=10 palms)*

Results revealed that the release of *N. baraki* at different frequencies did not result in lowering the coconut mite populations on button nuts or number of damaged nuts in the harvest. However, following the release of *N. baraki*, the percentage of harvested nuts that are sold at half-price was lowest (Fig. 1) and the percentage of harvested nuts with discontinued damage scars from the perianth was highest (Fig. 2) in the plot where predatory mites were released at 2-month intervals. This indicates that the release of *N. baraki* at 2-month intervals has some positive effects in improving the quality of the harvest (Fernando, 2007).

Use of *Hirsutella thompsonii*

Hirsutella thompsonii Fisher (Deuteromycetes: Monilianes) is an entomopathogenic fungus which can attack many phytophagous mites of Tetranychidae and Eriophyidae (Baker & Neunzig, 1968; McCoy and Selhime, 1974). It has been reported as a potential biological control agent of coconut mite in other countries (Hall *et al.*, 1980; Cabrera, 1982, 2002; Espinosa-Becerril and Carrillo-Sanchez, 1986; Suarez *et al.*, 1989; Beevi *et al.*, 1999; Rabindra and Sreerama Kumar, 2003). However, the effect of *H. thompsonii* appears to be variable probably due to differences in the isolates used and the micro- and macro-climatic conditions prevailed in the areas where the studies were conducted. In Sri Lanka, experiments were conducted to evaluate *H. thompsonii* as a potential biological control agent against the coconut mite. *H. thompsonii* appears to have no detrimental effects on *N. baraki* (Fernando *et al.*, 2007).

Table 2. *Percentage of nuts (S.E) in different damage categories at harvest, after application of H. thompsonii at 2- and, 3-month intervals and in untreated control, at Ariyagama.*

Damage category	2-monthly	3-monthly	control
Undamaged	0.23±0.01A	0.23±0.01A	0.12±0.02B
Damaged-discontinued	0.34±0.03A	0.37±0.03A	0.16±0.9B
Damaged-continued	0.19±0.03A	0.22±0.03A	0.41±0.04B
Damaged-small size	0.15±0.12A	0.12±0.18A	0.24±0.03B
Damaged-deformed	0.06±0.01	0.03±0.01	0.05±0.01

Means followed by the same letter are not significantly different at $p<0.05$

Table 3. *Percentage of nuts (S.E) in different damage categories at harvest after application of H. thompsonii at 2- and, 3-month intervals and in untreated control, at Madurankuliya.*

Damage category	2-monthly	3-monthly	control
Undamaged	0.14±0.01	0.18±0.01	0.16±0.01
Damaged-discontinued	0.22±0.03	0.20±0.03	0.19±0.03
Damaged-continued	0.50±0.03	0.46±0.03	0.48±0.03
Damaged-small size	0.07±0.01A	0.07±0.01A	0.11±0.01B
Damaged-deformed	0.03±0.01	0.04±0.01	0.03±0.01

A survey carried out in Puttalam, Kurunegala, Gampaha and Anuradhapura districts revealed that *H. thompsonii* is found in association with the coconut mite, but at a low incidence (Edgington *et al.*, 2008) indicating an insufficient spread in the nature. Out of several *H. thompsonii* isolates collected from different geographical regions of Sri Lanka, four isolates, namely IMI 390486, IMI 391722, IMI 391942 and IMI 390486 were superior to others in growth characteristics and sporulation in culture and they were used in biological profiling studies (Edgington *et al.*, 2008) and evaluation in the field (Fernando *et al.*, 2007).

Effect of *H. thompsonii* on coconut mite

The four isolates (IMI 390486, IMI 391722, IMI 391723 and IMI 391942) were evaluated in a site at Madurankuliya to identify the most effective isolate for the control of coconut mite (Fernando *et al.*, 2007). The impact of the four isolates on the coconut mite and the persistence of the fungus on nuts varied. IMI 391722 showed the highest efficacy against coconut mite populations over time. The proportion of nuts with more than 100 live mites remained significantly lower than the control up to 4 weeks after the application of the fungus in the block that received IMI 391722. Thereafter, the results were less consistent. Also, there was evidence of dead coconut mites showing mycosis up to 18 weeks with the isolate IMI 391722, which had the longest potency among the four isolates. Based on this study IMI 391722 was found to have the highest efficacy against coconut mite populations. However, the effect of a single application of *H. thompsonii* is relatively short in duration, suggesting frequent application for long-term management of the coconut mite. Also, *H. thompsonii* has not been recorded on the nuts, which have not been present on the treated palms at the time of treatment indicating the poor ability of the fungus to disseminate naturally.

Frequency of application of *H. thompsonii*

Based on the potential effect on lowering the coconut mite populations in the field (Fernando *et al.*, 2007), *H. thompsonii* isolate IMI 391722 was used to determine the most suitable frequency of application against the coconut mite. *H. thompsonii* isolate IMI 391722 was sprayed either at 2-month or 3-month intervals for one year in two estates; one in Ariyagama (intermediate zone) and the other in Madurankuliya (dry zone). Dead coconut mites due to mycosis by *H. thompsonii* were found in 60% of the nuts. Also, the application of the fungus showed a positive impact on the damage levels of harvested nuts, although it varied in the two sites. At both sites, percentages of damaged-smaller size nuts in the treated palms were nearly half that of the untreated palms (Table 2 and 3). In addition, at Ariyagama, applications have increased the percentage of undamaged and damaged nuts with discontinued scars from the perianth by nearly 2-fold than that of the untreated palms (Table 2). This suggests that *H. thompsonii* can perform better in wetter areas. Both 2- and 3-monthly application of the fungus resulted in similar mortality levels in coconut mites and reduction of damage on nuts (Fernando, 2007).

DISCUSSION

As a matter of fact, coconut mite is relatively low in quality as a food source for many predatory mites and it has been adapted to live in concealed habitats. Hence, it is less likely to find specialized predatory mites against the coconut mite. However, like many other phytoseiid-eriophyid systems, a close association between phytoseiid mites and the coconut mite may occur, especially with the phytoseiids that show habitat specialization. According to the classification by McMurtry and Croft (1997), *N. baraki* is a Type III predatory mite. Behaviour of Type III phytoseiids may strongly be influenced by the anatomy of the plant. The presence of concealed habitats is more important than the availability of prey on the abundance of many Type III phytoseiids (McMurtry and Croft, 1997). Hence, it is likely that *N. baraki* has evolved more in response to conditions of the area underneath the perianth than to the abundance of coconut mite. Conditions underneath the perianth

that are favourable for *N. baraki* include the microclimate with high humidity and low temperature, increased protection from hyper predators and the increased contact rate with their prey, the coconut mite.

As with many Type III predatory mites, *N. baraki* is expected to have many other alternative food sources. Coconut pollen, extra-floral exudates and most certainly, mites other than the coconut mite may form an important component in their diet. Moreover, *N. baraki* appears not to aggregate so intensively in mite colonies. It has been observed that they move out of the perianth frequently (Kumara, 2007). Oviposition sites might also have no correlation with the location of the prey patch. There are certainly many other safer places on the coconut palm such as bark crevices, area under the spathe, where it can lay its eggs. All these features can contribute to the effectiveness of *N. baraki* as a predatory mite against the coconut mite.

Being a generalist predatory mite, it is likely that *N. baraki* would not reduce the pest population to a level that is achieved by a specialist predatory mite. Whether the reduction in the pest population or the increase in the quality/quantity of the harvested nuts achieved after the augmentative release of *N. baraki* is sufficient for the grower to maintain a profitable crop is an open question. Mass-rearing of *N. baraki* essentially requires a sufficiently clean environment (preferably air-conditioned), fairly sophisticated equipment and skilled labour that come at a high cost to the grower. Therefore, augmentative releases of *N. baraki* alone would not be the ideal control measure against the coconut mite. Moreover, unlike the insect parasitoids, these wingless mites have to be released on to the tender coconut bunches where they would find the coconut mites. Due to the scarcity of climbers, there would certainly be limitations in the adoption of this method of control by the growers. Future experiments will aim at cost-benefit analysis of the release of *N. baraki* for the control of coconut mite.

Like all mites, *N. baraki* does not have any self-regulation over the place where they land during dispersal. It is very likely that they land on other places, even on other plants, than on their prey patches. If a suitable host is not available in places where *N. baraki* lands, they are vulnerable to be destroyed by various reasons (e.g. of hunger, predation by hyper-predators). As a result, release of *N. baraki* at a short frequency (at 2-3 months intervals) would be necessary, which is not practically feasible and economically viable.

The IMI 391722 isolate of *H. thompsonii* causes mortality of coconut mite, has the ability to reduce the coconut mite population and results in reduced damage levels in harvested nuts, when treated at 2- or 3- month intervals. However, its ability to significantly reduce the coconut mite numbers on the treated nuts for more than a month and disseminate to surrounding palms and even to the untreated nuts of the treated palms seems lacking. Also, its effect is variable in different sites.

Why *H. thompsonii* did not persist on treated nuts sufficiently to cause significant epizootics after 4 weeks is not clear. The movement of coconut mites underneath the coconut perianth is mostly confined to individual colonies. Thus, the chances of a slow growing fungus such as *H. thompsonii* spreading between colonies are low, particularly when the number of mites on a nut is lowered after the treatment (Fernando *et al.*, 2007). Variable effect of *H. thompsonii* on coconut mite populations appears to be a common problem experienced by scientists elsewhere ((Espinosa-Becerril and Carrillo-Sanchez, 1986; Suarez *et al.*, 1989; Cabrera, 2002; Nair, C.P.R. pers. comm.). Micro-climatic conditions, particularly, high relative humidity in different sites and variable virulence level of the isolate due to continuous laboratory culturing may be a likely reason, which needs to be carefully looked into before the application.

The cost effectiveness of frequent applications of *H. thompsonii* to maintain low population levels of coconut mite should be critically evaluated before its use in the management of coconut mite. Commercial production of the fungus on a large

scale involves high capital cost, skilled personnel and strict quality control measures while frequent application incurs high labour cost. Pilot studies have been planned to determine the cost-benefits of the treatments with *H. thomsponii.*

Due to the various constraints that have been discussed above (plus many more), it is quite evident that the use of *N. baraki* alone or *H. thompsonii* alone is not a suitable approach for the control of coconut mite. Sustainable and economically profitable control of the coconut mite would be achieved by the integration of two or more control methods. None of the studies done in Sri Lanka or elsewhere has addressed the possibility of integration of *N. baraki* with one or more species of other predatory mites and/or with *H. thompsonii* to enhance the control of coconut mite. Based on the fact that *H. thompsonii* is not harmful to *N. baraki*, it is possible to apply the fungus, simultaneously with the release of *N. baraki* in the field. While wandering on the nut, *N. baraki* would carry spores of the fungus into the bracts, increasing the incidence of the disease amongst coconut mites. Hence, future studies should attempt to formulate integration of *H. thompsonii* and *N. baraki* to increase the level of effectiveness of using these biological control agents. Usually Type III predatory mites are known to be more suitable in conservation biological control (McMurtry and Croft, 1997). Therefore, use *N. baraki* in a conservation biological control approach against the coconut mite would be another profitable attempt. Timely interventions into outbreaks of the coconut mite with these two biological control agents and introduction of scrupulously designed cropping systems that improve the conditions favourable for the fungus (e.g. high relative humidity) and the predatory mites (e.g. providing shade/alternative food) would be a viable proposition for the control of the coconut mite.

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