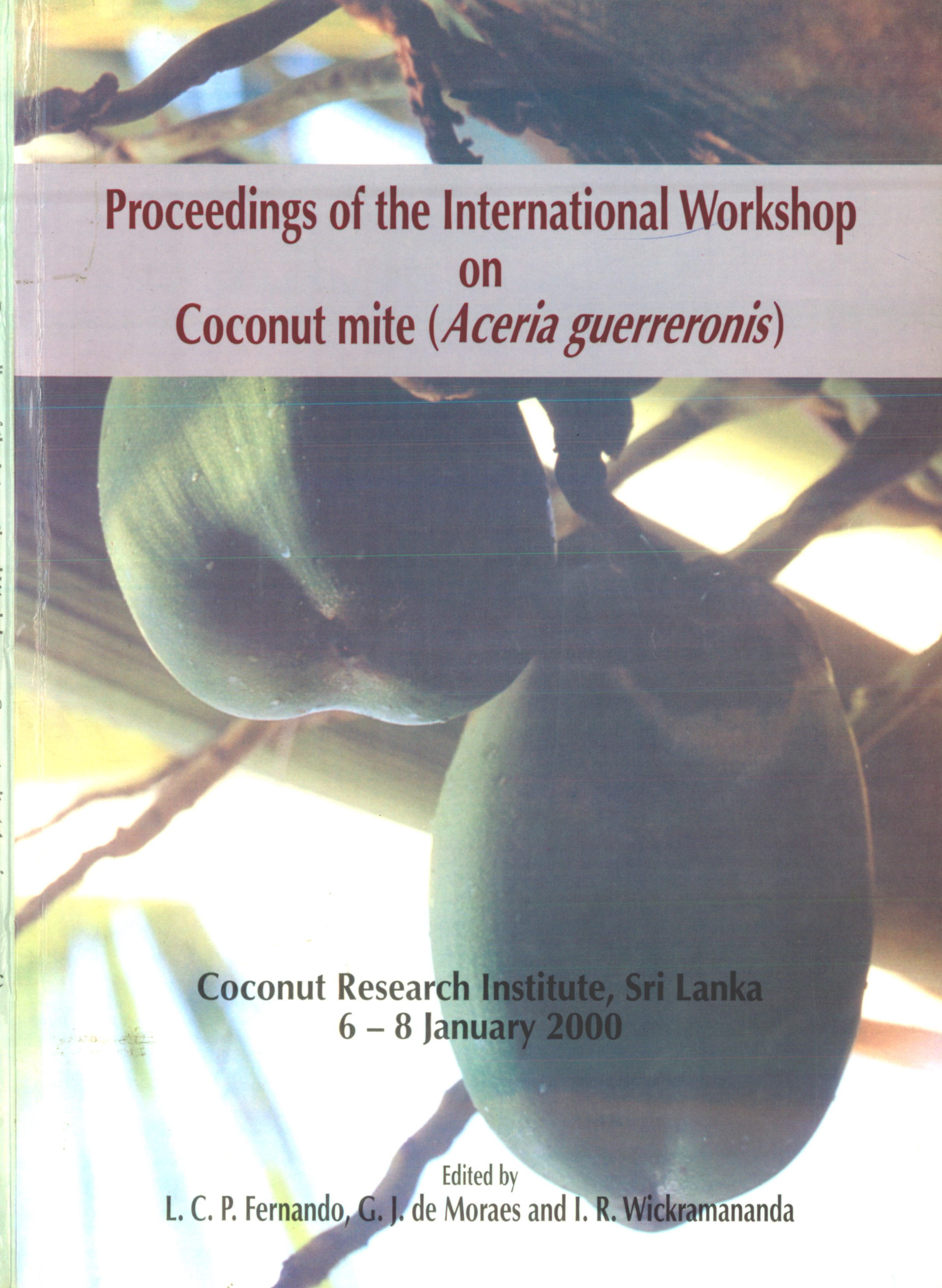

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Coconut Research Institute, Sri Lanka
6 – 8 January 2000

Edited by
L. C. P. Fernando, G. J. de Moraes and I. R. Wickramananda

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Publisher: Coconut Research Institute 2002

ISBN 055-9013-02-5

SARVODAYA
VISHVA LEKHA
Printers

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Organized by
Coconut Research Institute of Sri Lanka

With support from
United Nations Development Programme

Citation:

Fernando, L.C.P., Moraes, G.J. de, Wickramananda, I.R. (eds.) (2002) Proceedings of the International workshop on Coconut mite (*Aceria guerreronis*). Coconut Research Institute, Sri Lanka, January 6-8 2000. Coconut Research Institute, Sri Lanka.

ISBN : 055-9013-02-5

Publisher:
Coconut Research Institute
Lunuwila,
Sri Lanka.

Tel. No.: (94) 31 55300
Fax No.: (94) 31 57391
E-mail: dircri@sri.lanka.net

The Coconut Research Institute of Sri Lanka was initially established as the Coconut Research Scheme in 1928, and later developed and elevated into fully fledged national research organization of excellence in coconut research and development in Asia and Pacific Region. It is the first ever Research Institute established in the world devoted for coconut.

The Coconut Research Institute has a team of dynamic, enthusiastic, innovative scientists, qualified technical staff, material resources and sophisticated analytical facilities to support its research. The vision of the institute is to excel in research and generate innovative technology to meet the challenges of the coconut industry.

Institute consists of eight research divisions mandated to develop appropriate technologies in crop production, protection and post harvest processing. It also acts as a national repository for genetic resources of coconut and produces quality seed nuts. Development of environmentally and ecologically sound coconut based farming systems, transfer of technologies collecting, collating and dissemination of technical information on coconut and related subjects are also covered in its mandate.

The United Nations Development Program is the UNs main arm for providing and coordinating development assistance.It aims to help people in over 170 countries design and implement programmes that create employment and sustainable livelihoods, regenerate the environment and empower women.Poverty alleviation is UNDPs top priority. UNDP also responds to government requests for assistance with public and private sector development and building democratic institutions. UNDP joins other UN agencies in rehabilitating areas in the aftermath of conflict. UNDPs funding comes from voluntary contributions of UN member states. Governments in developing countries and beneficiaries themselves also make vital contributions. More than half of UNDPs disbursements go to the worlds least developed countries, and 87% is utilized in nations with per capita GNP of US$ 750 or less.

Cooperation between the Government of Sri Lanka and UNDP dates back to the early 1950s. Throughout this long association UNDP efforts have conformed to Sri Lankas development strategy.

UNDP in Sri Lanka launched its new five-year Country Cooperation Framework in 1997. The priorities of the frame work parallel those of the Government, and include: **Growth with equity**, by stimulating sustainable human development in economically suppressed areas, **Relief and rehabilitation** in Sri Lankas conflict affected areas supporting the revitalization of the Jaffna economy and helping returnees in rebuilding their lives; **Protection and regeneration of the environment** by developing national skills to manage sectors such as national parks, supporting environment planning in rural and urban areas and curbing industrial pollution; **Good governance** by assisting economic and socials planning, the wider participation of women in politics and economic infrastructure management.

Acknowledgements

We wish to thank all of the authors for highlighting the importance of controlling the coconut mite and freely contributing their experience and results of their research. Several persons have helped in the production of these proceedings and we are particularly grateful to United Nations Development Fund for partly sponsoring the workshop, Head and Mr. I M S K. Idirisinghe of the Extension Division and Ms. N.S Aratchige, Crop Protection Division of the Coconut Research Institute for editorial assistance and Dr. U P. de S Waidyanatha, Chairman of the Coconut Research Board for his useful suggestions on this publication. We also thank Chairman, Coconut Research Board, Dr. (Mrs.) C. Jayasekara, Acting Director of the Coconut Research Institute, the Working Committee of the Mite Control Programme and the Organizing committee of the Workshop for their untiring commitment to make the workshop a success.

L.C.P. Fernando & I.R. Wickramananda
Coconut Research Institute, Sri Lanka

G.J. de Moraes
University of São Paulo,
Brazil

Contents

Introduction

The nut infesting coconut mite, *Aceria guerreronis* Keifer has been a serious pest of coconut in Central and South America, and Africa (Crop Protection Compendium, 1999). Confined to these regions for the last few decades, the pest was recently reported for the first time in Sri Lanka (Fernando, 1998) and India in late 1997 (Sathiamma *et al.*, 1998).

A. guerreronis develops in the meristematic region of the nuts, which is covered by the perianth (tepals). Feeding damage causes uneven growth of nuts resulting in distorted and stunted nuts and premature nut fall. Crop loss in the form of reduced copra yield and nut fall has been estimated in the range of 10 - 70%, depending on the severity of the infestation (Hernandez, 1977; Julia & Mariau, 1979; Moore *et al.*, 1989). Therefore, the recent invasion of the coconut mite into South-east Asian region has raised serious concern. Coconut is a major plantation crop in South-east Asia and the Pacific regions that accounts for over 80% of the world coconut production and supports the economies of these countries as an important foreign exchange earner. Moreover it is important in the daily diet, food and beverages of local community.

At present, chemical control is the most widespread means used to control the pest. Highly toxic acaricides/insecticides have to be sprayed on bunches at frequent intervals to suppress the pest (Hernandez, 1977; Julia & Mariau, 1979). Repeated applications of chemicals at 1-2 month intervals is uneconomical and impractical and, moreover, environmentally hazardous. Therefore, the search for alternative control methods is urgently needed. Although several predators of *A. guerreronis* have been identified, intensive studies in this sense have not been undertaken (Howard *et al.*, 1990). Possibility of using entomopathogenic fungi is encouraging and is being investigated (Cabrera & Dominguez, 1987).

It is recognized that coconut mite has not received the research attention it warrants and many aspects of its biology and ecology are poorly understood (Moore & Howard, 1996). This has prompted us to organize an international workshop as an interactive forum, to address research needs for the effective control of *A. guerreronis* and alert other Asian and Pacific countries of the possible threat of the pest in future.

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SESSION 1
COUNTRY PAPERS

CHAIRMAN : R. MAHINDAPALA

Status of coconut mite, *Aceria guerreronis* in Sri Lanka

L.C.P Fernando, I.R. Wickramananda and N.S. Aratchige
Coconut Research Institute, Lunuwila, Sri Lanka

Summary

The coconut mite, ***Aceria guerreronis*** *Keifer (Acari: Eriophyidae), a serious pest of coconut in the world was reported for the first time in Sri Lanka in late 1997. The pest first appeared in the Kalpitiya peninsula of the North Western Province and subsequently spread to nearly 15,000 ac of the surrounding areas causing an outbreak. The incidence of the pest varied from 5% to 100%. Quarantine measures and chemical control were adopted as interim measures to contain and suppress the outbreak.*

Considering the effectiveness of different acaricides/insecticides and the environmental conditions of the area, trunk injection of monocrotophos 60%, spraying of sulphur and bunch pruning were initially recommended. Preliminary studies indicated that monocrotophos controls the pest up to 80%-100%, but the effectiveness lasts only for 1.5 months. Two botanicals viz. 2% neem oil and garlic mixture, which is being used in India, and NeemAzal 1% were recommended for continued application. Both botanicals could reduce the pest population by 60%.

Efficacy of several acaricides/insecticides against ***A. guerreronis*** *was evaluated, but none caused a considerable reduction of the pest. A reliable technique for the estimation of mite population in the nuts was developed. Two species of predatory mites viz.* ***Neoseiulus paspalivorus*** *and* ***Bdella*** *sp. were recorded inhabiting infested nuts and feeding on* ***A. guerreronis****. Significant reduction in pest populations occurs in nuts occupied by* ***N. paspalivorus****.*

An integrated management strategy with emphasis on biological control agents need to be explored for successful control of ***A. guerreronis****. The concerns, considerations and constraints in utilizing predators and entomopathogens in the infested area are discussed.*

Introduction

Coconut is the most widely grown plantation crop in Sri Lanka, occupying about 450,000 ha corresponding to about 6.4% of the total land extent. It is grown extensively in the coastal belt and extends interior to the northwest. Coconut is considered one of the key plantation crops in the country because it contributes to the Gross National Product and most importantly in the daily diet of the average Sri Lankan with an estimated per capita consumption of 110 nuts per year, providing 25% of the daily caloric intake. Approximately 80% of the total 2522 million nuts produced (Sri Lanka Coconut Statistics, 1998 unpublished report) are consumed locally whilst exports of copra and oil mainly accounts for the rest of the production.

Occurrence and distribution of coconut mite

The coconut mite, *Aceria guerreronis* Keifer (Acari: Eriophyidae) was reported for the first time in Sri Lanka in late 1997. It first appeared in the Kalpitiya peninsula of the Puttalam District (North-western Province) and was the first report of a serious mite pest and a serious nut infesting pest reported on coconut in Sri Lanka. Puttalam District is a major coconut-growing area of the country, approximately comprising 14% of the total coconut extent.

A survey carried out in the area revealed that the pest is distributed in Kalpitiya, Wanathavillu, Puttalum, Madurankuliya and Rajakadaluwa areas of the district and two isolated pockets in Chilaw and Kuliyapitiya areas (Kurunegala District, NWP) (Fig. 1). Approximately 150,000 palms in about 15,000 ac. were infested. However the pest was in epidemic proportion only in an area about 6000 ha. The incidence of infestation ranged from 5-100% and the highest incidence (80%-100%) and intensity was reported from Kalpitiya area while it gradually declined towards south and west of Kalpitiya.

Interim control measures

Several steps to contain and suppress the pest were taken in March 1999.

a. Quarantine measures

The studies conducted by the Coconut Research Institute showed that live mites are present on the harvested nuts (12-13 months old) up to 3 weeks. Therefore, it was assumed that *A. guerreronis* could spread to uninfested areas by transportation of fresh nuts. The coconut mite was declared as a quarantine pest and transportation of fresh nuts with husks and green husks out of the infested area was prohibited.

b. Management by chemicals

Different methods to control the pest have been investigated intensively in the Americas and Africa. Spraying of monocrotophos, chinomethionate and cyhexatin to the bunches of developing nuts at 20-30 days intervals significantly reduced damage (Hernandez, 1977; Julia and Mariau, 1979). Furthermore no effective biological control method has been developed so far. Therefore, chemical control was considered as the main method of suppression of the outbreak in Sri Lanka.

Several factors were taken into consideration in recommending acaricides/insecticides. There is a narrow range of acaricides or insecticides with acaricidal properties available in the local market. Because the majority of them are contact chemicals, their effectiveness in reducing the mite population well protected beneath the perianth is limited. Furthermore, there are serious limitations to their application. Spraying of toxic chemicals to the crown would cause severe environmental pollution as the infested area is bordered by water bodies and a high water table. Wind and high day temperatures, common in the area further hamper the use of chemicals. Application of monocrotophos by trunk injection is considered as a safe and effective method for mass treatment. Therefore, on preliminary experiments injection of 20 ml of monocrotophos was recommended. Spraying of 0.5% sulphur WP 80% as a prophylactic measure and pruning of nuts in low and new infested areas were also recommended.

Effectiveness of monocrotophos

A trial conducted to evaluate the effectiveness of trunk injection of 20 ml monocrotophos to 15 tall palms revealed that the reduction in the pest population due to the treatment was highly significant ($P<0.0001$). The highest reduction (90%) was obtained 4 weeks after the treatment (Fig. 2). After 6 weeks there was no considerable differences between treated and untreated palms indicating that application of monocrotophos has to be repeated in 1.5 months intervals. Monocrotophos showed a slight deleterious effect on the predator population (Fig. 3). However, fluctuations of the predator populations in treated and untreated palms showed a similar trend.

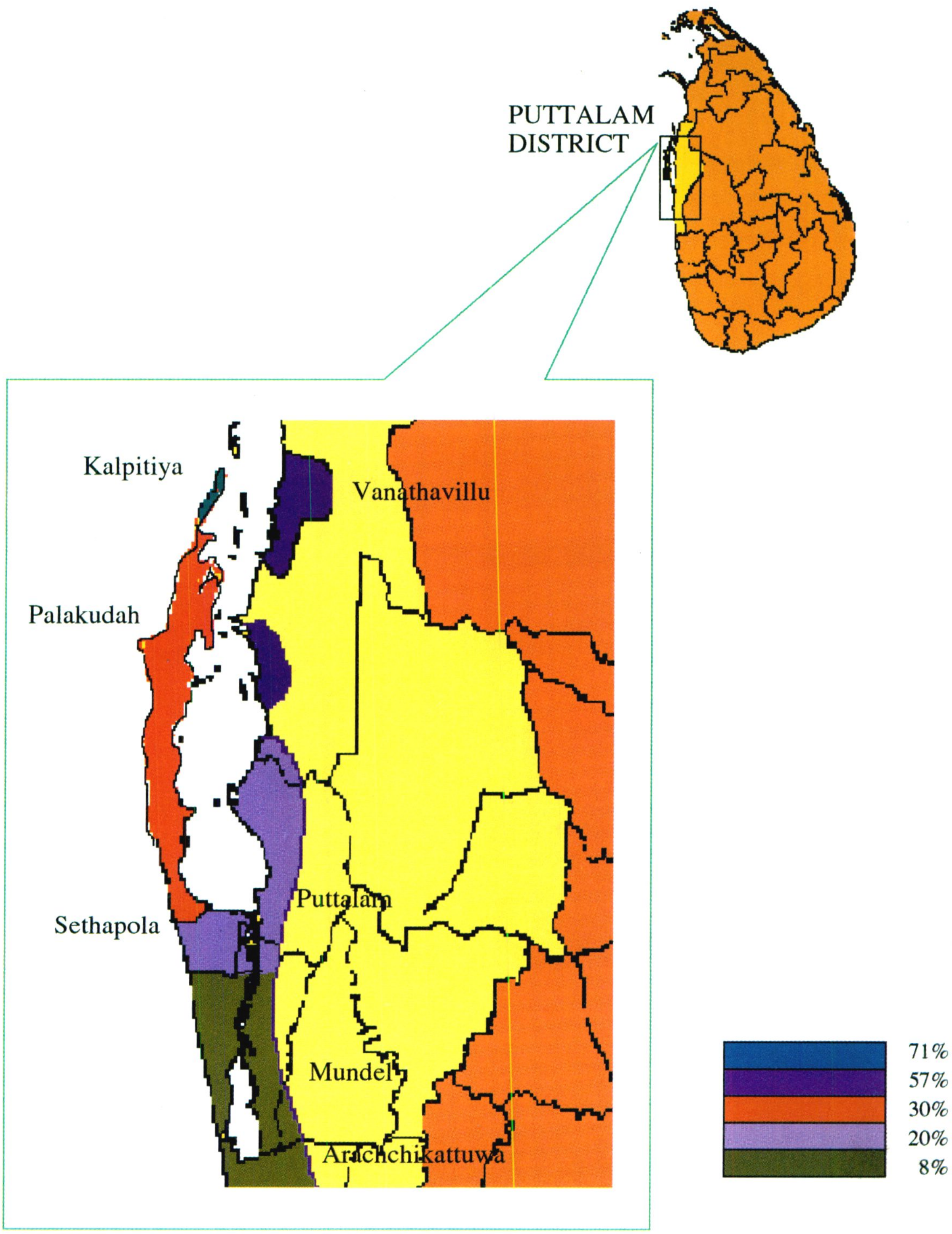

Fig. 1: Distribution and incidence of *Aceria guerreronis* in North-Western Province of Sri Lanka

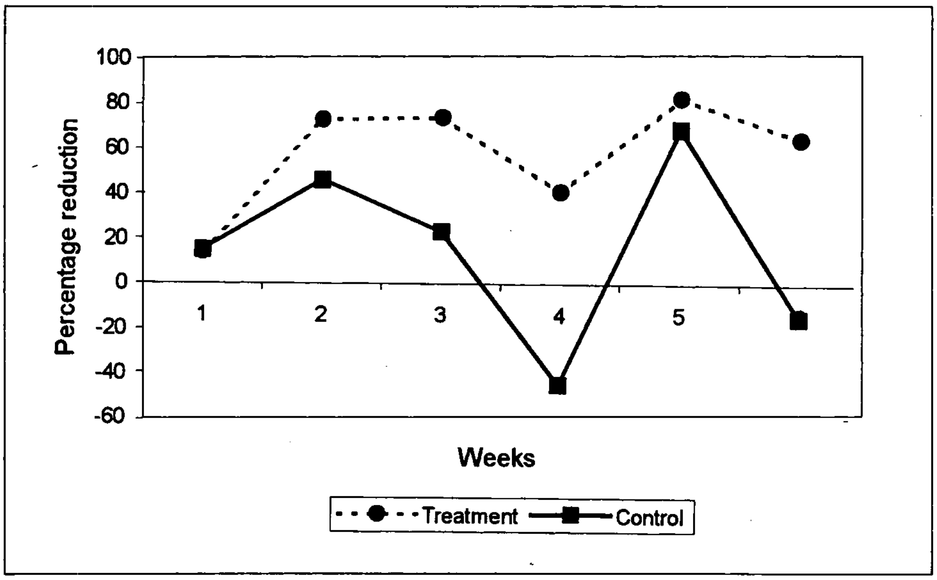

Fig. 2: Reduction in *Aceria guerreronis* population with respect to the pre-treatment population

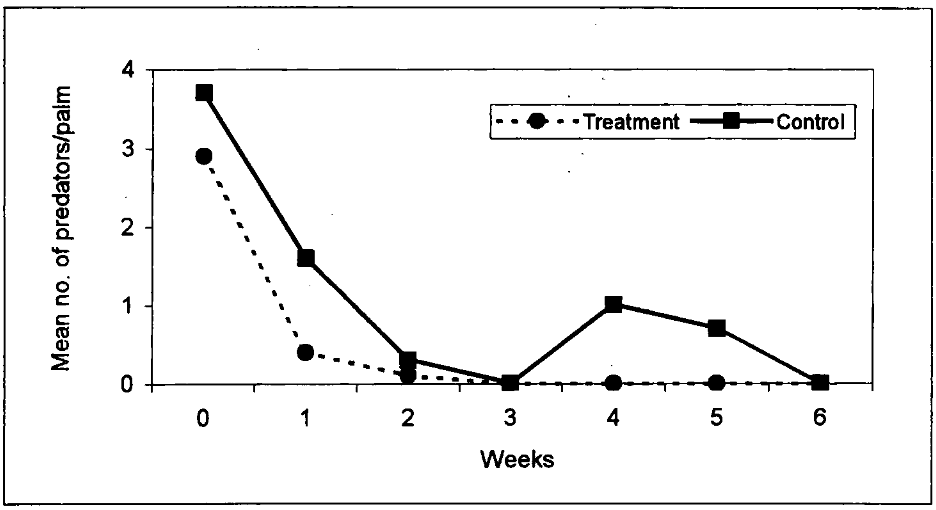

Fig. 3: Effect of monocrotophos on the predator population of*Aceria guerreronis*

New Chemicals

Due to the high toxicity and permanent damage caused to the trunk, monocrotophos could not be recommended for long-term use. Therefore, two new chemicals viz. 2% neem oil and garlic mixture and NeemAzal T/S were recommended based on preliminary studies.

Neem oil and garlic mixture has been recommended for the control of the mite in India. It was also evaluated in Sri Lanka to determine the effectiveness in local conditions. The results indicated a significant drop ($P<0.0001$) in the total pest population due to the treatment while the population in the untreated palms kept increasing (Fig. 4). The highest reduction was observed at 4 weeks after treatment. Thereafter pest population increased gradually and reached the pre treatment population level in 12 weeks. Those products also affected the predator population up to 4 weeks after application (Fig. 5).

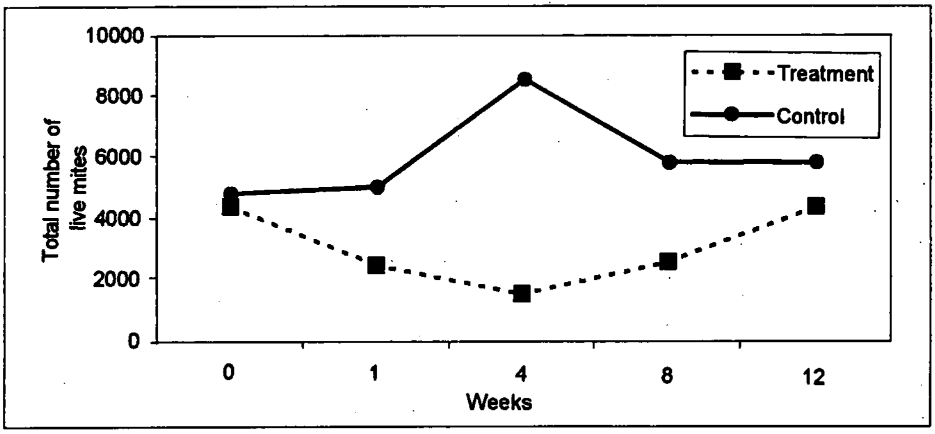

Fig. 4: Effect of neem oil and garlic mixture on *Aceria guerreronis*

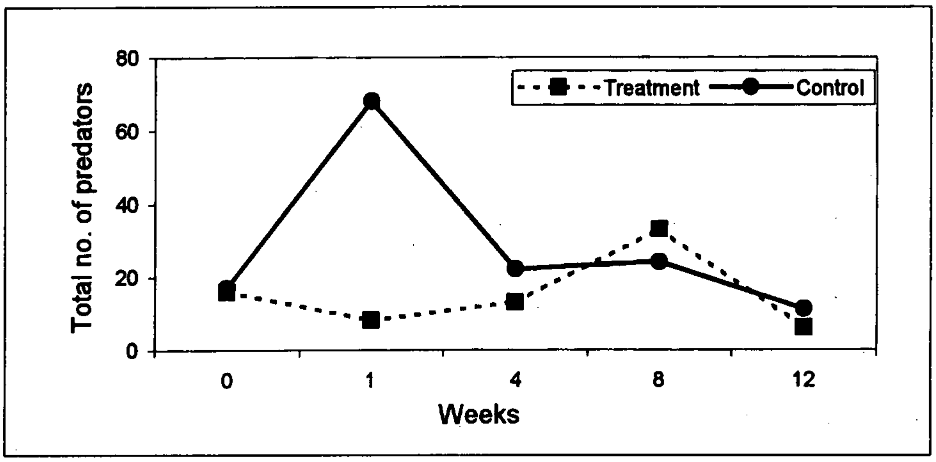

Fig. 5: Effect of neem oil and garlic mixture on the population of predator of *Aceria guerreronis*

Similarly the effect of two doses of NeemAzal (1% Azadirachtin) viz. 2 ml/l and 4 ml/l were evaluated. The results showed that percentage live mites in the treated palms decreased up to 3 weeks after treatment (Fig. 6). A lower percentage of live mites was observed in the higher dose. A range of other insecticides and acaricides was also screened, but none showed a significant reduction in the pest population.

New technique to estimate mite population

Direct counting of total number of mites is difficult due to the large numbers of mites present on a single nut. Techniques developed to estimate the mite populations are either relative estimates (Moore and Alexander, 1987) or estimate the population with the assumption that mites are evenly distributed in the colonies, hence not reliable (Howard *et al.*, 1990). A reliable and effective method was developed to estimate the total population on a nut (Siriwardene, 1999, unpublished report). The perianth of the nut is removed and the bracts are arranged in a funnel. The nut surface and the bracts are washed with 30 ml detergent solution and the wash is shaken for few seconds. Soon after shaking, the number of mites in 1 ml of the solution is counted and the total population is estimated. This method gives a uniform distribution of mites in the solution. The disadvantage of this method is that live and dead mites cannot be distinguished in the solution.

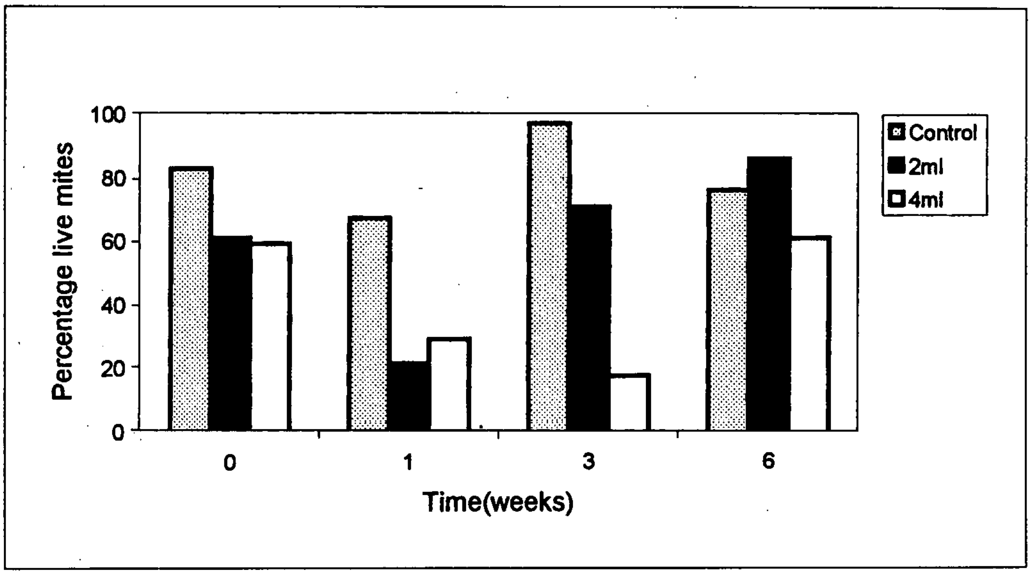

Fig. 6: Effect of two concentrations of NeemAzal on *Aceria guerreronis*

Natural enemies

Attempts were initiated to search for natural enemies and explore the possibilities of utilizing them as biological control agents in the control of the pest. A preliminary survey showed that predatory mites, *Neoseiulus paspalivorus* DeLeon (Phytoseiidae) and *Bdella* sp. (Bdellidae) were common on infested nuts. *N. paspalivorus* was more prevalent. This observation is in contrast to the observations made in America and Africa where extremely low numbers of predators have been recorded (Mariau, 1977; Howard *et al.*, 1990). The fluctuations of this species in three infested areas were monitored. The mean number of predators per nut (3-4 months old) in each area varied considerably over time (Fig. 7). Also, they were not found in all infested nuts and their distribution among nuts varied largely. However, interestingly, pest numbers were low on nuts containing the predators.

Future research

The aim of the future research programme is to keep the pest below economic threshold by an integrated management strategy in which priority is always given to biological control of the pest. In Sri Lanka, other coconut pests such as coconut caterpillar, black beetle and red weevil are managed by using the same strategy.

Importance of cultural practices in reducing the incidence of coconut mite has been reviewed (Moore & Howard, 1996). Although several chemicals have been used to manage the pest effectively, focus should be given for the use of chemicals of low toxicity such as botanicals. Improved application techniques have to be developed since there are several difficulties in using power sprayers and finding climbers for the application of chemicals.

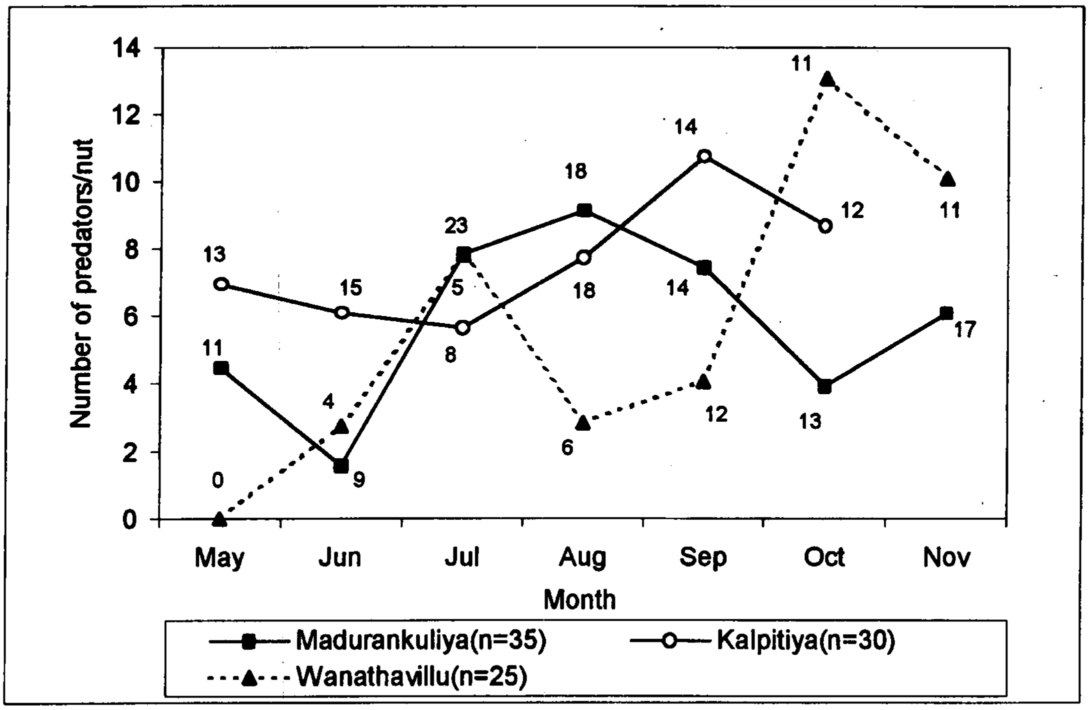

Fig. 7: Fluctuation of *N. paspalivorus* populations in three infested sites (numbers near data points are the number of nuts on which predators were present)

Although several species of natural enemies have been recorded in Americas and Africa (Julia & Mariau, 1979; Howard *et al.*, 1990) their regulatory effect on *A. guerreronis* was not adequately known. Therefore no studies have been undertaken in the past to utilize predators in a biological control programme. Our observations have shown that *N. paspalivorus* is a prospective candidate and studies on the biology and ecology should be undertaken. The fungus, *Hirsutella thompsonii* has been considered a promising agent in other countries (Julia & Mariau, 1979; Hall *et al.*, 1982; Lampedro & Rosas, 1989). It has also been isolated from another nut infesting mite in coconut, *Dolichotetranychus* sp. in Sri Lanka (Hall *et al.*, 1982). Therefore pathogenecity and use of the local and exotic strains in Sri Lanka need to be investigated.

Several factors need to be considered for the successful utilization of natural enemies in the control of coconut mite in Sri Lanka. The climatic conditions in the affected areas are very characteristic. Generally, the area is windy, has low rainfall distributed in two seasons and has day temperatures over 30C throughout the year. Also a very high relative humidity (>80%) prevails through out the area because sea, lagoon or water bodies surround most part of the affected area. Further the area is extensively cultivated with cashew, vegetables and fruit trees. Hence, bio control agents should not affect the existing natural balance of the arthropod complexes in these crops.

Considering the above factors research needs to be initiated to select effective natural enemies (predators and fungus), their culturing, determination release/application techniques and evaluation of their success in the field.

Acknowledgements

We are grateful to the staff of the Crop Protection Division for their dedication and assistance in every step of the mite control programme. We thank the management and the staff of the Coconut Research Institute and Coconut Cultivation Board for their contribution to success of above programme. We acknowledge Dr. T.S.G Peiris for analysing the experimental data.

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Status of coconut eriophyid mite *Aceria guerreronis* Keifer in India

C. P. R. Nair
Central Plantation Crops Research Institute, Regional Station, Kayangulam 690533, India

Summary

Heavy incidence of the coconut mite ***Aceria guerreronis*** *(=* ***Eriophyes guerreronis****) Keifer occurred in Ernakulam District of Kerala State in 1998. This was the first report of the pest in India. The fast spreading nature of the pest was revealed in a survey carried out in subsequent months. Today, the pest occupies a wide area in the entire Kerala State and also in many pockets in adjacent states like Tamil Nadu, Karnataka and Andhra Pradesh in South India. Observations on the seasonal abundance of the mite showed the persistent nature of the pest with the population peaking in summer months (April May). The extent of damage varies from 20 60%. Currently the management of the pest is achieved by spraying of pesticides like monocrotophos, dicofol and methyl dematon and the botanical pesticide (2% neem oil garlic mixture). Observations on the bio-ecology of the pest and the results obtained from the management trials carried out in India are discussed in the paper.*

Introduction

Coconut plays a vital role in the prosperity of millions of small and marginal farmers in India. With a total of 1.79 million ha under coconut and an annual production of 13,968 million nuts, India is the largest producer of coconut. Though coconut palm is infested by a number of insect and non-insect arthropods in India only a few of them, like rhinoceros beetle, red palm weevil, black-headed caterpillar and white grub have been considered to be the major pests. During the past decade pests such as coreid bug *Paradasynus rostratus* Dist. and many species of mealybugs and scale insects have assumed serious proportion in certain locations.

The coconut mite, *Aceria guerreronis* Keifer (Eriophyidae: Acari) was reported for the first time in India by Sathiamma *et al.* (1998).Consequent to the reports on widespread occurrence of an unknown malady in and around Cochin during early 1998, investigations paid more attention to the problem. Preliminary studies on this malady by the Central Plantation Crops Research Institute revealed the widespread occurrence of this notorious pest on coconut in India. Today, *A. guerreronis* has occupied the status of a potential pest with a wide distribution in all major coconut growing states of peninsula India. In this paper information available from an ongoing research programme on *A. guerreronis* in India has been discussed.

First occurrence and spread of the pest

A. guerreronis was totally unknown to the country. The pest occurrence was first noticed in Ernakulam district. The coconut cultivators observed production of extremely small sized and disfigured nuts in October 1997 and they fetched only 50% of the market rate of the normal nuts. This situation became acute in early 1998 and the studies on the new malady finally led to the report on the occurrence of *A. guerreronis* in Ernakulam district in April 1998.

The Scientists of CPCRI conducted a rowing survey in May 1998, detecting the spread of the mite infestation in adjacent districts viz., Trichur, Alapuzha and Kottayam.Today, the pest is seen in all the 14 districts of Kerala State. During August 1998 examination of nuts from Pollachi in Tamil Nadu and Bangalore in Karnataka also indicated heavy infestation by the mite. Thus, in 1997 1998 the pest appeared simultaneously in all the three states of South India. In 1999 the pest was also reported from Andhra Pradesh. From the initial pocket it has spread to distant areas.An appraisal of the current scenario reveals that within one year the mite has become an established pest of coconut palm in India. A recent study on the intensity of infestation carried out by the Kerala State Agricultural Department indicated that a total of 2.99 lakh hectares out of 10.2 lakh hectares of coconut in Kerala has been affected by *A. guerreronis*.

Seasonal incidence

Studies on seasonal incidence of the mite have been in progress at Kayangulam, South Kerala since September 1998. Observations on the pest incidence were recorded at monthly intervals from 100 sample palms from a 50 ha plantation. They revealed that the pest was active throughout the year. The mite population was assessed by counting a portion of the colony from sample nuts collected from 10 palms of the observational garden. The population reached a peak during April-May. Damage of buttons during early stages of the growth was also monitored on these sample palms. Damage on developing nuts also figured high during March to June. During the hot and humid months a higher percentage of younger buttons was affected. On a particular palm, infestation by mite did not occur for more than the 4 to 6 months.

Rate of spread

The rate of spread of the pest was monitored at monthly intervals in a garden (3 ha) right from the first occurrence of the pest. The pest showed a tremendous rate of spread from 8.5% incidence in February 1999 to 73.2% in October 1999.It is inferred that the population growth of pest was accelerated by favourable weather factors like temperature and relative humidity.

Extent of damage

Within a period of less than two years the mite has assumed serious proportions in the major coconut-growing tracts. In Kerala, the major producer of coconut in India, it is estimated that 223.45 lakhs coconut palms are affected. Depending on the intensity of infestation button shedding and immature nut fall take place. The rate of nut fall increases with the onset of summer months. A pilot study conducted at Kayangulam indicated that shedding is more intense in the first 3 to 5 months of nut development.

The affected nuts that continue their growth either develop to barren nuts with no kernel or partially developed kernel. Formation of undersized nuts is common. A comparative study revealed that average weight of copra was 68.5 g in heavily infested nuts and 153.4 g in unaffected nuts. The husk also showed a reduction of fibre content and in severely infested nuts the husk was unsuitable for retting of coir.A loss of 40% fibre has been reported by the coir industry.

Mite population during developmental period of nuts

Nuts during various growth stages from 2nd month to 12th month (full maturity) were observed for mite population. Ten nuts each from a particular age group were observed during March 1999. The sample nuts were drawn from palms showing heavy infestation symptoms. Mites were present in all growth stages . From sixth month onwards there was a drastic decline in the number of mites present in the perianth region. The population lodged in the nuts of 10 -12 month maturity was highly negligible. Maximum colonization of mites in the meristem below perianth was observed between 3-5 months.

Field tolerance in cultivars

The most widely cultivated variety in Kerala is the highly heterogeneous West Coast Tall (WCT). WCT palms with green coloured nuts have been found to be more susceptible than WCT with red or bronze coloured nuts. Chawghat Dwarf Green is more susceptible than Chawghat Dwarf Orange, which has shown the least mite incidence in the field. The shape of the nut and the compactness of perianth seem to have great influence on mite infestation. These preliminary observations however, require in depth studies for confirmation.

Management of mites

In India, various studies have been conducted on the management of the eriophyid mite.Chemical control methods are currently practiced. Various workers have tried different methods of applications.

Root feeding of pesticides

Root feeding of insecticides was tried at three places in India. Trials carried out at CPCRI in 1998 with 10 ml monocrotophos mixed with 10 ml water at 45 day intervals showed reduction in pest incidence in 94.4 percent palms. Root feeding with triazophos 20 ml in 20 ml water also showed reduction in pest incidence. In both cases two rounds of application were required. Mohanasundaram *et al.* (1999) reported that triazophos at 20 ml mixed with 20 ml water provided satisfactory control of the mite when the pesticide was applied at an interval of 45 days. The trials at Tamil Nadu Agricultural University, Coimbatore, also indicated that administration of monocrotophos at 10-15 ml mixed with equal volume of water once in 45 days provided control of the mite.

The residue of monocrotophos lasts for 45 days and hence it could be recommended for root feeding only when harvest of tender nuts and mature nuts is to be done only after that period. Root feeding is not a feasible technique for states such as Kerala where the nuts are harvested for daily consumption and the farms are not on commercial basis.

Topical application of insecticides

Trials are in progress at CPCRI to develop a suitable chemical control method. Among the various pesticides tried during 1998 - 1999, spraying of monocrotophos, dicofol, carbosulfan, triazophos and endosulfan have been found effective. It has been observed that the pest buildup could be regulated at low levels up to 75 days after the pesticidal application.

Based on these preliminary results and the data on fast spread of the pest during post rainy months from September onwards, the ongoing field experiments on insecticidal spraying has been designed to workout the feasibility of 3 rounds of pesticidal spray in September October (post rainy), December January (early summer) and April May (peak summer). The trials carried out by Kerala Agricultural University, Trichur, have indicated effectiveness of dicofol spraying at 6 ml per litre water.The chemical has been widely used in Kerala for the management of the pest. Tamil Nadu Agricultural University, Coimbatore, recommends application of methyl dematon, triazophos and monocrotophos.

Use of biopesticides and eco-friendly chemicals

The Kerala Agricultural University recommends application of 2 percent neem oil garlic mixture containing 0.5% washing soap, for the management of the pest.Trials carried out at CPCRI have also indicated 66.9% control with two applications of neem oil garlic mixture, compared to 78.1% reduction obtained with chemical application .Preliminary screening of neem based commercial biopesticides carried out at CPCRI revealed effectiveness of NemAzal, which was comparable to the neem oil garlic mixture. Other biopesticides viz., nimbicidine and N.S.K. extract also provided more than 50% reduction in mite incidence.Recently, wettable sulphur was tested as an alternative to chemical pesticides. Two rounds of wettable sulphur 0.2% applied at monthly intervals gave encouraging results.

Search for biocontrol agents

Two species of predaceous mites are seen associated with eriophyid mite colonies in the field. The role of these agents is yet to be assessed. A dipteran maggot and a coccinellid have also been seen associated with mite colonies. Search for pathogenic fungi have not been successful so far.

Other management practices suggested

Removal and burying of shed buttons and young nuts affected by the mite is practiced as a sanitational method. As moisture stress has been found to aggravate the mite problem, irrigation of palms is recommended. Mite infestation has been observed to weaken the palms and the yield loss is accelerated by poor palm nutrition. Better nutritional management is therefore suggested.

Current research programmes

The eriophyid mite has assumed the status of a major pest of coconut in India. To tackle the menace at National level a co-ordinated research project has been formulated recently in which the Central Institutes and State Agricultural Universities are involved. The priority areas in the current investigations include development of botanical pesticides and other eco-friendly methods of management, intensified search for bio-control agents, assessment of crop loss and basic studies on bio ecological aspects of the pest.

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Studies on coconut eriophyid mite, *Aceria guerreronis* Keifer in Tamil Nadu, India

K. Ramaraju, K. Natarajan, P.C. Sundara Babu, S. Palanisamy and R.J. Rabindra
Department of Agricultural Entomology, Centre for Plant Protection Studies
Tamil Nadu Agricultural University, Coimbatore - 641 003.

Summary

India ranks first in the world in coconut production with 13 billion nuts per year accounting for 24.5% of the world production. Among the coconut growing states, Tamil Nadu ranks second in area as well as production and productivity. It is grown in an area of 3.2 lakh hectares and the total production was 3,716 million nuts with an average yield of 11,620 nuts/ha during 1997-98.Although nine species of eriophyid mites have been reported to affect coconut leaves and nuts, only ***Aceria (=Eriophyes) guerreronis*** *Keifer feeding on tender nuts has been found to cause heavy damage resulting in the loss of production of nuts. Other mites viz.,* ***Tetranychus neocaledonicus,Dolichotetranychus*** *sp.,* ***Tyrophagus putrescentiae*** *from perianth and* ***Neocypholaelaps stridulans*** *from inflorescence have also been recorded. Stray occurrence of* ***A. guerreronis*** *was observed at Srivilliputhur in Tamil Nadu during 1984. This pest was considered to be a minor one until it was reported in a severe form from Kerala and Tamil Nadu during 1998.*

A preliminary survey conducted in a few villages of Coimbatore district on the incidence of this mite indicated that its infestation ranged from 5.0 - 48.0% in the nuts on the trees and 12 - 52% in the harvested nuts. The mites develop on the meristematic tissues of the growing nuts under the perianth by desapping the soft tissues of the buttons. The population was very high in 2 - 6 month old buttons.As many as 2 - 140 motile stages of the mite along with a large number of eggs were found in an area of 4 sq.mm. on infested nuts. Studies on population dynamics revealed that there is no clear relationship between mite population and weather factors.Even though all coconut genotypes/ germplasm maintained at ARS, Aliyanagar were found infested by the mite, the cultivar Kenthali (tender coconut cultivar) was least susceptible to its attack.

Two species of predatory mites viz., ***Amblyseius (Neoseiulus) paspalivorus*** *and a tarsonemid mite were found inhabiting the perianth region. These mites were observed in very low population inside the perianth and the preliminary observations indicate that they do not cause any significant reduction in the population of the eriophyid mite.*

Bioefficacy of different insecticides/acaricide and a few botanicals against this mite was evaluated through crown spraying and root feeding during 1998-1999. Spraying of triazophos 40EC 5 ml/l, methyl demeton 25EC 4ml/l or monocrotophos 36 SL 1.5 ml/l was found to significantly reduce mite population. Since it is difficult to spray the chemicals in taller trees, root feeding of monocrotophos 15 ml with 15ml of water per tree is suggested.But none of the chemicals was *found to control this pest completely. Repeated application of insecticides/acaricide at short interval is warranted.*

Introduction

Coconut is extensively grown in about 80 countries of the world with a total annual production of over 49 billion nuts. India ranks first in the world with 13 billion nuts per year and accounting for 24.5% of the world production. The productivity of the crop is the highest in India with 6898 nuts/ha with an area of 1.90 million hectares. Among the coconut growing states, Tamil Nadu ranks second in area as well as production and productivity. It is grown in an area of 3.2 lakh hectares and the total production was 3716 million nuts with an average yield of 11620 nuts/ha during 1997-98 (Markose, 1999). Several insects and non insect pests have been reported to affect the coconut palm. Recently, outbreak of an eriophyid mite was noticed in severe form in different parts of Tamil Nadu. Nine species of eriophyid mites have been reported to attack coconut leaves and nuts (Amrine, Jr. and Stasny, 1994) and among them only *Aceria* (=*Eriophyes*) *guerreronis* (Keifer) [Acari : Eriophyidae] feeding on tender nuts has been found to cause heavy damage, resulting in loss of production of nuts.

H.H. Keifer was the first to describe the coconut eriophyid mite *A. guerreronis* from Mexico in 1965. In addition, this mite was also reported to infest coconut in Central and South America, Caribbean islands and West Africa.

In recent years, it was detected only when population levels in many localities increased due to some unknown ecological factors (Howard *et al.*, 1990). It is likely to be present in some localities where it has not yet been reported. Stray occurrence of this mite was observed in Srivilliputhur in Tamil Nadu during 1984 (Gunathilagaraj, 1984). This pest was considered to be a minor one (Ramaraju *et al.*, 1998) till it was reported in a severe form from Kerala during February, 1998 (Sathiamma *et al.*, 1998) and also from Pollachi and Udumalpet taluks of Coimbatore district in Tamil Nadu during August 1998. The dry weather that prevailed in different districts supposedly favoured the multiplication of the pest during 1998, especially, in Pollachi and Udumalpet taluks of Coimbatore district and in the districts of Erode and Dindigul. Since February, 1999, the incidence of the mite has been reported from the districts of Thanjavur, Trichy, Thiruvarur, Nagapattinam, Kanyakumari, Vellore, Madurai, Virudhunagar, Tirunelveli and other parts of the state.

The estimated loss of copra was 10% in Benin (Mariau and Julia, 1970), 16% in Ivory Coast (Julia and Mariau, 1979), 30% in Mexico (Hernandez, 1977) and 11 - 28% in St Lucia (Moore, 1986). Mariau and Julia (1970) and Moore and Alexander (1987a) reported that the mites were not found under the bracts of unfertilized female flowers but were present under the external bracts, just after fertilization. Field use of pathogenic *Hirsutella thompsonii* (Fisher), against this mite, has had variable results (Moore and Howard, 1996). The arrangement of the bracts of the growing nuts was found to influence the pattern of attack by the mite (Moore, 1986).

Spraying the bunches of developing fruits with dicrotophos, monocrotophos or chinomethionate every 20 or 30 days was found reduce damage significantly (Hernandez, 1977). Similar results were obtained with acaricides applied at 15 days intervals (Mariau and Tchibozo, 1973). Julia and Mariau (1979) found the stem injection of monocrotophos, at two month intervals, to be effective on young dwarf plants. While stem injection of vamidothion was proposed by Griffith (1984), the same was found ineffective by Moore and Alexander (1987b). Mohanasundaram *et al.* (1999) reported that spraying of methyldemeton 4ml/l and triazophos 5ml/l was effective. So far, no studies have been carried out on the management of this mite in Tamil Nadu, India. Considering the importance and serious nature of the problem, studies were carried out on population dynamics, varietal susceptibility and the effect of certain insecticides/acaricides against *A. guerreronis* in that state.

Materials and methods

Survey

A survey on the incidence of *A. guerreronis* and its damage to coconut was conducted in Pollachi and Udumalpet taluks of Coimbatore district during September, 1998. The extent of the coconut mite infestation was estimated based on the total number of trees, the number of trees infested and by working out the percentage of infested trees. Besides, the per cent damage to nuts was estimated from the harvested nuts based on the symptoms.

Damage symptoms

The samples of infested coconut buttons (1-9 months old) were collected from the affected gardens and the nature of damage and population density of mites in 1-6 month old nuts were observed in the laboratory. Different species of mite occurring underneath the perianth were also recorded.

Population dynamics

Seasonal incidence of *A. guerreronis* and its predatory mite *Amblyseius(=Neoseiulus) paspalivorus* was studied by assessing the population of mites (immatures and adults) at monthly interval from September, 1998 to November, 1999 on ten, three to four month old infested coconut buttons sampled from five trees at Agricultural Research Station (ARS), Aliyarnagar. The number of eriophyid mites per 4 sq.mm (2mm x 2mm) area on surface of each nut and the total number of predatory mites/nut were recorded. Correlation and multiple regression analysis were made on the incidence of mite with the prevailing weather factors to know their combined influence.

Varietal screening

A total of 19 genotypes/ germplasm maintained at ARS, Aliyarnagar were screened for their level of susceptibility against coconut eriophyid mite. A total of 25 nuts in each cultivar were assessed for mite damage at the time of harvest. Each nut was assessed for surface damage based on a 1 - 5 scale adopted by Julia and Mariau (1979).The damage categories 3 - 5 have been taken into account and the percentage of infested nuts was estimated. Samples of two, three to four month old infested buttons were collected from each cultivar and the population density was recorded in 8 sq.mm area both on the innermost bract and nut surface.

Bioefficacy of insecticides/acaricide

Four field experiments, two in ARS,Aliyarnagar and two in farmers holdings, one each at Avalur (Erode taluk) and Thathur (Pollachi taluk), were conducted to evaluate the bioefficacy of different insecticides / acaricide. In all field experiments, two rounds of crown spraying or root feeding were given. Root feeding of chemicals was done through live, yellow or orange-brown coloured roots. In all four field experiments live and dead mite populations were recorded in 4 sq.mm area each on the innermost bract and nut surface in every sample. On 7, 15 and 23 days after treatment, the percentage mortality was determined.

Crown spraying : ARS, Aliyarnagar

The experiment was carried out at the Agricultural Research Station, Aliyarnagar on 10 years old and 20' - 30' tall VHC2 (Veppankulam hybrid coconut) palms between October 7, 1998 and November 23, 1998.Each of the 18 treatments consisted of 2 replications with 2 palms per replication.

Crown spraying and root feeding : Thathur

The experiment was conducted at Thathur on 6 years old, 20' (for spraying) and 30 (for root feeding) tall hybrid palms between October 9, 1998 and November 9, 1998. Each of 17 (spraying) and 20 (root feeding) treatments consisted of 2 replications with 2 palms per replication.

Crown spraying and root feeding :Avalur

The experiment was conducted at Avalur on 25 years old and 50' - 60' tall East coast tall (ECT) between October 2, 1998 and November 19, 1998.Each of 17 treatments consisted of 2 replications with 2 palms per replication and were sprayed with 1 l of the chemical using a Hercules hand sprayer/Ganesh sprayer.

Root feeding : Aliyarnagar

The experiment was carried out at ARS, Aliyarnagar on 10-12 years old, 25' - 35' high East coast tall (ECT) palms between October 9, 1998 and November 9, 1998. Each of 11 treatments consisted of 2 replications with 3 palms per replication.

Evaluation of bioefficacy of insecticides/acaricide against eriophyid mite, based on damage symptoms

A field experiment was conducted at ARS, Aliyarnagar to evaluate the bioefficacy of insecticides / acaricide based on the surface damage symptoms on nuts. The experiment was conducted in a randomised block design with 12 treatments (Table 13) and five replications. Three rounds of treatments *viz.*, crown spraying and root feeding were given on 16.04.99, 18.06.99 and 20.08.99.

On 4th November 1999 the percentage of infestation on green nuts (bunches 3 - 6) on the trees was assessed by observing the total number of nuts and infested nuts in each bunch. The nuts harvested six months after the commencement of treatments were also assessed on the same day based on a damage scale from 1 (no damage) to 5 (severe damage and distortion of the nut) adopted by Julia and Mariau (1979).

Results and discussion

The preliminary survey, conducted in 17 villages of Pollachi and Udumalpet taluks on the incidence of coconut mite, indicated that the mite infestation ranged from 5.0 to 48.0% in the trees (Table 1). The infestation on nuts varied from 3.6 to 44.5% on the trees (Table 2) and 12 to 52% in the harvested heaps (Table 3). The mite infestation on the harvested nuts was calculated based on the external symptoms.

This eriophyid mite measures about 200-250 in length and has pairs of legs (Plate 1). It is pale in colour, with elongate, worm-like body. It occurs in large numbers inside the perianth of 2-6 month old nuts (Plate 2).

Table 1. Mite incidence on coconut trees in Pollachi and Udumalpet taluks

No.	Place	Name of the farmer	Total trees (No.)	Trees sampled (No.)	Trees(No.) infested in the sample	Infested trees (%)
	POLLACHI					
1.	Ponnayagoundanur	-	300	20	1	5.0
2.	S.Ponnapuram	P.T.Balu	1500	30	2	6.7
3.	Kanjampatti	Balachandran	550	40	3	7.5
4.	S.Nallur	Nachimuthu	1500	40	3	7.5
5.	Samathur	R.Govindaraju	1700	50	4	8.0
6.	Thondamuthur	Natarajan	700	25	2	8.0
7.	Unjavelampatti	Chinnasamy	350	50	4	8.0
8.	Thondamuthur	Giri	500	30	3	10.0
9.	Pulliyankandi	Natarajan	450	20	2	10.0
10.	Aliyarnagar	-	977	70	7	10.0
11.	Nambiamuthur	Gopalsamy	500	40	11	27.5
	UDUMALPET					
1.	Komangalam	-	350	40	3	7.5
2.	Amaravathi Nagar	Kabilan	3000	75	36	48.0

Table 2. Mite infestation on nuts in Pollachi and Udumalpet taluks

No.	Name of the village	Name of the farmer	Total trees	Sample of 8 trees		% nuts infested
				Total nuts	Infested nuts	
	POLLACHI					
1.	Kanjampatti	S.Balachandran	550	334	12	3.6
2.	Ammaigoundanur	Somasundaram	1750	262	19	7.3
	UDUMALPET					
1.	Gomangalam Pudur	G.V.Ranganathan	1330	334	22	6.6
2.	Kurichikottai	S.Govindaraj	1050	472	32	6.8
3.	Poolankinaru	M.N.Mohanraj	1190	346	52	15.0
4.	Amaravathi Nagar	J.Kabilan	3000	321	143	44.5

Table 3. Percentage infestation on harvested nuts

Place	Name of the farmer	Total nuts examined	Infested nuts %
Unjavelampatti	N.Chinnasamy	100	10
Kanjampatti	S.Balachandran	100	12
Avalur	Mani	100	20
Thathur	Krishnasamy	100	43
Samathur	Kuppusamy	100	52
Avalur	Venkittu	100	48
Gomangalam	Ramasamy	100	39

When the age of nut increases the population decreases. The populations ranged from 2-140 mites per 4 sq.mm area of an infested button along with plenty of eggs (Fig. 1). The mites cause damage by sucking the cell content from the soft meristematic tissues of the buttons.In the initial stage the damage occurs as triangular patches close to the perianth which later turn into brown patches (Plate 3). As the nuts grow in size, the feeding injury results in warting and longitudinal splits on the outer surface of the developing nuts (Plate 4). Severe infestation on young nuts results in poor growth, reduction in size and copra content and, hardening of the husk (Plate 5).

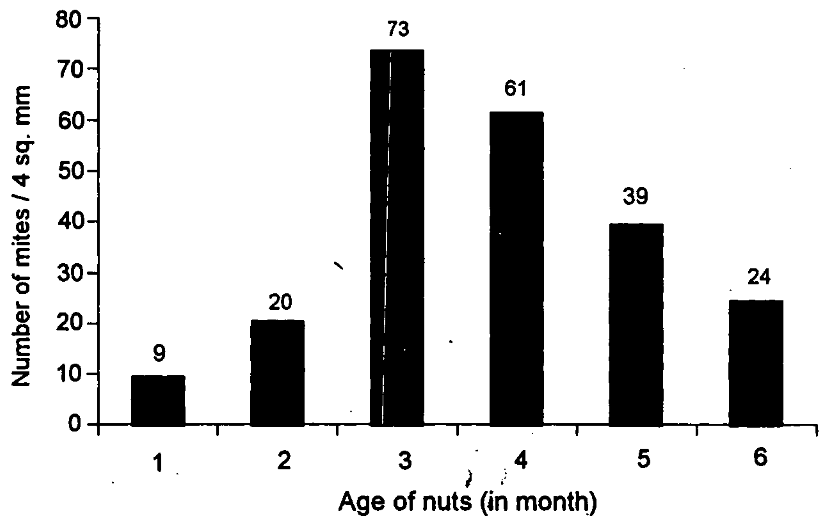

Fig. 1: Population density of *Aceria guerreronis* in nuts of different ages at Aliyarnagar

Besides the eriophyid mite other species of mites such as *Tetranychus neocaledonicus* Andre (Tetranychidae) *Dolichotetranychus* sp. (Tenuipalpidae), *Amblyseius* (*Neoseiulus) paspalivorus* DeLeon (Phytoseiidae), *Tyrophagus putrescentiae* (Schrank) (Acaridae) and an unidentified tarsonemid mites were also found to inhabit the nut underneath the perianth.The predaceous phytoseiid mites were observed in very low populations and there was no clear evidence that they were feeding on the eriophyids and reducting their population. Large number of *Neocypholaelaps stridulans* (Evans) were recorded from coconut inflorescence and on the developing buttons but the exact role of this mite is not known. The elongate pale red coloured mite, *Dolichotetranychus* sp. was recorded in very low populations, but cause the button shedding. *Tyrophagus* found inside the perianth may probably feed on the fungal spores.

Population dynamics

The population build up of eriophyid mite was maximum during May, 1999 (86/4 sq.mm) followed by April, 1999 (73) and March, 1999 (70). The mite population found to be fairly high even in October, 1999 (53), November, 1998 (40) and December (52) which recorded a higher rainfall of 339, 274 and 550 mm respectively. Since these mites occupy a completely protected niche under the bracts the reach of the toxicants applied to the target site is greatly impeded. The population of predatory mites *A. paspalivorus* was very low, ranging between 2.2 and 8.2/nut (Fig. 2). Correlation and multiple regression analysis between the population of eriophyid mite and weather factors revealed no significant relationship.

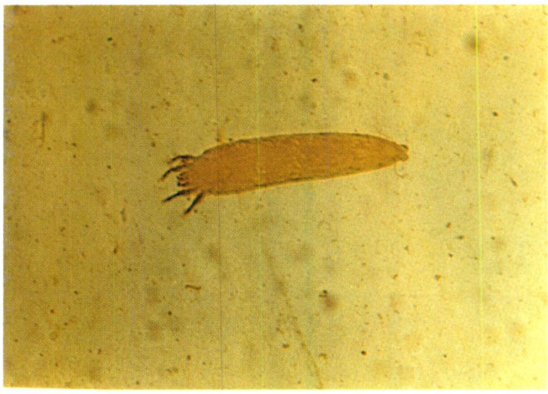

Plate 1: Photomicrograph of eriophyid mite (Full view)

Plate 1a: Magnified view of mouth parts and appendages

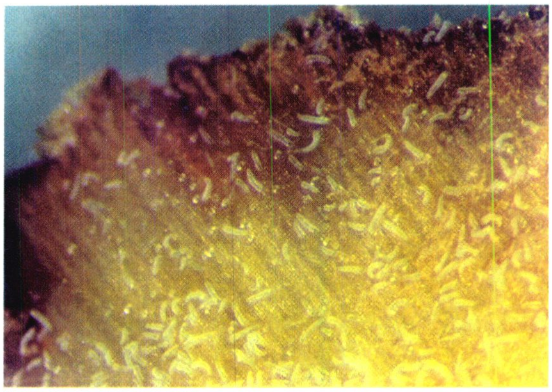

Plate 2: A colony of nut infesting coonut eriophyid mite *Aceria guerreronis* K

Plate 3: Development of symptoms in young nuts

Plate 4: Severe warting, cracking and gummy exudation on the infested nut

Plate 5: Nuts harvested from a severely infested garden

$Y = -22.71 + 3.23X^1 + 1.31X^2 - 0.54X^3 - 0.03X^4$ (R2 0.27) where,

X^1 - Maximum temperature; X^2 - Minimum temperature; X^3 - Relative humidity; X^4 - Rainfall in cm.

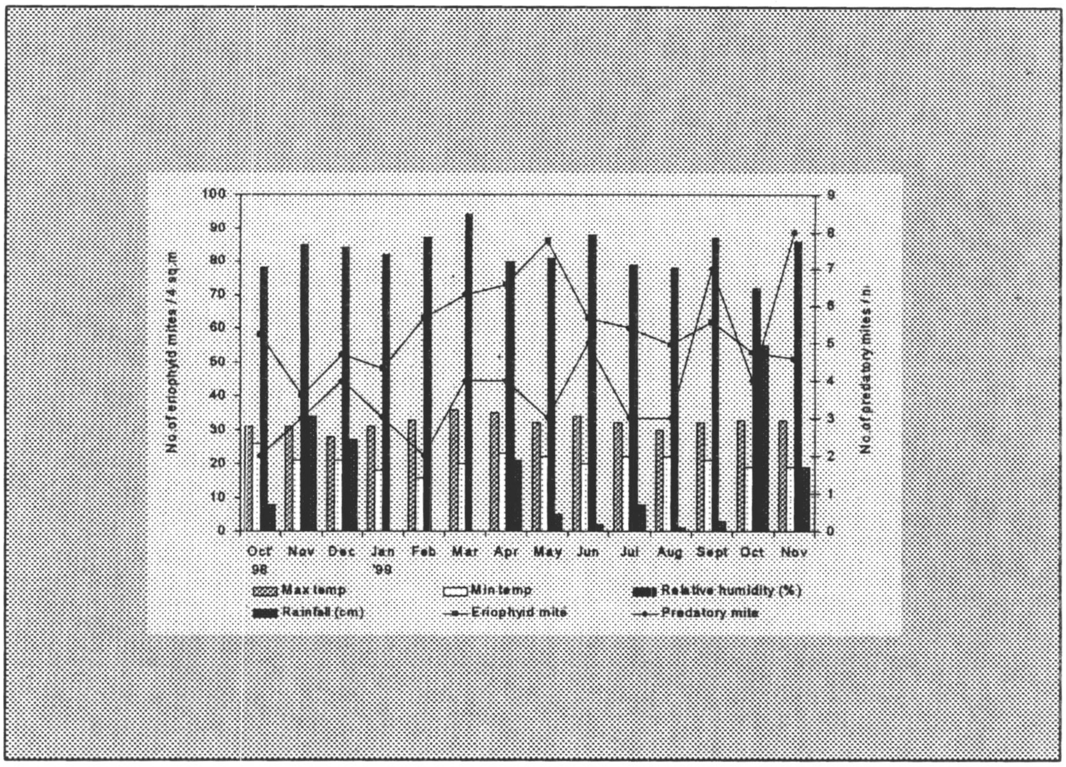

Fig. 2: Population dynamics of *Aceria guerreronis* and *Amblyseius paspalivorus* at Aliyarnagar

Varietal reaction

The harvested nuts from various genotypes were assessed for the intensity of damage adopting a scale of 1 to 5. Genotype Kenthali and British Solomon Island recorded the lowest surface damage of 20 and 40 per cent respectively. Tiptur Tall was the most susceptible cultivar recording the highest damage (84%) followed by St. Vincent, East Coast Tall and West Coast Tall(76%). Genotypes Kenthali recorded the lowest mite population (16.33 / 4sq.mm) followed by WCTXCOD (19.00), BSI (27.00) as against Tiptur Tall with 140.33. In other cultivars the population ranged from 38.33 to 120.67 mites / 4sq.mm. (Table 4).

Bioefficacy of insecticides.acaricide

Crown spraying : ARS, Aliyarnagar

Triazophos 5 ml/l, triazophos 1.5 ml/l and methyl demeton 4 ml/l recorded 70.29%, 32.82% and 31.46% mite mortality, respectively, at seven days after first round of treatment. Fifteen days after spraying monocrotophos 1.5 ml/lrecorded 57.98% mortality followed by methyl demeton 4 ml/l (44.59%), triazophos 5 ml/l (42.79%) and dicofol 2.5 ml/l (38.38%).At 23 days after treatment (DAT),differences among treatments were not significant (Table 5).

Table 4. Screening of coconut genotypes / germplasms for their level of susceptibility to coconut mite

Genotypes/germplasms	% of nuts in damage categories 3-5	No. of mites / 8 sq.mm
Philippines ordinary	72	111.00 (10.52)^{hi}
Sanramon	68	77.68 (8.83)$^{c-h}$
Gonthembili	64	38.33 (5.98)^{abc}
WCT x GB	52	38.33 (6.18)^{abc}
COD x WCT	60	92.00 (9.46)$^{f-i}$
Kenthali	20	16.33 (4.10)^{a}
Andaman ordinary	72	75.67 (8.70)$^{d-h}$
Strait settlement green	60	52.67 (7.10)$^{c-f}$
Tiptur Tall	84	140.33 (11.86)^{i}
Lakshadeep Ordinary	68	120.67 (10.96)^{hi}
WCT x COD	52	19.00 (4.36)^{ab}
ECT x MYD	48	48.33 (6.67)$^{b-e}$
Zanzibar	64	44.33 (6.54)$^{d-e}$
Java	64	54.00 (7.28)$^{c-g}$
St. vincent	76	45.00 (6.74)$^{b-e}$
West Coast Tall (WCT)	76	87.00 (9.34)^{fgh}
East Coast Tall (ECT)	76	95.00 (9.76)^{ghi}
Federated Malay States	68	50.33 (7.13)$^{c-f}$
British Solomon Island (BSI)	40	27.00 (4.99)^{abc}

Mean followed by a common letters are not significantly different at 5% level by DMRT.
Values in parentheses are (x+0.5)transformed values

Table 5. Bioefficacy of insecticide/acaricides against coconut mite, *Aceria guerreronis* (ARS, Aliyarnagar - I Round)

No.	Treatments	Per cent mortality		
		7 DAT	15 DAT	23 DAT
1.	Monocrotophos 36 WSC 1.5ml/l	23.28 (28.77)^{bc}	57.98 (49.59)^{a}	36.57 (36.81)^{a}
2.	Dimethoate 30 EC 2.0ml/l	25.21 (29.35)^{bc}	15.78 (23.41)^{cde}	32.55 (34.77)^{a}
3.	Dicofol 2.5 18.5 EC ml/l	15.77 (23.28)^{bc}	38.38 (38.20)^{abc}	20.49 (26.44)^{a}
4.	Wettable sulphur 80WP 2g/lit	14.66 (22.43)^{bc}	15.91 (22.97)^{cde}	19.71 (26.07)^{a}
5.	Ethion 50EC 2ml/lit	28.10 (32.15)^{bc}	36.70 (36.96)$^{a-d}$	19.27 (25.94)^{a}
6.	Dichlorvos 76EC 1ml/lit	13.55 (21.53)^{bc}	8.40 (16.45)^{e}	26.26 (30.68)^{a}
7.	Endosulfan 35EC 2ml/lit	23.32 (28.15)^{bc}	18.73 (25.64)$^{b-e}$	27.58 (30.76)^{a}
8.	Phosalone 35EC 2ml/lit	14.59 (21.96)^{bc}	31.22 (33.65)$^{a-d}$	10.94 (18.88)^{a}
9.	Acephate 75SP 1g/lit	28.46 (32.21)^{bc}	12.97 (20.80)^{de}	26.23 (30.58)^{a}
10.	Triazophos 40EC 1.5m/lit	32.82 (34.81)^{b}	33.68 (35.45)$^{a-d}$	36.76 (37.31)^{a}
11.	TNAU Neem oil 60 EC (C) 3%	12.44 (20.62)^{bc}	28.07 (31.98)$^{b-e}$	26.03 (29.25)^{a}
12.	TNAU Neem oil 0.03% EC	11.03 (19.15)^{bc}	28.66 (32.28)$^{b-e}$	18.37 (25.08)^{a}
13.	Methyldemeton 25EC 2ml/lit	26.53 (30.97)^{bc}	33.61 (35.39)$^{a-d}$	25.56 (30.37)^{a}
14.	Fenthion 100 EC 1ml/l	21.48 (27.11)^{bc}	29.42 (32.18)$^{b-e}$	34.05 (35.19)^{a}
15.	Triazophos 5ml/lit	70.29 (57.02)^{a}	42.79 (40.75)^{ab}	37.44 (37.58)^{a}
16.	Methyldemeton 4ml/lit	31.46 (34.05)^{bc}	44.59 (41.88)^{ab}	39.75 (38.98)^{a}
17.	Phosalone 3ml/lit	16.75 (24.12)^{bc}	32.13 (34.47)$^{a-d}$	33.59 (35.22)^{a}
18.	Untreated control	9.85 (18.27)^{c}	13.38 (20.56)^{de}	16.16 (23.66)^{a} NS

DAT - Days after treatment - Figures in parentheses are arcsine P tr ansformed values.
Means followed by common letter(s) are not significantly different at 5% level by DMRT.

Also after the second round of treatment, monocrotophos 1.5ml/l was significantly superior to all other treatments and recorded 54.34 per cent mortality seven days after second spraying, and it was followed by monocrotophos 3ml/l (50.29%), dicofol 6 ml/l (41.30%) and fenthion 1 ml/l (41.15%).

Fifteen days after the second round, monocrotophos 3ml/l was found to be the most effective causing 56.75% mortality, followed by triazophos 5 ml/l (49.97%), monocrotophos 1.5 ml/l (49.75%) and dicofol 6 ml/l (47.76%). Likewise, 23 DAT the order of efficacy was, methyl demeton 4ml (72.49%), triazophos 5ml (70.92%), phosalone 3ml (68.07%) and they were on par with each other (Table 6).

Table 6. Bioefficacy of insecticide/acaricides against coconut mite, *Aceria guerreronis* ARS, Aliyarnagar - II Round Mite mortality percentage

No.	Treatments	Per cent mortality		
		7 DAT	15 DAT	23 DAT
1.	Monocrotophos 1.5ml/l	54.34 (47.55)[a]	49.75 (44.85)[ab]	62.68 (52.46)[abc]
2.	Dimethoate 2.0ml/l	38.74 (37.58)[a-d]	29.61 (32.92)[b-f]	47.73 (43.68)[a-f]
3.	Dicofol 2.5 ml/l	30.19 (33.33)[a-d]	26.46 (30.92)[c-f]	65.10 (53.94)[ab]
4.	Wettable sulphur 2g/lit	19.75(26.37) [bcd]	21.14 (27.34) [def]	36.91 (36.99)[b-g]
5.	Ethion 2ml/lit	32.57 (34.27) [a-d]	18.12 (25.19)[def]	31.31 (33.86)[d-g]
6.	Dichlorvos 1ml/lit	25.96 (30.46)[a-d]	15.45 (22.98)[ef]	32.58 (34.80)[c-g]
7.	Endosulfan 2ml/lit	39.89 (39.16)[a-d]	30.70 (33.63)[b-f]	45.94 (42.67)[a-f]
8.	Phosalone 2ml/lit	16.51 (23.93)[cd]	35.46 (36.54)[a-e]	31.93 (34.39)[d-g]
9.	Acephate 1g/lit	36.03 (35.83)[a-d]	38.31 (38.23)[a-d]	20.97 (27.24)[f-g]
10.	Triazophos 1.5m/lit	24.25 (29.50)[a-d]	33.74 (35.50)[b-e]	48.81 (44.31)[a-f]
11.	TNAU Neem oil 60 EC (C) 3%	38.06 (37.74)[a-d]	25.91 (30.54)[c-f]	55.65 (48.25)[a-e]
12.	TNAU Neem oil 0.03 EC	15.73 (23.35)[cd]	13.48 (21.51)[f]	13.53 (21.36)[g]
13.	Methyldemeton 2ml/lit	39.28 (38.81)[a-d]	25.38 (30.24)[c-f]	29.90 (33.14)[d-g]
14.	Fenthion 1ml/l	41.15 (39.80)[abc]	38.16 (37.57)[a-d]	58.08 (49.71)[a-d]
15.	Triazophos 5ml/lit	34.43 (35.92)[a-d]	49.97 (44.98)[ab]	70.92 (57.66)[a]
16.	Methyldemeton 4ml/lit	39.20 (38.73)[a-d]	31.68 (34.25)[b-f]	72.49 (58.49)[a]
17.	Phosalone 3ml/lit	35.22 (36.36)[a-d]	33.51 (35.36)[b-e]	68.07 (55.63)[a]
18.	Monocrotophos 3ml/l	50.29 (45.17)[ab]	56.75 (48.88)[a]	51.71 (45.98)[a-e]
19.	Dicofol 6ml/l	41.30 (39.96)[abc]	47.76 (43.62)[abc]	63.53 (52.95)[ab]
20.	Neem oil 2%+Garlic extract 25g/l	25.14 (30.06)[a-d]	32.69 (34.68)[b-f]	45.52 (42.13)[af]
21.	Untreated control	11.91 (20.08)[d]	15.27 (23.00)[ef]	26.33 (30.60)[efg]

DAT - Days after treatment - Figures in parentheses are arcsin P tr ansformed values.Means followed by common letter(s) are not significantly different at 5% level by DMRT.

Crown spraying : Thathur

Dicofol 2.5ml/l, monocrotophos 1.5 ml/l and triazophos 5 ml/l recorded significantly higher mortality of 41.79, 40.90 and 37.84 per cent at seven days after first spraying.On 15th day after treatment, triazophos 5ml (68.16%) recorded significantly higher mortality. Triazophos 2 ml (54.76%), methyl demeton 4 ml (52.63%) and monocrotophos 1.5 ml/l (51.23%) were next in order.

Monocrotophos 1.5ml/l and triazophos 5ml/l were significantly effective at 23 days after first spraying by recording 52.35 and 51.29 per cent mortality, respectively.At 15 days after second spraying differences among treatments were not significant. Methyl demeton 4ml was the most effective at 23 DAT by recording 61.89 per cent mortality (Tables 7 & 8).

Root feeding : Thathur

Root feeding of dimethoate 10ml + 10ml water recorded a maximum mortality of 52.65 per cent seven days after the first round and it was on par with triazophos 10 ml + 10ml,methyl demeton 10ml + 10ml water and monocrotophos 10ml + 10ml water. Methyl demeton 10ml + 10ml water recorded a higher mortality of 75.77% at 15 DAT. Monocrotophos 10ml + 10ml water recorded 45.20% mortality at 23 days after first round of root feeding which was on par with triazophos 10ml+10ml water. Similarly, 23 days after second round of root feeding, monocrotophos, methyl demeton 10ml + 10ml water and triazophos 20ml + 20ml water were on par with control recording 31.53% to 35.80% mortality (Tables 7 & 8).

Table 7. Bioefficacy of insecticides/acaricides against coconut mite, *Aceria guerreronis*. (Tathur, I Round (Mite mortality percentage)

No.	Treatments	Per cent mortality		
		7 DAT	15 DAT	23 DAT
1.	Methyl demeton 2ml/ l	27.09^{b-e} (31.34)	19.57^{c} (26.23)	20.77^{a-d} (27.08)
2.	Methyl demeton 4 ml/l	34.55^{abc} (36.00)	52.63^{abc} (46.63)	24.12^{a-d} (23.39)
3.	Phosalone 2 ml/l	15.42^{d-e} (23.07)	35.01^{bc} (35.58)	17.99^{cd} (24.31)
4.	Phosalone 3 ml/l	31.17^{a-d} (33.93)	39.34^{bc} (38.66)	14.02^{cd} (21.96)
5.	Triazophos 2 ml/l	19.33^{cde} (26.04)	54.76^{abc} (47.73)	29.59^{a-d} (32.81)
6.	Triazophos 5 ml/l	37.84^{abc} (37.86)	68.16^{ab} (56.07)	51.29^{ab} (45.75)
7.	Dimethoate 2 ml/l	31.64^{a-d} (33.96)	30.61^{c} (33.49)	33.57^{a-d} (35.32)
8.	Monocrotophos 1.5 ml/l	40.90^{ab} (39.76)	51.23^{ab} (45.83)	52.35^{a} (46.51)
9.	Dicofol 2.5 ml/l	41.79^{ab} (40.17)	39.10b^{c} (38.68)	31.91^{a-d} (34.39)
10.	Dichlorvos 1 ml/l	35.79^{abc} (36.70)	24.47^{c} (29.52)	19.35^{bcd} (25.82)
11.	TNAU Neem oil 60 EC (C) 3%	31.80^{a-d} (34.18)	28.52^{c} (31.98)	33.44^{a-d} (34.63)
12.	Triazophos 20 ml + 20 ml water	30.08^{bcd} (33.13)	50.56^{ab} (45.32)	23.21^{a-d} (30.50)
13.	Triazophos 10 ml + 10 ml water	39.73^{ab} (38.94)	47.03^{abc} (43.29)	43.51^{abc} (41.20)
14.	Monocrotophos 10ml+10ml water	36.59^{abc} (37.21)	37.61^{bc} (37.82)	45.20^{abc} (42.27)
15.	Methyl demeton 10ml+10ml water	43.00^{ab} (40.98)	75.77^{a} (60.67)	22.55^{a-d} (27.66)
16.	Dimethoate 10 ml+10 ml water	52.65^{a} (46.63)	45.64^{abc} (42.17)	21.12^{a-d} (27.30)
17.	Untreated control	11.62^{e} (19.80)	36.22^{bc} (36.96)	10.84^{d} (19.21)

DAT - Days after treatment

Figures in parentheses are arcsin P transformed values.

Means followed by common letter (s) are not significantly different at 5% level by DMRT

Crown spraying : Avalur

Among the treatments, TNAU neem oil 60 EC (C) 3% was significantly superior to all other treatments by recording 46.50 and 58.57% mortality seven days after first and second spraying, respectively. At 15 days after second round of spraying, triazophos 1.5 ml recorded the highest mortality of 51.07% (Tables 9 & 10).

Table 8. Bioefficacy of insecticides/acaricides against coconut mite, Aceria guerreronis (Tathur, II Round (Mite mortality percentage)

Sl.No.	Treatments	Per cent mortality	
		15 DAT	23 DAT
1.	Methyl demeton 2 ml/l	48.07 (43.81)[a]	40.91 (39.59) [abc]
2.	Methyl demeton 4 ml/l	61.11 (51.46)[a]	61.89 (51.95) [a]
3.	Phosalone 2 ml/l	43.57 (40.96)[a]	47.80 (43.69) [abc]
4.	Phosalone 3 ml/l	54.05 (47.33)[a]	40.21 (39.33) [abc]
5.	Triazophos 2 ml/l	50.58 (45.39)[a]	43.71 (41.04) [abc]
6.	Triazophos 5 ml/l	60.86 (51.33)[a]	52.07 (46.52) [abc]
7.	Dimethoate 2 ml/l	59.67 (50.73)[a]	44.07 (40.77) [abc]
8.	Monocrotophos 1.5 ml/l	60.09 (50.88)[a]	45.56 (42.44) [abc]
9.	Dicofol 2.5 ml/l	68.50 (55.93)[a]	41.37 (39.85) [abc]
10.	Dichlorvos 1 ml/l	39.71 (39.05)[a]	43.46 (41.18) [abc]
11.	TNAU Neem oil 60 EC(C) 3%	33.52 (35.35)[a]	55.14 (48.06) [ab]
12.	Triazophos 20 ml + 20 ml water	64.34 (53.59)[a]	33.46 (35.33) [abc]
13.	Triazophos 10 ml + 10 ml water	57.06 (49.28)[a]	14.62 (22.22) [c]
14.	Monocrotophos 10 ml + 10 ml water	63.96 (53.26)[a]	31.53 (34.15) [abc]
15.	Methyl demeton 10 ml + 10 ml water	59.41 (50.43)[a]	35.80 (36.73) [abc]
16.	Dimethoate 10 ml + 10 ml water	39.61 (38.41)[a]	18.33 (24.98) [bc]
17.	Monocrotophos 3 ml/l	53.39 (46.98)[a]	56.75 (48.89) [ab]
18.	Dicofol 6 ml/l	44.05 (41.55)[a]	46.05 (42.72) [abc]
19.	Neem oil 2% + Garlic extract 25 g/l	31.29 (37.00)[a]	28.49 (32.25) [abc]
20.	Untreated control	28.06 (31.93)[a]	31.57 (32.68) [abc]
		NS	

DAT - Days after treatment

Figures in parentheses are arcsine P tr ansformed values

Means followed by common letter(s) are not significantly different at 5% level by DMRT

Table 9. Bioefficacy of insecticides/acaricides against coconut mite, *Aceria guerreronis* (Avalur, I Round (Mite mortality percentage)

Sl.No.	Treatments	Per cent mortality		
		7 DAT	15 DAT	23 DAT
1.	Monocrotophos 10ml+10ml water	26.46 (30.70) [ab]	41.57 (39.83) [a]	13.02 (21.13) [a]
2.	Methyldemeton 10ml+10ml water	20.85 (26.91) [ab]	11.20 (19.41) [a]	4.76 (8.99) [a]
3.	Dimethoate 10ml+10ml water	22.19 (27.98) [ab]	24.91 (29.93) [a]	3.84 (10.90) [a]
4.	Phosphamidon 5ml+5ml water	23.15 (28.75) [ab]	31.49 (33.89) [a]	17.30 (23.12) [a]
5.	Monocrotophos 1.5 ml/l	26.54 (30.94) [ab]	17.65 (18.22) [a]	33.34 (27.37) [a]
6.	Dimethoate 2ml/l	15.89 (22.55)[b]	13.43 (20.97) [a]	16.66 (22.89) [a]
7.	Dicofol 2.5ml/l	23.52 (29.00) [ab]	33.61 (35.43) [a]	5.88 (10.03) [a]
8.	Wettable sulphur 2g/l	28.74 (31.69) [ab]	17.47 (18.11) [a]	7.12 (15.28) [a]
9.	Ethion 2ml / l	22.69 (28.33) [ab]	6.85 (15.10) [a]	15.00 (16.61) [a]
10.	Dichlorvos 1ml/l	38.19 (36.91) [ab]	33.34 (27.37) [a]	13.70 (15.78) [a]
11.	Endosulfan 2ml/l	14.75 (22.39)[b]	23.78 (29.08) [a]	9.59 (17.00) [a]
12.	Phosalone 2ml/l	35.53 (35.96) [ab]	27.10 (30.46) [a]	23.13 (28.43) [a]
13.	Acephate 1 g/l	36.59 (37.20) [ab]	18.63 (24.17) [a]	31.28 (34.00) [a]
14.	Triazophos 1.5 ml/l	31.42 (34.04) [ab]	18.80 (24.71) [a]	5.52 (11.60) [a]
15.	TNAU Neem oil 60EC (C) 3%	46.50 (42.80)[a]	25.50 (31.50) [a]	23.34 (27.10) [a]
16.	TNAU Neem oil 0.03% EC	16.34 (23.83) [ab]	3.73 (11.13) [a]	40.00 (38.08) [a]
17.	Untreated control	12.17 (20.19)[b]	7.26 (15.58) [a]	10.89 (17.84) [a]
			NS	NS

DAT - Days after treatment

Figures in parentheses are arcsine P tr ansformed values

Means followed by common letter (s) are not significantly different at 5% level by DMRT

Root feeding : Avalur

After both the rounds of root feeding, only monocrotophos 10ml + 10ml water recorded higher mortality of mites, which ranged from 26.46 to 56.44 per cent (Tables 9 & 10).

Table 10. Bioefficacy of insecticides/acaricides against coconut mite, *Aceria guerreronis* (Avalur, II Round (Mite mortality percentage)

No.	Treatments	Per cent mortality		
		7 DAT	15 DAT	23 DAT
1.	Monocrotophos 10ml + 10ml water	56.44 (48.81)[ab]	32.37 (34.56)[abc]	47.85 (43.67)[a]
2.	Methyldemeton 10ml+10ml water	20.19 (26.07)[c]	24.76 (29.81)[abc]	35.02 (36.27)[a]
3.	Dimethoate 10ml + 10ml water	24.31 (29.36)[c]	24.92 (29.89)[abc]	43.08 (40.99)[a]
4.	Phosphamidon 5ml + 5ml water	22.35 (28.21)[c]	31.29 (33.95)[abc]	30.12 (32.61)[a]
5.	Monocrotophos 1.5 ml/l	0.75 (4.90)[d]	20.38 (26.78)[bcd]	19.97 (26.32)[a]
6.	Dimethoate 2ml/l	31.96 (33.94)	29.49 (31.65)[abc]	25.84 (30.37)[a]
7.	Dicofol 2.5ml/l	26.47 (30.86)[bc]	26.76 (31.11)[abc]	33.15 (34.99)[a]
8.	Wettable sulphur 2g/l	32.62 (34.67)[abc]	36.93 (37.42)[abc]	42.12 (40.13)[a]
9.	Ethion 2ml / l	16.47 (23.77)[c]	29.60 (32.81)[abc]	35.13 (36.21)[a]
10.	Endosulfan 2ml/l	17.41 (24.53)[c]	43.01 (40..97)[ab]	31.73 (34.16)[a]
11.	Phosalone 2ml/l	19.13 (25.93)[c]	8.34 (12.05)[d]	20.55 (26.78)[a]
12.	Acephate 1 g/l	17.49 (24.28)[c]	21.36 (27.50)[bcd]	22.24 (28.10)[a]
13.	Triazophos 1.5 ml/l	31.26 (34.99)[abc]	51.07 (45.62)[a]	51.95 (46.15)[a]
14.	TNAU Neem oil 60EC(C) 3%	58.57 (50.56)[a]	14.98 (21.62)[cd]	26.80 (31.17)[a]
15.	TNAU Neem oil 0.03% EC	26.71 (30.85)[bc]	11.77 (20.04)[cd]	19.76 (25.59)[a]
16.	Triazophos 10ml + 10ml water	13.58 (21.32)[cd]	33.81 (35.49)[abc]	38.62 (37.65)[a]
17.	Untreated control	10.93 (10.26)[cd]	20.30 (26.78)[bcd]	17.74 (23.55)[a]
				NS

DAT - Days after treatment
Figures in parentheses are arcsine P tr ansformed values
Means followed by common letter(s) are not significantly different at 5% level by DMRT

Root feeding: Aliyarnagar

Monocrotophos 10ml + 10ml water recorded a mortality of 31.62%, 38.94% and 48.51%, after the first round and 41.33%, 45.93% and 54.56% after second round of root feeding at seven, 15 and 23 days, respectively. Similarly, triazophos 10 ml + 10 ml water also recorded 46.16%, 36.05% and 38.32% mortality on seven, 15 and 23 days after first round of root feeding and 44.47% at 7 days after treatment in the second round. Monocrotophos 15 + 15 ml water was significantly superior to all other chemicals 15 days after treatment, both after the first (61.57%) and second round (73.55%) of treatments. All other treatments were either on par with monocrotophos 10ml + 10ml water and triazophos 10ml + 10ml water or less effective than monocrotophos 15 + 15ml water (Tables 11 & 12).

Evaluation of bioefficacy of insecticides / acaricide against coconut eriophyid mite based on the damage symptoms

Crown application/spraying of triazophos 5ml/l recorded the highest percentage of undamaged green nuts on the trees *viz.*, 90.62, 89.45, 90.18 and 81.36 on bunch 3, 4, 5 and 6 respectively. In monocrotophos 3 ml/l the percentage of undamaged nuts ranged between 60 and 75 followed by monocrotophos 1.5 ml/l (38.90 - 79.28), methyl-demeton 4ml/l (36.21 - 63.73) as against 12.50 - 57.41% in untreated check. Among the root fed chemicals, monocrotophos 15ml + 15ml water registered 34.80 to 62.85 per cent undamaged nuts. The data on bunch 3 revealed that all the treatments were on par with each other indicating the need for repeated application. Even though all the treatments were on par with regard to damage on bunch 3, the control trees had lower per cent of undamaged nuts on bunch 5 (12.50) and 6 (16.80) than other treatments. This may be due to the cumulative effect of the chemicals applied during the preceeding months which prevented further damage or migration of mites onto the treated trees (Table 13).

In the harvested nuts the per cent infestation was less in monocrotophos 3 ml/l (12.50) followed by monocrotophos 10 + 10 ml water (56.25) and methyl demeton 4ml/l (57.14) as against untreated in control (93.10). A maximum of 73 nuts were harvested from monocrotophos 15 + 15ml.

Table 11. Bioefficacy of insecticides against coconut mite, *Aceria guerreronis* (ARS, Aliyarnagar I Round (Percentage mortality of mites)

No.	Treatments	Per cent mortality		
		7 DAT	15 DAT	23 DAT
1.	Monocrotophos 15ml + 15ml water	39.88 (38.13) b	61.57 (51.56) a	35.70 (36.53) abc
2.	Monocrotophos 10ml + 10ml water	31.62 (32.47) ab	38.94 (38.04) bc	48.51 (44.12) a
3.	Methyl demeton 15ml + 15ml water	33.24 (35.10) ab	44.48 (41.49) b	21.93 (27.80) bc
4.	Methyl demeton 10ml + 10ml water	22.96 (27.80) ab	30.87 (33.13) bc	36.51 (37.06) ab
5.	Dimethoate15ml + 15ml water	29.08 (31.44) ab	27.08 (31.14) bc	24.43 (29.39) bc
6.	Dimethoate 10ml + 10ml water	33.77 (34.18) ab	29.86 (33.03) bc	30.09 (33.14) abc
7.	Phosphamidon 10ml + 10ml water	26.34 (30.85) ab	45.45 (42.38) b	33.22 (35.17) abc
8.	Phosphamidon 5ml + 5ml water	20.42 (26.05) ab	44.51 (41.67) b	30.85 (33.64) abc
9.	Triazophos 20ml + 20ml water	31.86 (34.25) ab	41.03 (39.77) b	44.78 (41.97) a
10.	Triazophos 10ml + 10ml water	46.16 (42.33) a	36.05 (36.88) bc	38.32 (38.10) ab
11.	Untreated control	11.76 (19.59) b	15.29 (22.89) c	18.54 (24.98) c

DAT - Days after treatment
Figures in parentheses are arcsine P tr ansformed values
Means followed by common letter(s) are not significantly different at 5% level by DMRT

Table 12. Bioefficacy of insecticides against coconut mite, *Aceria guerreronis* (ARS, Aliyarnagar II Round (Percentage mortality of mites)

No.	Treatments	Percent mortality		
		7 DAT	15 DAT	23 DAT
1.	Monocrotophos15ml + 15ml water	33.98 (35.63) abc	73.55 (59.69) a	41.11 (39.80) ab
2.	Monocrotophos 10ml + 10ml water	41.33 (39.99) a	45.93 (42.66) bc	54.56 (47.75) a
3.	Methyl demeton 15ml + 15ml water	14.83 (21.94) c	48.12 (44.06) bc	46.28 (42.52) ab
4.	Methyl demeton 10ml + 10ml water	45.77 (42.56) a	40.42 (39.46) bc	29.52 (32.53) b
5.	Dimethoate 15ml + 15ml water	47.01 (43.28) a	33.58 (35.36) bc	36.35 (36.75) ab
6.	Dimethoate 10ml + 10ml water	38.19 (37.76) ab	31.23 (33.81) bc	47.49 (43.56) ab
7.	Phosphamidon10ml + 10ml water	28.10 (31.81) abc	47.40 (43.46) bc	42.06 (40.39) ab
8.	Phosphamidon5ml + 5ml water	33.18 (34.72) abc	51.94 (46.14) b	28.00 (31.74) b
9.	Triazophos20ml + 20ml water	28.27 (31.93) abc	36.39 (37.04) bc	42.92 (40.78) ab
10.	Triazophos 10ml + 10ml water	44.47 (41.78) a	31.10 (33.83) bc	33.05 (35.04) ab
11.	Untreated control	17.32 (24.05) bc	24.88 (29.58) c	24.69 (29.49) b

DAT - Days after treatment -
Figures in parentheses are arcsine P tr ansformed values
Means followed by common letter(s) are not significantly different at 5% level by DMRT

Table 13. Effect of insecticides on mite damage to nuts

No.	Treatment	Percentage of nuts in							
		Bunch 3		Bunch 4		Bunch 5		Bunch 6	
		Damaged	Undamaged	Damaged	Undamaged	Damaged	Undamaged	Damaged	Undamaged
1.	Monocrotophos 36 SL 10ml + 10ml (RF)	50.39^{ab} (45.19)	49.61	42.38^{abc} (40.19)	57.62	69.45^{cd} (56.71)	30.55	73.64^{bc} (66.71)	26.36
2.	Monocrotophos 15ml + 15ml (RF)	37.15^{ab} (33.65)	62.85	51.74^{abc} (46.16)	48.26	52.93^{ab} (46.75)	47.07	65.20^{bc} (57.92)	34.80
3.	Triazophos 40EC 10ml + 10ml (RF)	68.75^{b} (60.00)	31.25	65.63^{bc} (58.06)	34.37	60.72^{bcd} (55.22)	39.28	73.61^{bc} (63.11)	26.39
4.	Monocrotophos 1.5 ml/l	61.10^{ab} (55.45)	38.90	45.00^{abc} (41.83)	55.00	20.72^{ab} (20.03)	79.28	47.72^{abc} (39.87)	52.28
5.	Monocrotophos 3ml/l	40.00^{ab} (35.19	60.00	25.00^{ab} (22.50)	75.00	25.00^{abc} (22.50)	75.00	37.50^{ab} (37.34)	62.50
6.	Triazphos 5 ml/l	9.38^{a} (9.44)	90.62	10.55^{a} (13.67)	89.45	9.82^{a} (15.90)	90.18	18.64^{a} (25.27)	81.36
7.	Methly demeton 25 EC 4 ml/l	36.97^{ab} (33.58)	63.03	36.27^{abc} (33.11)	63.73	63.79^{bcd} (57.13)	36.21	42.21^{abc} (36.51)	57.88
8.	Dicofol 18.5 EC 2.5 ml/l	35.27^{ab} (32.39)	64.73	87.50^{c} (78.75)	12.50	84.82^{d} (73.33)	15.18	85.42^{c} (73.92)	14.58
9.	Dicofol 5 ml/l	45.83^{ab} (42.57)	54.17	75.92^{bc} (64.99)	24.08	68.66^{cd} (60.70)	31.34	61.54^{abc} (55.70)	38.46
10.	Monocrotophos 1.5ml + Phorate 10G @ 10g/tree	27.08^{ab} (27.57)	72.92	45.25^{abc} (41.74)	54.75	75.17^{d} (67.60)	24.83	75.17^{bc} (67.60)	24.83
11.	Phorate 10g/tree	46.33^{ab} (42.53)	53.67	85.00^{c} (77.31)	15.00	76.04^{d} (64.76)	23.96	75.00^{bc} (67.50)	25.00
12.	Control	45.59^{ab} (36.72)	57.41	69.01^{bc} (63.50)	30.99	87.50^{d} (75.06)	12.50	83.20^{bc} (68.83)	16.80

Means followed by a common letter(s) are not significantly different at the 5% level by DMRT.
RF - Root Feeding
Values in parentheses are arcsin percentage transformed values.

Table 14. Bioefficacy of insecticides / acaricide against coconut eriophyid mite based on the damage symptoms

Treatment	Total no.of harvested nuts	Total no. of infested nuts	Infested nuts (%)	Number and percentage of harvested nuts in each damage category					Mean grade
				1	2	3	4	5	
Monocrotophos 10 ml + 10ml water	32	18	56.25	14(43.75)	13(40.63)	2(6.25)	1(3.12)	2(6.25)	1.88
Monocrotophos 15 ml + 15 ml water	73	57	78.08	16(21.92)	37(50.68)	10(13.7)	6(8.22)	4(5.48)	2.25
Triazophos 10 ml + 10 ml water	23	16	69.56	7(30.43)	9(39.13)	5(21.74)	1(4.35)	1(4.35)	2.13
Monocrotophos 1.5ml/l	42	31	73.81	11(26.19)	19(45.24)	6(14.29)	0	6(14.29)	2.31
Monocrotophos 3.0 ml/l	8	1	12.50	7(87.5)	1(12.50	0	0	0	1.12
Triazophos 5ml/l	35	25	71.43	10(28.57)	16(45.71)	2(5.71)	3(8.57)	4(11.43)	2.29
Methyldemeton 4ml/l	21	12	57.14	9(42.85)	6(28.57)	1(4.76)	1(4.76)	4(19.05)	2.29
Dicofol 2.5 ml/l	39	31	79.49	8(20.51)	16(41.02)	1(2.56)	4(10.26)	10(25.64)	2.79
Dicofol 5.0 ml/l	15	10	66.66	5(33.33)	7(46.67)	0	2(13.33)	1(6.67)	2.13
Monocrotophos 1.5 ml/l + Phorate 10G @ 10g / tree	14	13	92.86	1(7.14)	2(14.29)	0	3(21.43)	8(57.14)	4.07
Phorate 10G @ 10g sachet / tree	28	19	67.86	9(32.14)	2(7.14)	4(14.29)	3(10.71)	10(35.71)	3.11
Control	29	27	93.10	2(6.90)	4(13.79)	5(17.24)	5(17.24)	13(44.83)	3.79

Root feeding of monocrotophos 10 ml + 10 ml water and 15 ml+ 15 ml water and spraying of monocrotophos 1.5 and 3 ml/l, methyl demeton 4 ml/l, dicofol 5 ml/l and triazophos 5 ml/l recorded more undamaged and slightly damaged nuts (categories 1 and 2) compared with more severely affected nuts (categories 3 - 5) than untreated trees.

Similarly, the mean grade of damage was low in monocrotophos 3 ml/l (1.12), monocrotophos 10 ml + 10ml water (1.88), triazophos 10ml + 10ml water, dicofol 5 ml/l (2.13) and monocrotophos 15 ml + 15 ml water (2.25) as against 4.07 in monocrotophos 1.5 ml+ phorate 10G @ 10g sachet/ tree. The mean grade recorded in the untreated check was 3.79 (Table 14).

Yield loss

In general the residual effect of the insecticides/acaricide sprayed on the crown (buttons and developing nuts) was seen upto 23 days as indicated by higher mortality upto three weeks. The mite population is likely to increase after 23 days with the multiplication of unaffected mites inside the perianth. In tall trees where spraying is difficult root feeding is the only alternative. The efficacy of root feeding treatments may vary depending upon the rate of absorption, type of root, age and height of the trees. A detailed study is required to confirm the role of these factors.Hence, it is necessary to spray the effective chemicals *viz.,* methyl demeton 4ml/l or triazophos 5ml/l or monocrotophos 1.5ml/l once in 20-30 days or resort to the root feeding once in 45 days until a satisfactory control is achieved which confirms the earlier findings of repeated application of chemicals by many authors.

Tender nuts and matured nuts should be harvested and used only after 30 and 45 days after spraying and root feeding, respectively

At the same time, repeated application of chemicals at regular intervals may lead to extermination of natural enemies, environmental hazards, development of resistance to chemicals, pesticide residues in the produce and a possible secondary outbreak of other minor pests.In the present study none of the chemical sprayed or fed through roots has effected complete control of mites. Hence, it is highly imperative to urgently strengthen our research on the following aspects to work out a suitable ecofriendly integrated management strategy against this pest.

Future thrust

Because this mite is spreading at an alarming rate to newer areas and threatening coconut cultivation, immediate attention is warranted for its management.Perusal of literature reveals that not much information is available in the fundamental aspects of this mite.Hence, it is absolutely necessary to give a thrust to the following aspects of research on this pest.

* Bio-ecology (biology, population dynamics, dissemination or dispersal, alternate host and reproduction)
* Mite-host relationship
* Influence of abiotic and biotic factors on the mite population
* Role of cultural practices *viz.,* the influence of irrigation, intercropping, organic amendments and nutrients
* Identification of resistant / tolerant cultivars
* Use of botanicals and development of biological control agents

Acknowledgement

The authors wish to express their sincere thanks to Tamil Nadu Agricultural University for providing facilities to conduct the experiments and to Thiru. T.A.Krishnasamy, Thathur and Th. N.K. Vengittu, Avalur who spared their coconut gardens for conducting the experiments. The senior author expresses his gratitude to Prof. Dr. S. Kanniyan, Vice-chancellor and Dr. P.C.Sundara Babu, Director, Centre for Plant Protection Studies, Tamil Nadu Agricultural University for their guidance, help and permission to attend the workshop.

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Infestation of coconut mite (*Aceria guerreronis* K.) in the Southern Indian State, Kerala

G. Madhavan Nair, Thomas Biju Mathew, K Saradamma and Naseema Beevi

College of Agriculture, Vellayani P.O. Trivandrum 695 522, India

Summary

India is the largest producer of coconut in the world and Kerala which is in the south west tip of the Indian peninsula, is the leading coconut growing state in the country. Coconut trees in and around Cochin, the port city of Kerala were found infested by the eriophyid mite, ***Aceria guerreronis*** *during the later part of 1997. Within a period of two years, the pest spread to most of the districts of the state and the neighbouring districts of Tamil Nadu and Karnataka.*

The mite infestation of coconut in Kerala has assumed the proportion of a natural calamity which has caused unexpected and extensive damage to the ecomony of the small farmers who depend on coconut for their livelihood. The annual loss is estimated around 1000 1500 million rupees. Coconut related products and industry such as copra, coconut oil, food processing and soap manufacturing are likely to be hit hard due to the fall in production. About half a million coir workers of the state, who solely depend on coir making from coconut husk for their livelihood are the other sufferers due to the mite infestation on coconut.

As soon as the first report of infestation was received, the Kerala Agricultural University swung into action and multilocational field trials were laid out to find effective measures for the control of the pest. Based on results of the trials, spraying a biopesticide, neem oil (2%) + garlic (2%) + soap emultion and alternatively a synthetic organic miticide, dicofol were recommended. The state government of Kerala have started a massive programme of spraying around fifty million affected coconut trees in the state with the recommended pesticides. The technical and extension supports to this massive programme are provided by the Kerala Agricultural University. The University has so far conducted about four hundred training cum demonstration classes at various levels for the coconut climbers, farmers, people representatives, village level workers and agricultural officers.

The scientists of the University have been successful in isolating a local strain of the entomopathogenic fungus, ***Hirsutella thompsonii synnematosa****, from the colonies of* ***A. guerreronis****. Two species of phytoseiid mites and one syrphid larva have been observed as to feed on the mites. Newer initiatives of the University include new experiments testing natural and synthetic products, testing effectiveness of innovative practices of farmers and laying out frontline demonstrations in farmer fields.*

Introduction

India is the largest producer of coconut in the world. The area under coconut has increased from 0.616 million hectares in 1950-51 to 1.795 million hectares in 1995-96 and the production from 3281 million nuts to 13967 million nuts, during the same period. These account increases of 186.6% in area and 325.6% in production.

Kerala, which is in the south-west tip of the Indian peninsula, is the leading coconut growing state in India. It contributes 53.4% of the area (1.1 million hectares) and 44.3 per cent (5759 million nuts per year) of the total nut production in the country. Ninety per cent of the crop is rainfed and is generally affected by long dry spells of 3-4 months a year. The number of unproductive and senile palms is high in the state, which is one of the main reasons for the low productivity.

In Kerala, coconuts in most of the places are cultivated not in plantations but in homesteads of varying sizes, the average being less than half an acre. Somebody flying above would notice the crowns of coconut trees only and scattered underneath are the houses, shops, schools and other buildings. Coconut is an integral part of every day life of almost every Keralite. It provides pulp and oil for his food, leaves for thatching his house and wood for constructing his house and making furniture. It gives the most wonderful drink that man has ever tasted.

The debilitating and dreaded root (wilt) disease is the major problem affecting the production and productivity of the crop in the state. The loss due to the disease was estimated to be 968 million nuts in 1984-85. The crop is also affected by other diseases, including budrot, leafrot, stem bleeding and Mahali. The major pests are red palm weevil, black-headed caterpiller, rhinoceros beetle, coreid bug, button mealybug and cockchafer beetle.

The genesis

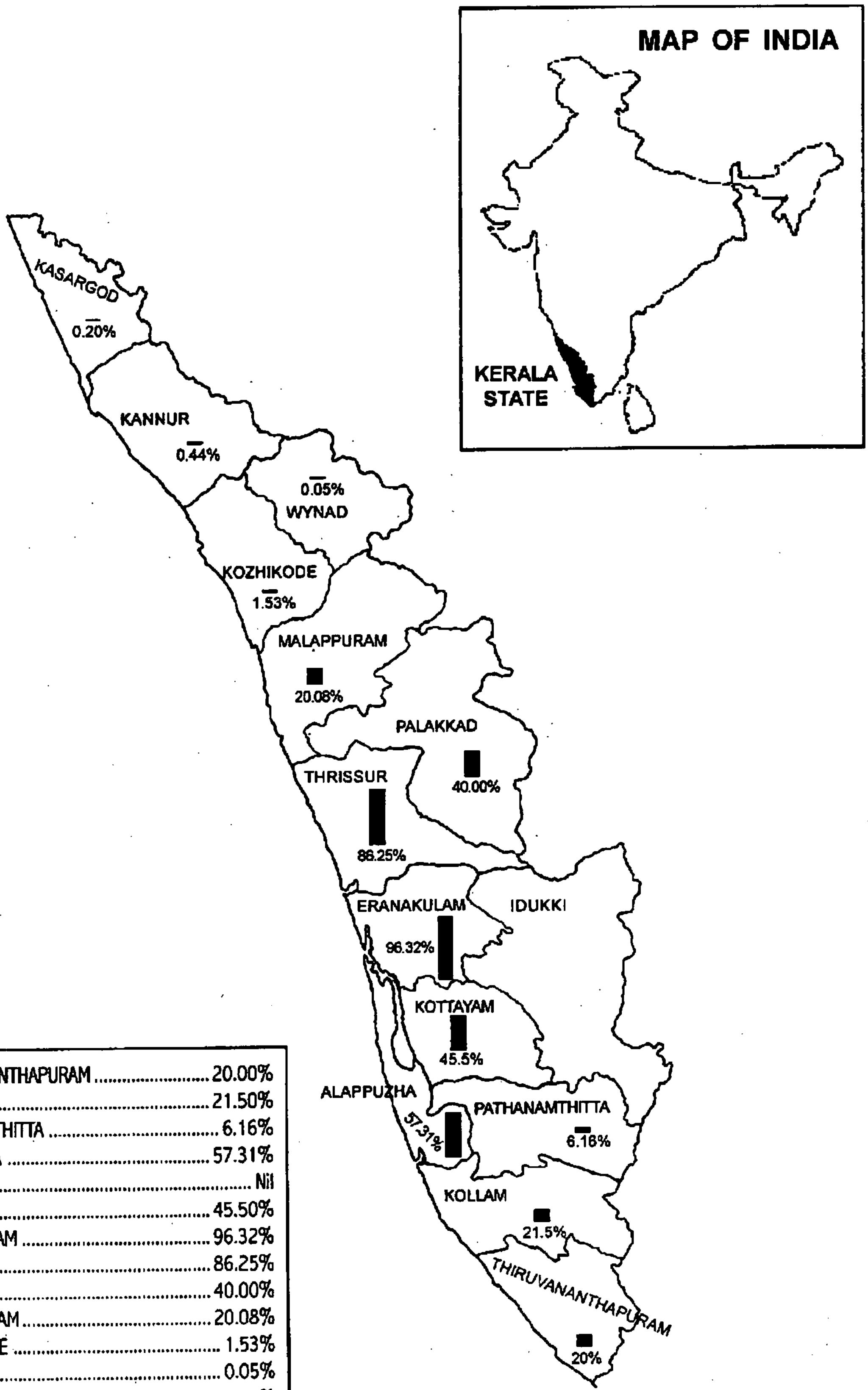
Coconut palms in and around Cochin, the port city of Kerala, were seen affected by an unknown pest during the later part of 1997. The causative pest was identified as *Aceria (Eriophyes) guerreronis*, an eryophid mite, first reported by Keifer (1965) from Mexico. It has been a serious pest in Tropical Americas and West Africa for many years. By the time the pest was identified from an area near Cochin, it has already spread to most of the neighbouring districts and to the border districts of the neighbouring states of Tamil Nadu and Karnataka.

The mite infestation of coconut in Kerala has assumed the proportion of a national disaster. This is like a natural calamity, which has caused unexpected and extensive damage to the economy of the small farmers of Kerala who depend up on coconut for their livelihood. In the recent history of the state this is a problem, that has attracted the attention of every segment of society.

Gravity of the problem

Preliminary studies indicate that there is a production fall of 30 to 40% in the most affected districts of the state. The percentage of area under coconut infested by the pest varied from 0.00 (Idukki District) to 96.32 (Eranakulam District) (Fig. 1). Annual loss due to mite infestation alone is estimated between Rs. 100-150 crores. The coconut related products and industry such as copra, coconut oil, food processing and soap manufacturing are likely to be hit hard due to the fall in production.

Another set of sufferers is the coir workers whose number is estimated to be half a million in the state. These people who live below the poverty line depend for their livelihood solely on coir making from coconut husk, the production of which will be substantially affected by the mite infestation.



THIRUVANANTHAPURAM	20.00%
KOLLAM	21.50%
PATHANAMTHITTA	6.16%
ALAPPUZHA	57.31%
IDUKKI	Nil
KOTTAYAM	45.50%
ERANAKULAM	96.32%
THRISSUR	86.25%
PALAKKAD	40.00%
MALAPPURAM	20.08%
KOZHIKODE	1.53%
WYNAD	0.05%
KANNUR	0.44%
KASARGOD	0.20%

Fig. 1: Percentage of area under coconut infested by *A. guerreronis* in the districts of Kerala

Initiatives of the Kerala Agricultural University

When the mite infestation was first reported in early 1998 from some places near Cochin, the Kerala Agricultural University under the leadership of the Vice-Chancellor, swung into action by constituting a task force to study the mite incidence in detail. The task force visited the places of infestation and started consultation with scientists of Tamil Nadu Agricultural University, Coimbatore and Central Plantation Crop Research Institute, Kayamkulam. The Government of Kerala with the Minister of Agriculture taking the lead immediately formed a high level technical committee to chalk out an action plan to find out an immediate and viable solution to contain the menace, which was spreading to all parts of the state at an alarming speed.

With approval of the high level technical committee and based on the fragmenting information which could be assembled, scientists of the Kerala Agricultural University, laid out a multilocational field trial in the coconut gardens of Erankulam district in April, 1998, to find out an effective and comparatively safter miticide to contain the mite population.

Treatments of the multilocational trial

Dimethoate	0.05%	Dimethoate	0.10%
Monocrotophos	0.05%	Monocrotophos	0.10%
Dicofol	0.05%	Dicofol	0.10%
Neem oil + garlic	1.00%	Neem oil + garlic	2.00%
Sulphur WP	0.20%	Sulphur WP	0.40%
Neem cake	1.00 kg/palm	Water spray	
No treatment			

Within a period of three months, the scientists were able to give an adhoc recommendation based on indications of the preliminary data collected from the multi-locational field trial (Fig. 2). The high level technical committee approved the recommendation and immediately passed on to the state Government for immediate adoption. The final results from the experiment are now available proves the *ad-hoc* recommendation valid (Fig. 3). The material recommended for spraying on infested coconut trees was an ecofriendly plant based pesticide, neem oil + garlic + soap emulsion (2%) and alternatively a synthetic organic chemical, dicofol (0.1 per cent) which is a common miticide recommended on fruit crops, tea, cotton etc. in many countries.

Preparation of ten litres of neem seed oil (2%) + garlic (2%) + soap emulsion

Ordinary soap flakes (50 g) are dissolved in 300 ml of lukewarm water. Garlic (200 g) is made into a paste and mixed with 500 ml of water and the extract is taken. Neem seed oil (200 ml) is mixed with the soap solution while stirring vigorously. The garlic extract is added to it. Nine litres of water is added and mix properly. Ten litres of 2% neem oil garlic soap emulsion is ready for spraying. This quantity is sufficient to spray about 10 infested coconut trees using conventional hand operated high volume sprayers.

The materials have to be sprayed on tender bunches up to seven months old. The newly emerged unfertilised inflorescence shall be avoided as the spraying may affect pollination. The crown cleaning has also been recommended before spraying. Based on experience gained from field application of the pesticide and considering the monsoon pattern in the state, three spraying are recommended in a year. The first one is during April - May, just before the onset of south west monsoon, the second in August - September during the dry spell between the south-west and north east monsoons and the third in December-January after the north east monsoon.

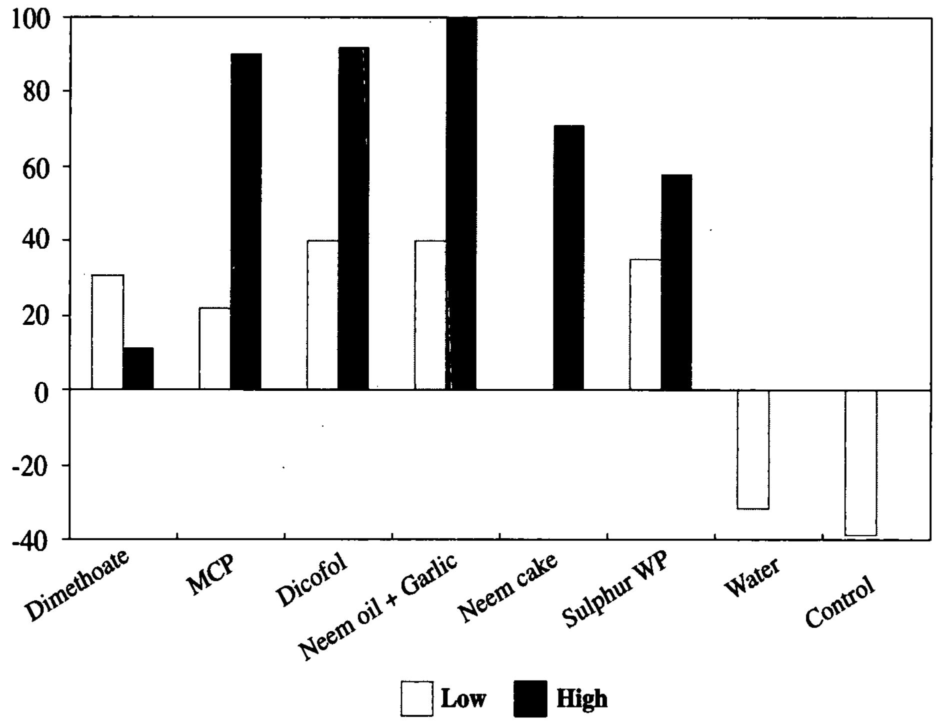


Fig. 2: Percentage reduction of mite population
(Preliminary data used for ad-hoc recommendation)

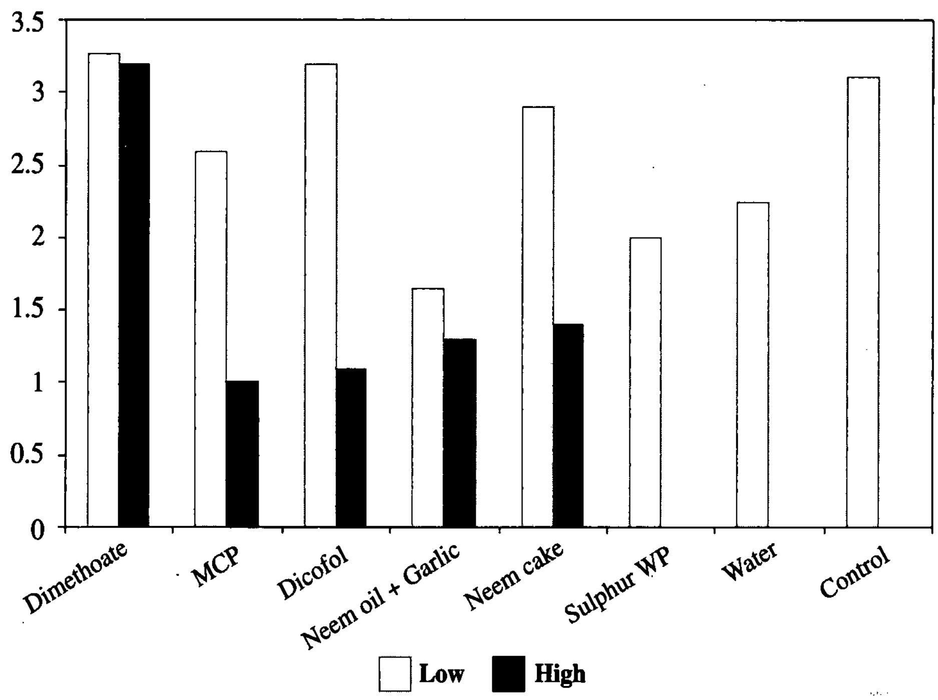


Fig. 3: Mean intensity score at harvest

Farmers innovations

The farmers of the state have adopted certain innovative practices to control the mite infestation in their palms. The Kerala Agricultural University has collected information on these practices and started action to test their effectiveness in the field. Some of these practices are listed below:

1.Applying neem cake powder, garlic powder, turmeric powder etc. on the crown.

2.Generating smoke from farm waste, garage waste, camphor etc. in the garden.

3.Hanging sticky traps on the crown.

4.Spraying salt water on infested bunches.

5.Spraying rice water and other sticky materials on the bunches.

Experiments in progress

The Kerala Agricultural University has laid out another multilocational field trial to test the efficacy of the following synthetic and natural products.

Natural products		Synthetic products	
Rubber seed oil	2%	Tafethion	0.10%
Neemazal	0.39%	Triazophos	0.20%
UNIM	0.5%	Fenpropathrin	0.02%
Neem oil	2%	Carbosulfan	0.05%
Neem oil 2% + garlic extract	2%		
Fish oil insecticidal soap	2.5%		

Front line demonstrations

Jointly by the Kerala Agricultural University, the Department of Agriculture and the CPCRI, 16 front line demonstrations have been laid out in farmer fields in the four most severely affected districts of the state.

Newer initiatives

The Kerala Agricultural University has initiated crop loss assessment studies in a systematic way. The weather and topographical factors, and the tolerance levels of different cultivars will also be studied.

Non-availability of trained coconut climbers is one of the major problems faced in the spraying programme. Easier application techniques, like root feeding and stem injection and development of application equipment are the needs of the hour. Research work on these aspects has been initiated.

Biocontrol

This is the area, most of the scientists the world over, place their hopes on so as to find a permanent solution to the problem. They are also of the view that no natural enemy is likely to be successful as a classical biological control agent.

Scientists (Pathummal Beevi, 1999 *pers. comm.*) of Kerala Agricultural University have been successful in isolating a local strain of the entomopathogenic fungus *Hirsutella thompsonii synnematosa* (subject to final confirmation) from the colonies of *A. guerreronis* (Plate 1). Works on the mandatory tests and standardisation of formulations and delivery system are progressing speedily.

Two species of phytoseid mites were observed as predators in the eriophyid colonies. They were identified provisionally as *Amblyseius* sp. and *Phytoseilus* sp. A syrphid larva has also been observed as feeding on the mites (Renjith *et al.*, 1999, *pers. comm.*). The effectiveness of these predators has to be investigated further. Extensive surveys were already initiated in the state by an experienced team of acarologists, insect pathologists and biocontrol specialists of Kerala Agricultural University to identify native strains of fungi, bacteria, parasites and predators associated with the pest complex infesting coconut buttons.

Even though the intial results are not encouraging, the pathogenicity of three fungi, *Metarrhizium anisopliae*, *Beauveria bassiana* and *Fusarium pallidoroseum* is being evaluated against the coconut mite.

Extension

The Kerala Agricultural University has taken initiative in imparting training to officers of departments, people's representatives and farmers at state, district, block and panchayat levels on the correct identification of mite infestation and its management techniques. The training should be a continuous process and the scientists of the University are engaged in conducting training programmes even now.

Training programmes conducted by scientists of Kerala Agricultural University

Training cum-Demonstration	Participants	No.of trainings
State level	Agricultural officers	1
District level	Agricultural officers, Agricultural assistants	20
Block level	Farmers and people's representatives	60
Village and Panchayat level	Farmers, people's representatives and voluntary organizations	205
Ward level	Farmers, farm labourers (climbers) and ward committee members	85

Initiatives of the Government

The Department of Agriculture and the state Government of Kerala have already started a massive programme of spraying the recommended chemicals on infested palms throughout the state. It is estimated that around five crores of coconut palms have to be sprayed. To mobilize the men and materials required is a herculian task. This kind of operation is quite unprecedented in the history of any pest management measure in the world. The entire responsibility of organizing the spraying programme is vested with the local bodies (village panchayat). The funds and material required are placed at their disposal. As a result of the decentralized planning in the state the village panchayats have their own funds, which are also being utilized to partially finance the spraying programme.

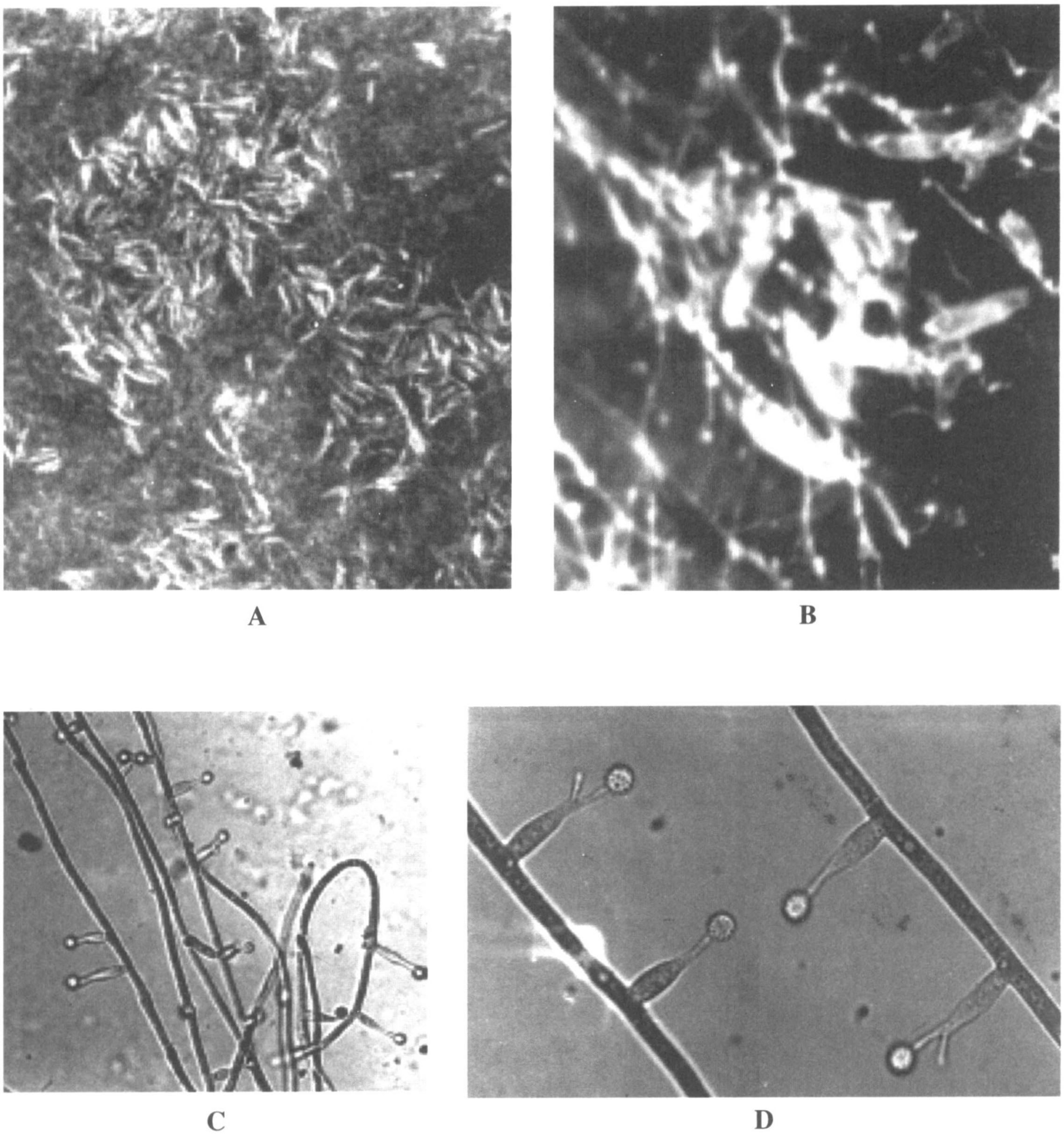


Plate 1: Microphotographs of *Hirsutella thompsonii* from *Eriophyes guerreronis* K.

A. Dead colony of *E. guerreronis* (60 x)
B. Fungal hyphae on mites (100 x)
C. Hyphae bearing phialides and globose rough - walled conidia (400 x)
D. Magnified view of hyphae, phialide, branched neck and verrucose conidia (1000 x)

Conclusion

The incidence of *A. guerreronis* in Kerala was first observed in the later part of 1997. Has it been introduced in recent times from another country or, has it already been present in the state in low population levels unnoticed by both the farmers and scientists. Is it due to the break down of an already existing control mechanism or due to the development of a virulent type that have spread to all parts of the state? Nobody knows the correct answer yet. Incidentally, in the annual report of the Tamil Nadu Agricultural University, for 1984 there was an indication of the presence of the coconut mite in some pockets of Tamil Nadu. Nothing more was heard about the pest until 1997.

The scientists of every coconut growing country should be vigilant about the possibility of an exotic pest, which may get entry in their country. They should also be vigilant about some of the minor pests, which may turn out to be major threats to the crop. Close co-operation in research activities and exchange of information among the scientists of the coconut growing countries are vital in this respect.

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Coconut mite invasion, injury and distribution

M. A. Haq, K. Sumangala* and N. Ramani
Division of Acarology, Department of Zoology, University of Calicut, Kerala 673635, India
*Department of Zoology, Zamorin's Guruvayurappan College, Calicut, Kerala - 673014, India

Summary

***Aceria guerreronis**, the popularly known coconut mite has been established as a serious pest in the coconut growing countries of the world. Recent invasion of the mite in peninsular India and neighbouring islands has created an alarming situation threatening the economy particularly in the State of Kerala. Analysis of the distribution pattern of the mite shows that the mite enjoys wide distribution in many countries of the entire coconut belt. Closer scrutiny of the infested nuts disclosed two courses of injurious manifestations involving crack development followed by nut fall and patch development leading to malformation of the nuts. The former proved to be severe in action compared to the latter. Results of field observation substantiated diurnal periodicity of the mite characterised by active day-time migration of the individuals to fresh inflorescence of the same plant. Repeated trials helped to endorse dispersal of the mite through wind during such migration. The paper further discusses the problems and prospects on control of the mite for supplementing possible ways for future consideration.*

Introduction

Coconut is a traditional plantation crop of the Indo-Pacific region where it is considered as nature's gift to mankind. The tall and erect nature of the plant seldom provides easy accessibility to invading organisms and hence was saved from pests and parasites for a long time. However, upsets in nature forcing animals to seek newer habitats in terms of survival behaviour, would often force some of them to settle on this plant temporarily if not permanently. This makes the glory of mites as palm pests and coconut being a widely cultivated plant became amenable to pest attack in due course of time. Mites though have succeeded as inhabitants of this crop, had not reached the status of major pests until recently. However, current invasion of *Aceria guerreronis* Keifer followed by its rapid spread, serious injury and associated drastic decline in yield have raised and established it as a major pest of coconut plantations of peninsular India. The mite though known from the Americas and Africa since three decades (Kiefer, 1965; Mariau, 1977; Hall and Espinosa, 1981; Griffith, 1984, Moore *et al.*, 1989), its incidence has been reported from India only recently (Sathiamma *et al.*, 1998). Recent studies (Haq, 1999a, b) have shown its subsequent invasion to Laskhadweep islands. Considering the impact of this mite in the socio-economic set up of the country, an analysis of the problem with respect to current status of distribution, nature and extent of injury caused by the mite and some aspects of its dispersal strategies is presented here.

World distribution

The coconut mite was first reported from the Guerrero State of Mexico (Keifer, 1965) as a nut-inhabiting mite. Later on, invasion, spread and injurious effects of this mite were demonstrated from parts of South America and neighbouring islands (Doreste, 1968). The pest status of the mite and its outbreak in Benin, Africa were studied subsequently (Mariau, 1969). Within a decade, the entire range of Central American and West African countries fell under the grip of this pest (Mariau, 1977, 1986; Hall and Espinosa, 1981; Griffith, 1984). Meanwhile, occurrence of this mite on an alternate host, *Lytocaryum weddellianum* was also reported from Brazil (Flechtmann, 1989). However, incidence of the mite had not been detected from the Asiatic region until its first report from Kerala during late 1990s. Following this, information on its spread and injury was gathered from several locations in Kerala, Tamil Nadu, parts of Karnataka, Lakshadweep and Sri Lanka (Haq, 1999b; Mohanasundaram *pers. comm.*).

While analysing the course of distribution of *A. guerreronis*, the question still persists as to whether the mite is a native of America or Asia. Available information suggests the possibility of its being a native of America (Flechtmann, 1989). More information regarding the association of this mite with the alternate host is needed to ascertain the origin of the species. However, it is quite evident that the mite has attained virulent status in the Americas initially and later exhibited similar trend in Africa and Asia. Considering the pattern of spread of the mite in those three continents, it is quite obvious that the pest has made rapid spread, encroaching far and wide locations. However, the mite seems to exhibit a transoceanic migration from continent to continent or main land to islands. Possibility of the presence of mite in unnoticeable proportion at many of the coconut growing areas of the world cannot be ruled out. The species might have attained high resistance and evolved to a virulent strain with efficient breeding and dispersal strategies under conducive circumstances, which occurred at different time at different areas. The same is marked by the population outbreak of the mite first in Americas followed by Africa and Asia. Destruction of natural enemies coupled with biochemical alterations induced on the host plant due to change in agro-climatic conditions and alterations in farm management practices may be attributed for the outbreak of the pest.

Injurious effects on coconut

The infestation produces various types of symptoms on developing nuts, which can be categorised sequentially, parallel to development of the nuts (Fig. 1). Generally, the infested nuts develop triangular creamy white patches, which extend downwards from the margin of the perianth. This marks the first visible symptom. Normally infested nuts carry 1 to 2 patches or rarely more which gradually increase in size expanding further down. Later on, the symptom follows two different courses. Some of the nuts develop longitudinal cracks or splits medially along the white patches. The split initiates from the border of the meristematic zone, in the form of a V, which proceed down along the white patch taking the form of a Y. The nuts on the bunches show only extended leg of the Y mark. Therefore, complete picture of Y is detectable only on removal of the perianth. The split grows deeper and deeper culminating in break up of the nut and discharge of its water content. Often subsidiary cracks may also develop depending on severity of infestation. The nuts developing such cracks hardly undergo further development and eventually detach and fall off. Contrary, to this, few nuts develop the crack at a level below the margin of the perianth. Such nuts usually do not fall off and continue to grow. In addition to this Y shaped crack, few nuts develop irregular cracks or straight crack, along the feeding area of the meristematic zone of the nut.

The second course of injury observed on the nuts is relatively less severe when compared to the former. In this, the affected nuts continue to grow without nut fall. As a result, the triangular white patch extends through the entire length of the affected nuts. The colour of the feeding patch turns yellowish brown and then grey because of the drying up of the husk. During later stages, these patches develop numerous longitudinal fissures and furrows. The husk turns thin, dry and tightly adheres to the endocarp, thereby preventing the normal development of the nut. Very often the triangular patches are found localised but instances of their union to cover the entire surface of the nuts are also not rare. In many cases, the husk develops irregular folds imparting highly deformed appearance to the nuts. In addition to these symptoms, drying of entire young nuts of 4 to 8 weeks of age is also frequent among infested palms.

The above sequence of mite infestation can be analysed through regular observation of infested inflorescence. Young buttons of 3-5 weeks of age appear to be prone to mite invasion as this marks the sprouting stage of the nut beyond the perianth (Plate 1). These nuts are often visited by pollinating / nectar collecting insects. However, visible symptom of injury can be detected only after 4 to 5 weeks of mite invasion. This is marked by the appearance of small triangular white patches on nuts of 8-11 weeks of age (Plate 2). This is followed by the appearance of deep cracks on husk (Plate 3) among several nuts. Most of the nuts with crack on their husk detach from the perianth and fall off (Plate 4). Flourishing colony of the mite (Plate 5) with eggs and developing stages can be detected on meristematic zone of the affected nuts. However, majority of the infested nuts sustain mite infestation and continue growth. Such nuts are characterised by deformed husk with abnormal shapes and reduced size (Plate 6).

The symptoms of injury observed on affected nuts appear to be similar in all parts of the world (Hernandez, 1977, Mariau, 1977, Moore and Howard, 1996). Mariau (1977) suspected the role of this mite in inducing early nut fall. However, development of deep cracks and subsequent fall of young affected nuts appeared to be a common occurrence in Kerala (Haq, 1999b). This symptom represents the most destructive type of damage among affected nuts. More investigation on different varieties of coconut under various climatic conditions has to be made to confirm such effect of the mite on developing nuts. From the different symptoms observed on infested nuts it is apparent that the mite induces varied types of alterations in the normal development of the nuts. The exact reasons for such alterations are yet to be analysed. The age of nut at the time of mite invasion appears to be one of the key factors influencing the course of damage symptoms. Of course, this must be supported by other factors like varietal difference of palms, population replenishment of the mites, influence of climatic factors, etc.

Dispersal strategies

A. guerreronis has established high rate of infestation in all coconut plantations of South India (Haq, 1999b). However, dispersal strategies and mode of transmission of the mite remain unexplored. Wind current has been attributed to be the transmitting agent of the mite (Griffith, 1984, Moore and Howard, 1996; Ramarethinam and Marimuthu, 1998, Haq, 1999b). Meanwhile, involvement of other agents such as flower visiting insects and human activities have also been attributed earlier (Moore and Howard, 1996; Haq, 1999b). An extensive knowledge on biology and behaviour of the mite is essential for ascertaining its strategies. Earlier studies have confirmed that the mite feeds on meristematic tissue of the developing nut beneath the perianth. It has also been reported that breeding activity of the mite also takes place in the same region resulting in extensive colony formation comprising eggs, nymphs and adults (Moore and Howard, 1996; Haq 1999a, 2000). Close scrutiny of the infested nuts in the field has revealed a diurnal periodicity of the mites on the outer surface of the nuts. This trend probably initiates at the time of sufficient population build up of the mites on individual nuts. Both adults and nymphs are found wandering on and around the perianth. Usually the mites start to come out after sunrise and continue their activity till night. Activity of the mites is not limited to their host nut alone. Many of them probably migrate to young buttons of neighbouring inflorescence, as presence of mites has been detected on them. Therefore, it can be assumed that the mites are regularly visiting the young buttons of infested palms and invading them at a critical period. Nuts of about 4 to 6 weeks of age are found invaded by the mite during previous study (Haq, 1999a). In the light of the diurnal periodicity of the mite observed outside the perianth of the infested nuts, it can be assumed that the mites visit young buttons/female flowers soon after fertilisation of the latter and invade the meristematic zone when the size of the nut and way of invasion turn amicable. The exact nature of invasion has yet to

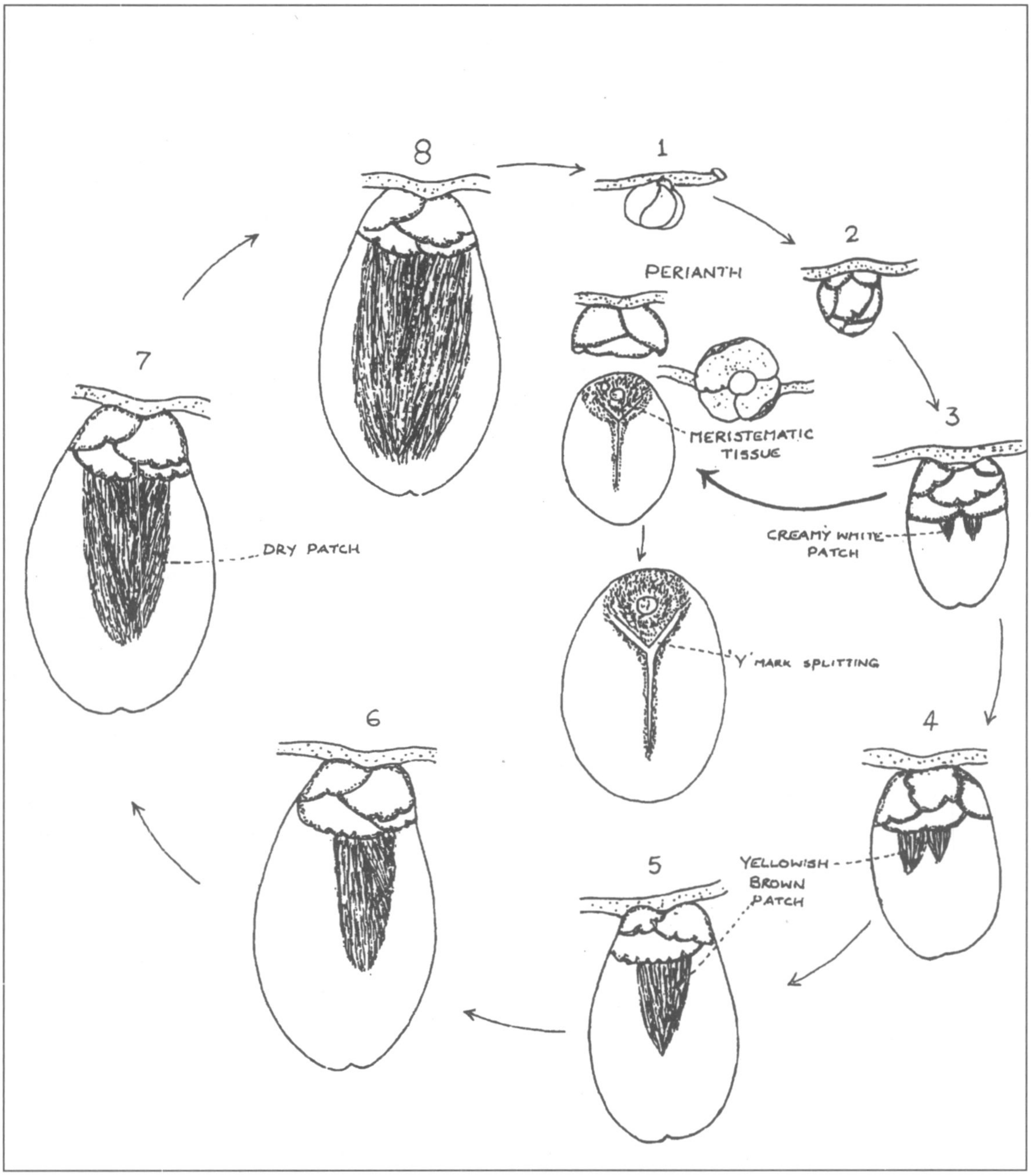

Fig. 1: Sequence of damage induced by *Aceria guerreronis* on coconut

be found with more experimental trials. Dispersal of the mite to neighbouring palms is possible through agents visiting inflorescence as well as through wind. Rapid spread and establishment of the pest is possible due to its enormous breeding potential and short duration of development. Further, the diurnal periodicity may help the mite to disseminate through all possible means for several days from an infested nut.

Plate 1: Sprouting buttons on inflorescence with honey bee

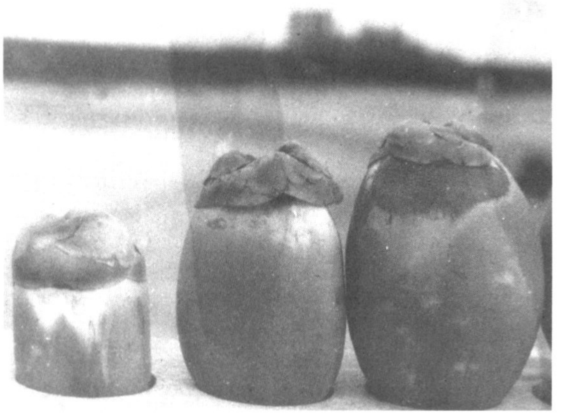

Plate 2: Triangular patches on various stages of nut development

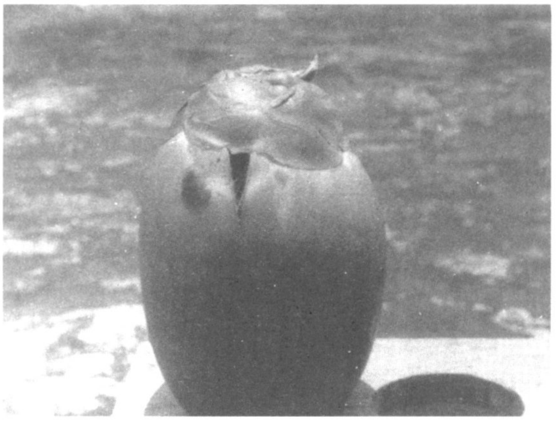

Plate 3: Crack development as seen outside the intact perianth showing partial extended leg of Y

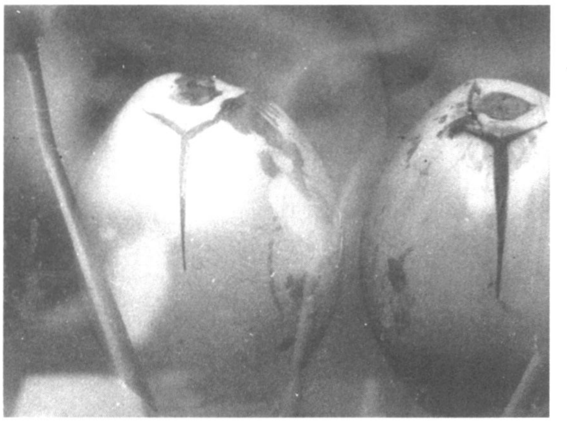

Plate 4: Infested nut after removal of perianth showing complete Y mark crack

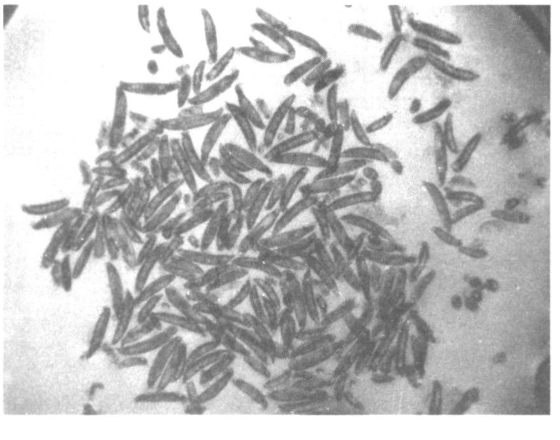

Plate 5: A colony of*Aceria guerreronis*

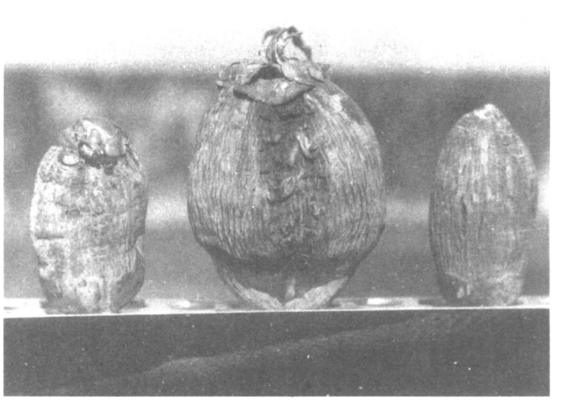

Plate 6: Nut malformation due to infestation by *A. guerreronis*

Control aspects: problems and prospects

A. guerreronis has established currently as a serious pest in many countries in the world and appears to be capable enough to build up persistent populations over the entire range of its geographical distribution. Ironically, an effective method of prevention/regulation of this pest has not been framed successfully so far, although three decades have already been lapsed since its first detection. As a matter of fact, the mite still remains as a challenge in coconut plantations of the world. While considering the economics of the outbreak of *A. guerreronis* in Indian subcontinent, the situation appears alarming, as the State of Kerala alone accounts for 200 to 250 crores of rupees of annual loss due to this pest (Haq, 1999b). The loss will be manifold in the context of the invasion of Lakshadweep islands by this mite pest. Therefore, augmentation of effective control tactics against this mite should be done at an emergency basis.

From the above view point, it seems appropriate to make a summary of the measures already in use for regulating the mite and to evaluate more cost-effective ways of combating the pest problem. While considering this, it appears indispensable to fill up the lacunae in knowledge regarding certain crucial aspects of the mite, such as susceptible period of the nuts to mite invasion, mode of invasion of the mite into meristematic zone of the nut, relationship between time of mite invasion and extent of damage on individual nut and mechanism(s) of dispersal of the pest. Coming to the control strategies, it appears to be more appropriate to think in terms of integration of different ways of preventive/regulatory methods of the mite in predetermined sequence to evaluate an effective control package.

Mite invasion to fresh nuts can be prevented through application of mite repellents at regular intervals during susceptible period of the nuts to infestation. Similarly, application of these repellents on infested nuts will help to minimise the dispersal of mites from them. Neem oil preparation like Nembicidine 0.03% aza has been identified as a repellent (Ramarethinam and Marimuthu, 1998) of this mite. Therefore, this can be tried to prevent invasion and dispersal of the mite. Root feeding of various insecticides like triazophos (Hostathion) and monocrotophos has been recommended (Mohanasundaram *et al.,* 1998) and practised in Tamil Nadu with success.

Control of the mite population on infested palms

Chemical control

This has so far been mainly attempted through spraying or root feeding of certain chemical pesticides. Methyl demeton (Metasystox), phosalone (Zolone), cyhexatin (Plictran) and barxistin represent some of the pesticides recommended for aerial spray of affected palms (Mariau, 1993; Mohanasundaram *et al.*, 1998). In addition to these, triazophos (Hostathion), mixture of monocrotophos/dimethoate with sandonit and dicofol are in use as an aerial spray as well as root feeding chemicals (David and Kumaraswamy, 1978; Mohanasundaram *et al.*, 1998). Apart from this, bio-pesticide formulation such as neem oil + soap emulsion has also been recommended to regulate the mite.

Biological control

Biological control of *A. guerreronis* has not yet standardised in any part of the world. However, natural enemies of the mite such as predatory mites and fungal pathogens have been reported from different parts. Among the predatory mites, *Lupotarsonemus* sp. (*Hall et al.*, 1980), *Bdella indicata* (Mariau, 1977), *Amblyseius* sp., *Phytoseiulus* sp. *(pers. comm.)*, *Amblyseius largoensis, Neoseiulus mumai* and *N. paspalivorus* (Howard *et al.*, 1990) have been identified as prospective agents for control of this pest.

Among the pathogens attacking *A. guerreronis* fungi have been detected as promising agents. Of these,*Hirsutella thompsonii*, appears to be widespread and effective, as it has been recorded from various parts of the world (Julia and Mariau, 1979; Hall *et al.*, 1980; Espinosa and Carrillo, 1986; Carbrera and Dominguez, 1987; Lampedro and Rosas, 1989). In addition, association of other fungi like *Metarhizium anisopliae, Beauveria bassiana,* and *Fusarium pallidoroseum* have been recorded in Kerala. However, more investigations on their efficacy have to be worked out.

Natural predators

During recent survey on natural enemies of *A. guerreronis* along the infested tracts of Malabar area in Kerala, quite encouraging observations have been made with regard to the predatory activity of mites and insects on infested nuts. Several predatory insects like ants, staphylinids, collembolans, thrips, caterpillars and few species of mites (Plate 7) are found associated with the inflorescence. The ant belongs to the genus *Flagiolepis* while the mites belong to *Phytoseiulus* and *Amblyseius* (Plate 8). Of these, the mites and staphylinids appear to be more promising owing to their frequent occurrence and active predation on mites of infested nuts. Usually, these mites and staphylinids are found on nuts at comparatively advanced stage of infestation and often probing the edges of tepals. They are found chasing and feeding upon the coconut mites, which come out of the perianth. Occasionally, these predators are found entering the meristematic zone of the nuts through broken edges of tepals. Further studies along this line are in progress to consider their combatibility in this regard.

Cultural management

Identification and cultivation of those varieties of coconut palms that exhibit less susceptibility towards *A. guerreronis* infestation has been suggested by many. Practical attempt along this line has identified the hybrid variety MYDXWAT in Benin (Mariau, 1986). Similarly, Muthiah and Bhaskaran (1999) have identified Lakshadweep ordinary, Cochinchina, Andaman ordinary and Gangabondam cultivars of coconut as less susceptible and promising varieties. More studies on regional basis are needed to identify the available varieties under each coconut plantation zones of the world to achieve success in this regard. Similarly, modification of farm management practices through irrigation and optimum utilisation of chemical fertilisers have also been suggested to regulate the mite population in the field (Moore *et al.*, 1991).

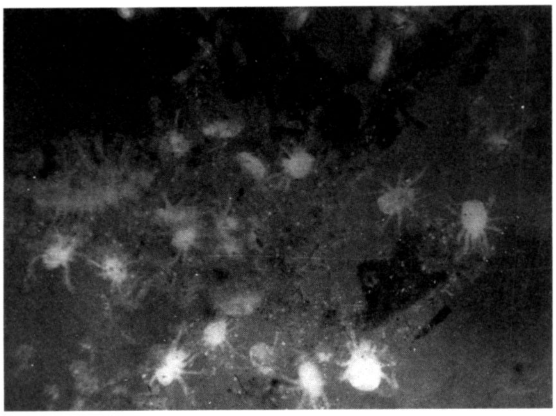

Plate 7: A view of predatory fauna collected from the infested inflorescence

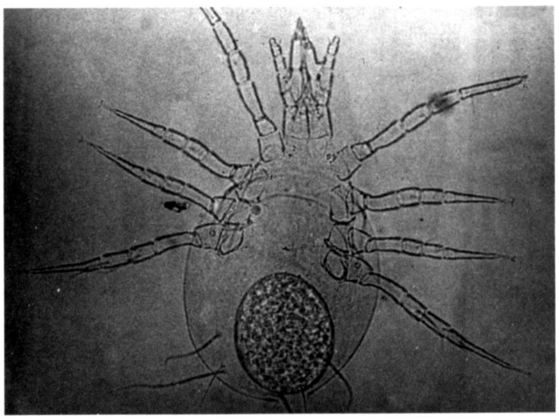

Plate 8: Predatory mite belonging Amblyseius sp. collected from an infested nut

Collective efforts of scientists working in different fields of biological sciences are warranted for streamlined investigation and standardisation of the promising methods of prevention/control of the mite. Field tirals of the integrated package should be carried out at different geographical/ agroclimatic conditions and suitable alteration in the sequence/dosage/application method/timings etc. may be made as and when needed to obtain promising results.

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Containing the eriophyid mite on coconut - an approach

K. Arulmozhi, IAS
Director of Agriculture, Chepauk, Chennai 600 005, Tamil Nadu, India

Summary

*The occurrence of the Eriophyid mite **Aceria guerreronis** on coconut, affecting the plantations in large areas of southern states of Tamil Nadu and neighbouring states has drawn the attention of the researchers, administrators, traders and the farming community as a whole due to its threat to the coconut industry and the livelihood of the millions. Though the occurrence has been noticed well during the ninteen eighties, the conspicuous and alarming destruction that it has caused to coconut palm recently has triggered the necessity for its successful containment by focussing all the possible research solutions covering all the facets of management strategies. One of the strategies that started paying divident is the chemical control measure with monocrotophos rather than the permanent remedy. Here in this paper, the ways and means of containing this obnoxious pest involving the community with the strategies that can be contemplated on the lines of participatory technology development with an integrated approach are discussed.*

Introduction

The crisis of the eriophyid mite *Aceria (= Eriophyes) guerreronis* has brought us all here to the Land of Beauty to solve the problems facing us with a dire and catastrophic consequences. Let us work out strategies, in this workshop to combat the mighty mite with an everlasting solution and get rid of this scourge.

Locus standi

To place some statistical facts about the coconut scenario, I would say that Tamil Nadu holds the second position in area, production and productivity in India with an area of 3.51 lakh ha. producing 4,356 million nuts, or 12,382 nuts/ha.

Magnitude of incidence

The occurrence of *A. guerreronis* eriophyid mite was noticed during August 1998 in a small area of Coimbatore District and gradually spread to about 11.53 lakh trees in 6 districts over 4 months. The spread was very quick thereafter affecting 68.96 lakh trees in 10 districts in another 9 months and at present the magnitude of occurrence has reached an alarming figure of about 141 lakh trees in 24 districts covering almost the entire state, over a span of 16 months. The affected area of 81042 ha. is more than 22% of the total area under coconut in Tamil Nadu State.

Strategies adopted

The State Agricultural University at Coimbatore has come out with the chemical control measure by recommending the spraying of

methyl demeton 25 EC at 4 ml/litre of water, or

triazophos 40 EC at 5 ml/litre of water or

monocrotophos 36 WSC at 1.5 ml/litre of water once in 30 days, or root feeding of

monocrotophos 36 WSC at 15 ml/15 ml of water once in 45 days.

The above recommended plant protection measures are being adopted by the coconut growers. However the spread of the mite keeps on swelling unabated, though the percentage of control is said to be 80%.

Suggestions

Here at this juncture, I would like to remind the scientific community involved in containing the mite that the chemical control alone is not going to be the panacea for this problem. This problem needs to be approached by a sustainable, eco-friendly and everlasting solution. This can be better accomplished by making serious attempts on the following suggestions

* *Evolving the bio-efficacy of botanical insecticides / acaricides*

  The advent of organic insecticides with indiscriminate application of potent broad spectrum insecticide resulted in several complications in the agro ecosystem which lead to development of insect resistance, resurgence, rise of secondary pests and environmental contamination leading to great hazards for man and his livestock. Because of these problems the focus should be on the botanical pesticides based on neem and garlic.

* *Identification of natural enemies like parasites, predators and pathogens*

  Because of the increasing environmental degradation due to large scale usage of insecticides and considering the cost of the insecticides, we better turn on the naturally existing defenders for a diversified programme of pest suppression. Here the already recorded pathogenic fungi *Hirsutella thompsonii* and *H. nodulosa* need to be tried against this mite along with the predatory mite.

* *Augmentation of the natural enemies by mass production*

  Mass production and release of the identified natural enemies can be contemplated to build an optimum population level for containing the mite. However it should be economical for production in large scale and they should also act rapidly on the targeted pest. We can also obtain natural enemies from other countries, multiply them in our laboratories and release them in plantations.

* *Integrating chemical control with biological pest suppression*

  Wherever the balance of the host and the biological suppressants is not seen and the pest is on the dominance and beyond the economic threshhold level (ETL) resorting to chemical control measures is imminent. The IPM principle establishes pesticide use as one of the weapons in the management armoury, to be used sensibly integrating with other weapons. Pesticides should be used according to the need.

* *Adopting the Integrated Nutrient Management with major, minor and organic manuring.*

  Serious attempts have to be made on a practical scale to alter plants nutritionally for the management of this mite, because one way to manage a pest is to modify intrinsically favourable habitats in such a way that they no longer provide the conducive environment for the population build up of the pest involved i.e. by providing unsuitable sources of food. Host plant nutrition is a key component in pest infestations. Potassium has been recognized not only as a major nutrient of direct use to crops, but also playing a role in pest and damage suppression and so as the application of neem cake combined with the micro nutrients.

* *Conducting mass scale pest control campaigns at community level*

Since the pests have developed special anti-desiccation mechanism there by perpetuating under all kinds of adverse environments, they cannot be easily controlled unless the control operations are carried out over a large area simultaneously. Otherwise the good effect of control operation is diluted or nullified by the migration of insect from the surrounding untreated areas. These campaigns need to be carried out with the community approach.

* *Involving the coconut community, allied industries and other NGOs in the control programme*

Cooperative endeavour is essential for pest control. A pest control campaign can be best organized by involving the agencies depending on the production of coconut in addition to the efforts rendered by the Government Departments. There should be a symbiotic collaboration between the producer and the industries involved for their common benefit. NGOs can be better involved in this endeavour. If the control programmes are carried out with the united efforts of these agencies 100% coverage can be ensured.

* *Monitoring, interchanging and disseminating the information globally and locally through internet.*

It is of prime importance to share the research findings and the outcome of the projects among the agencies involved in the uphill task of containing the eriophyid mite among the organizations involved at global and local levels. Only then the fruits of the efforts will be put into better and timely use. A research consortium approach is the need at this juncture.

* *Training the farmers in survey, participatory role land skill and information empowerment*

The modern crisis management requires a multi disciplinary involvement and free exchange of the information about the developments and the readily accepting of the proven and genuine skills which are location specific and suggestions from the farmers by extending a participatory role to the local community in working out the strategies in the process of containing this melody challenging us.

Participatory Technology Development (PTD) as the medium for improving the technology available to the farmers in the target area can be thought over. The process builds on the inevitable fact that farmers are, of necessity, experimenters. It provides a good linkage between all contributors to the process.

* *Sponsoring the multi disciplinary research support programmes by the Asian Pacific Coconut Community*

Since the Asian Pacific Coconut Community (APCC)'s agenda is boosting of the production of coconut, improving the welfare of the contributors to the coconut industry and safeguarding the economic interest of the people engaged in coconut throughout the coconut growing regions of the world, the research programmes and other projects should be sponsored partially or full by APCC (Asian Pacific Coconut Community).

Conclusion

Now on going by the developments in the Southern districts of India and Sri Lanka we need not wait for long to see this notorious pest spreading all over the country posing a formidable challenge to the crop protection specialists, administrators and ultimately the coconut growers and so the coconut industry in India and elsewhere in the World, so let us work out a common agenda to combat this eriophyid mite to the welfare of the humanity.

Incidence, distribution and economic importance of the coconut eryiophyid mite, *Aceria guerreronis* Keifer in Tanzanian coconut based cropping systems

Z. Seguni

Agricultural Research Institute Mikocheni, P. O. Box 6226, Dar es Salaam, Tanzania.

Summary

A new coconut pest, ***Eriophyes (Aceria) guerreronis*** *Keifer is widely distributed in all coconut growing areas of Mainland Tanzania and on the Islands of Mafia, Zanzibar and Pemba. In two surveys conducted in 1992 and 1996 crop losses in dry weight of coconut meat attributable to the worst mite infestations cases were between 20-30% of the potential crop yield. Losses due to premature nutfall were between 10-100% with wide variations (mean of 21%) between localities. Premature nutfall is additionally influenced by damage by the coreid bug,* ***Pseudotheraptus wayi*** *Brown an indigenous and widespread pest.*

Most coconut varieties are susceptible to infestation by ***A. guerreronis*** *including most subpopulations of the local East African Tall (EAT) and dwarf varieties, although evaluations on EAT did not differentiate the subpopulations which show genetic variations. However, some of the introduced varieties including Polynesian Tall (PYT), Malayan Red Dwarf (MRD), Rennel Tall (RLT), Cameroon Red Dwarf (CRD) and Equatorial Green Dwarf (EGD) have nuts which show more tolerance to mite attack. In solving the mite problem it seems appropriate under Tanzanian coconut growing conditions to search for, and utilise coconut germplasm within the EAT showing less susceptibility to attack by the coconut mite, as a source of planting material. The emphasis on EAT is based on the fact that this variety is adapted to drought conditions prevailing in most coconut growing areas of Tanzania. This effort could be complemented by the introduction of appropriate natural enemies as biological control agents.*

Importance of coconut palm in Tanzania

Coconut farming is one of the most significant branches of agricultural production in the coastal region of Tanzania both for household units and for the national economy as a whole (Hopp *et al.*, (1981). The coconut tree is justifiably called "the tree of life" (Ohler, 1984) due to its multiple uses as a food crop and a source of fuel from wood, leaves, coconut husks and shells, shelter from leaves which are used as thatch, cattle feed, and timber. The main commercial products are fresh coconuts and copra, which is a source of vegetable oil for home consumption and industrial purposes and for stockfeed.

The area under coconut on the mainland and the Islands of Zanzibar, Mafia and Pemba is approximately 240,000 ha. More than 90% of the total area under coconut is cultivated by smallholders. For many years coconut production has shown a downward trend. Main reasons for the decline were unattractive pricing and underdeveloped marketing system, increasing overage structure of palm stands, poor maintenance, pests and diseases and limited availability of suitable planting material and information. To curb the downward trend, the government of Tanzania with the support of the government of the Federal Republic of Germany through its executing agency, GTZ, set up the National Coconut Development Programme (NCDP) was 1980. As part of the coconut improvement programme higher yielding dwarf x tall hybrid varieties were introduced in the early 1980s but these were not only prone to drought but were seemingly more susceptible to destruction by the coreid bug, *Pseudotheraptus wayi* than the local East African Tall (EAT) variety.

The coconut mite, *Aceria guerreronis* Keifer has become a new threat to coconut production in Tanzania and East Africa. The pest, endemic to Central and South America, was probably introduced into the country in the 1980s from West Africa where it was earlier reported (Mariau, 1977). The pest is wide spread in all coconut growing areas of Mainland Tanzania as well as in the Islands of Mafia, Pemba and Unguja (Table 1) (Varela, 1993; Meena, 1996). According to KAP studies (Knowledge, Attitude and Practice) conducted by National Coconut Development Programme (NCDP) in 1994, 1996 and 1999 in the important coconut growing areas farmers have singled out mite damage as one of their most important problems and have requested for intervention to solve it.

Economic importance of mites

The coconut mite causes significant losses to coconut. In St. Lucia, West Indies the estimated yield losses were around 20-30% (Moore *et al.*, 1989). In Venezuela damage was estimated at 70% (Doreste, 1968) while in Mexico it ranged between 30-80% (Olvera-Fonseca, 1986). In Ivory Coast, West Africa, copra content per nut was reduced up to 24% by mite attack (Mariau, 1977). In Mozambique managers of large coconut estates observed that more nuts were now required to make a kilogram of copra as a result of mite attack (Mpunami & Seguni, 1996). Two mite surveys conducted in Tanzania in 1993 and 1996 determine distribution, incidence and economic importance of the pest in the coconut growing areas of Tanga, Dar es Salaam, Coast, Morogoro, Lindi, Mtwara, and Zanzibar and it was determined that the pest damaged up to 70-100% of all coconut fruits sampled (Varela, 1993; Meena, 1996). This damage was associated with losses of 20-30% of the weight of fresh and oven dried nut meat. (Table 2) It was also observed that yield losses were higher in hybrids; it correspond to 61% for PB121 compared to 30% for the local East African Tall (EAT) (Tables 2&3). Crop losses were also in the form of premature nutfall; it was determined that an average 21% of all prematurely falling nutlets had mite attack and in some cases up to 100% (Meena, 1996). Although most coconut varieties are susceptible to attack by the coconut mite some varieties show differing degrees of tolerance. Notable among these are the Polynesian Tall (PYT), Malayan Red Dwarf MRD), Rennel Tall (RLT), Cameroon Red Dwarf (CRD) and Equatorial Green Dwarf (EGD).

Table 1. Survey of coconut mite attack in several coconut growing regions in Tanzania

Region	No. of palms	No. of nuts	Overall damage (%)	Damage to bunch 6
Pwani	188	10206	54.1	40.7
Lindi	255	21366	59.7	38.4
Mafia	208	13518	48.7	38.7
Mtwara	315	26458	48.7	28.3
Tanga	195	11404	65.7	55.5
Zanzibar	300	16505	54.3	49.2
Total/average	1461	99457	55.2	41.8

Table 2. Effect of mite damage on yield of harvested nuts of PB121 hybrid at Mkuranga in Tanzania

Damage category	Number of nuts	Fresh weight (g)(i)	Dry weight (g)(ii)	Yield loss (%) (iii)
0	51	299.2a	30.0a	-
1	73	272.6a	30.0a	8.9
2	147	237.5a	29.9a	20.6
3	194	216.5b	29.3a	27.6
4	175	150.4c	29.6ab	49.7
5	74	115.9d	27.3b	61.3

(i) Different letters indicate significant differences at P<= 0.05
(ii) Dry weight out of 50g of fresh meat
(iii) Yield loss based on potential yield: estimated by multiplying the average weight of fresh meat of nuts with no damage by the number of nuts in each damage category.

Table 3. Effect of mite damage on yield of harvested nuts of EAT at Mkuranga in Tanzania

Damage category	Number of nuts	Fresh weight (g)(i)	Yield loss (%)(ii)
0	54	350.9a	-
1	56	354.6a	1.0
2	57	333.4ab	5.0
3	67	287.8bc	18.0
4	46	251.3c	28.4
5	21	246.5c	29.8

(i) Different letters indicate significant differences at P<= 0.05
(ii) Yield loss based on potential yield: estimated by multiplying the average weight of fresh meat of nuts with no damage by the number of nuts in each damage category.

Control alternatives and their prospects for use in Tanzania

There have so far not been any control attempts against *A. guerreronis* in Tanzania. Elsewhere a large number of pesticides have been tested for its control (Julia and Mariau, 1979). Stem injections of monocrotophos, dicrotophos and chinomethionate to young palms were effective in the Ivory Coast but these had to be applied with a frequency which would make their application uneconomical, hazardous and likely to result in resistance. There have been reports of mixed success and frustration with the application of biological control methods such as the use of entomogenous fungi and predacious mites (Hall *et al.*, 1980). The use of biological agents with high humidity requirements may not be very appropriate for most of Tanzania where drought is one of the most important constraints in coconut growing.

The use of resistant cultivars is considered a promising method for management of the pest. Certain cultivars are less susceptible to attack than others. It is considered that the more rounded nuts with tightly adhering bracts might impede penetration of mites under the bracts. (Moore and Alexander, 1990). The use of resistant/tolerant varieties is therefore a promising method of long-term mite control. For instance it was observed in Tanzania that the Polynesian Tall (PYT) and Cameroon Red Dwarf (CRD) varieties showed significant lower percentage of damaged nuts compared to other varieties. However, although the above introduced coconut varieties were observed to have some resistance/tolerance to mite attack most of them would not be recommended for planting in Tanzania because they cannot survive well under the dry conditions of much of the coconut belt. Only the local EAT is drought tolerant. EAT is further known to exist as genetically diverse subpopulations polymorphic for colour and shape of fruits. These different traits can be exploited to determine and identify tolerant material from within the variety. These can be used by breeders in improvement programme and can at the same time be recommended to farmers.

Conclusion

In conclusion two surveys conducted in Tanzania indicated that the coconut mite is widespread in the country and cause economically unacceptable damage to coconut. Therefore a control programme against the pest is necessary and urgent to prevent economic crop losses. There is great need for regional/international collaboration in developing, testing and applying environmentally and economically sound control strategies against the coconut mite bearing in mind the economic difficulties of the bulk of the coconut farmers who are smallholders. This forum is therefore an appropriate venue for interactions and exchange of knowledge and expertise.

Acknowledgement

This work is part of the activities of the National Coconut Development Programme, a project financed by the Federal Republic of Germany and implemented by Agricultural Research Institute Mikocheni. I wish to thank my colleagues in Pest Control Unit for dedicating their time to this work, namely, Mrs V. Nyange, C. Materu, K. Lema, G Mwingira and W. Mwaiko. Lastly, I thank to the Officer In-charge, Dr A. Kullaya, for invaluable support.

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Questions and discussion: country papers

Paper: P. Fernando *et al.*

W. Modder : You mentioned that *A. guerreronis* was reported in Sri Lanka for the first time in 1997. Have there been any records earlier?

P. Fernando : This is the first record. However, there is another mite infestation, which shows similar symptoms that could lead to misinterpretation.

R. Rajapakse : Isn't there an unofficial report in 1990?

P. Fernando : Yes. According to CABI pest compendium there is a record but further communication with the CABI revealed that such a reference did not exist.

K. Ramaraju : What precautions have you taken when applying Monocrotophos treatment?

P. Fernando : Initially it was recommended to pick three bunches prior to the application of monocrotophos. However, later investigations revealed that Monocrotophos residues in the kernel were below tolerable levels.

K. Ramaraju : For effective results monocrotophos applications needs to be repeated every 45 days. What would be the cumulative residual effect?

P. Fernando : We do not intend to continue monocrotophos treatment. Our aim was only to bring down the mite population immediately. Neem oil and garlic mixture is recommended for further applications following the initial treatment with monocrotophos.

M. A. Haq : While determining the mite population of infested nuts by the washing method how can you assure that all mites are washed into the mild soap solution?

P. Fernando : We can assure that more than 95% of the mite population is washed into the solution because analysis of a second wash of the same nut shows very low mite population.

Paper: C. P. R. Nair

R. Mahindapala: It is evident that the mite is secured under the perianth of the nut. What is the potential of using predators in controlling the pest?

C.P.R.Nair : The potential depends on the space available for the predator to reach the

mite population through perianth.

W. Modder : What is sign ificance of green nuts being more susceptible to the mite?

C. P. R Nair : The reason is not known, but the susceptibility of green nuts is observed in other countries too.

P. Fernando : What is the frequency of sulphur application and what is its effectiveness with regard to progress of symptoms?

C. P. R. Nair : Two rounds of sulphur (2%) application at the frequency of once a month were applied and results were encouraging. In the first round a reduction of 38.4% was observed and in the second round 60% reduction was found.

U. P de S. Waidyanatha (to P. Fernando): Were you aware that infestation was more on green nuts?

P. Fernando : No. because the majority of the population in Sri Lanka bears green nuts.

Paper: K Ramaraju *et al.*

U. P de S. Waidyanatha : when you root feed with monocrotophos have you removed the edible bunches?

K. Ramaraju : We do not remove bunches, but there will be no harvesting up to 45 days after the application of monocrotophos.

Paper: G. M. Nair *et al.*

Weerakoon : How injurious is the monocrotophos treatment for humans? Has any survey been conducted?

G. M. Nair : We have not recommended monocrotophos.

R. Mahindapala : An earlier survey shows that residues could remain in the nut up to 60 days.

K. Ramaraju : For complete control of the pest repeated applications are necessary.

G. M. Nair : The aim is to contain the pest, not complete eradication.

Paper: M. A. Haq *et al.*

U. P de S. Waidyanatha : Have you cultured mites in the laboratory?

M. A. Haq : Yes. The most important factors for successful culturing is maintenance of the correct temperature and RH.

S. Subasinghe : How effective were the quarantine measures taken to avoid the spread of the pest?

U. P de S. Waidyanatha : Barriers were placed to avoid nuts being transported to other areas and this was effective.

C. Jayasekara : In addition the support of CRI offficers were provided to increase the effectiveness. Further, traders and general public were educated on this issue.

S. Subasinghe :There was political pressure backed by the traders. Why did the pest did not spread so fast in Sri Lanka as in India.

P. Fernando : The infested area extends up to Rajakadaluwa. The exact reason is not clear. It may be due to quarantine measures alone or other factors too may have contributed.

G.M.Nair : Quarantine measures would not help much in this regard.

T. Perring :What are the optimum temperature and substrate for culturing mites?

M. A. Haq : Temperature range of 32 - 36°C is found favourable for field conditions and temperature of 32 ± 2C° and RH of 60 - 80% are conducive for laboratory conditions.

SESSION 2
PAPERS BY EXPERTS

CHAIRMAN : D. MODDER

Non-Chemical Control of *Aceria guerreronis* on Coconuts

D. Moore
CABI Bioscience UK Centre Ascot, Silwood Park Ascot, Berks SL5 7TA, United Kingdom.

Summary

***Aceria guerreronis**, the coconut mite, has been a serious pest of coconuts in the Americas and West Africa for many years, and has recently been reported from the Indian sub-continent. It is thus a threat to the coconut industries of Asia and Oceania.*

Despite its spectacular effects, the coconut mite does not always cause the degree of yield loss attributed to it. Consequently crop loss assessments, in different areas and with different varieties are required. Crop breeding can produce great benefits, but is a long-term, and probably only partial, solution to the pest.

There is some research, and some anecdotal, evidence to suggest that plant nutrition is an important feature. Fertilizer experiments, monitoring mineral composition of the coconut, would demonstrate if certain mineral ranges and ratios influence mite levels and effect. The palms may become more tolerant of mite populations, showing reduced losses despite visible evidence of attack, or mite populations may begin to fall, reducing the inoculum available to continue the spread of the pest.

*No natural enemy appears likely to be successful as a classical biological control agent. Intervention techniques will be required if either predators or pathogens are to be used. The latter are the more likely to produce effective control and a programme to develop an effective myco-acaricide should begin immediately. Isolates are already known, with **Hirsutella** species most likely candidates, but more should be sought in areas with a long history of coconut mite problems. However any programme to develop a myco-acaricide must focus not only on isolate characteristics, but also on aspects of formulation, application and ecology.*

Introduction

The coconut mite, *Aceria guerreronis*, has proved one of the most intractable coconut pests in the Americas and West Africa, over the past 30 years. Its recent appearance in India and Sri Lanka could be the beginning of a significant threat to the major coconut producing regions of the world in Asia and Oceania.

Despite the importance of the pest, research has been minimal. Since a review in 1996 (Moore and Howard, 1996) there has been little additional work published in journals: CABPEST CD (CAB International, August 1999) records 34 papers published between 1973 to date. Consequently a review of recent research would be a sparse document and this paper focuses instead on the major areas where attention is warranted. This begins with loss assessment; is *A. guerreronis* as serious a pest as feared? Then I mention a feature of plant structure and growth which appears critical for the success of the mite, a query as to whether we are talking about a new migrant to Asia and brief discussions of the major techniques to possibly combat the mite. Finally, I advocate the areas of research where I believe quick results can be obtained, if the necessary inputs are made.

Although spread of the coconut mite further eastwards is inevitable, it is likely to take considerable time. The economic losses occurring in the Indian sub-continent (at present and for the whole industry in the future) are going to be great, making a serious impact on the countries and farmers involved. The cost of effective research will be relatively small compared with the cost of the pest.

Crop Loss Assessment

Accurate assessments of crop losses due to the mite are essential. In some parts of the world the assessments may obviate the need for any control measures. During the early 1980s yield losses due to the mite of up to 31.5% were recorded in St Lucia; this was relatively small compared to losses due to poor agronomy and other agricultural practices such as rat control (Moore *et al.*, 1989).

While the coconut production in Sri Lanka and India is much better than that practised in the Caribbean, crop loss assessments are still important to put an economic cost to the pest, both where it presently occurs and potential costs for areas yet to be colonised.

Physical Access A Critical Feature?

A critical feature of the success of the coconut mite appears to be its ability to exploit the physical characteristics of the developing nutlet. This is not to suggest that chemical parameters are not important, but these have not been investigated in depth.

Researchers have approached physical characteristics from a number of avenues. Early work in Benin (Mariau, 1977) examined varietal differences and highlighted a Cambodian variety, which was immune, probably because the floral parts adhered firmly to the nut, allowing no space for access to the nut surface by the mite. The same author (Mariau, 1986) observed that draught aggravated the pest problem by causing the nuts to develop more slowly and consequently remain at the susceptible stages for longer. This view was supported by Zuluaga and Sanchez (1971) and Griffith (1984). Although not specifically examined, slow early growth may be associated with a looser attachment of the nut to the floral parts. It should be noted that other work suggests that the percentage of nuts attacked is greater during wet rather than dry periods (Julia *et al.*, 1979; Julia and Mariau, 1979).

In a study of morphological features in St Lucia, Moore and Alexander (1990) demonstrated that round nuts from a tree were less susceptible to attack than the more elongated ones. The perianth on these rounded nuts adhered much more tightly to the nut than with the elongated nuts. Round and elongated nuts came from the same trees and bunches so the effect is probably not a genetic feature; more likely it is a matter of resource allocation. In any developing bunch young nuts will compete for resources and those more successful may develop as rounder nuts. The Cambodian variety, noted above, had very rounded nuts (Mariau, 1986).

The meristematic tissue of the nut is protected by the perianth, which consists of two layers each of three tepals. Each layer can form one of two patterns. Either each of the three tepals has one end overlapping and the other being overlapped or one tepal overlaps its neighbour at both ends, a second is overlapped at one end and overlaps its neighbour at the other, while the third tepal in the set is overlapped at both ends (Fig. 1). In the second form the tepal that overlaps at both ends has the most space between it and the underlying meristematic tissue, while the tepal that is over-lapped at either end has the least. Coconut mite damage was found to be greatest under the tepal that overlapped at both ends and least under the tepal that was overlapped at both ends (Moore, 1986). Tightness of the perianth to the nut was identified as a key factor in determining susceptibility or resistance to attack by *A. guerreronis* (Howard and Abreu-Rodriguez, 1991).

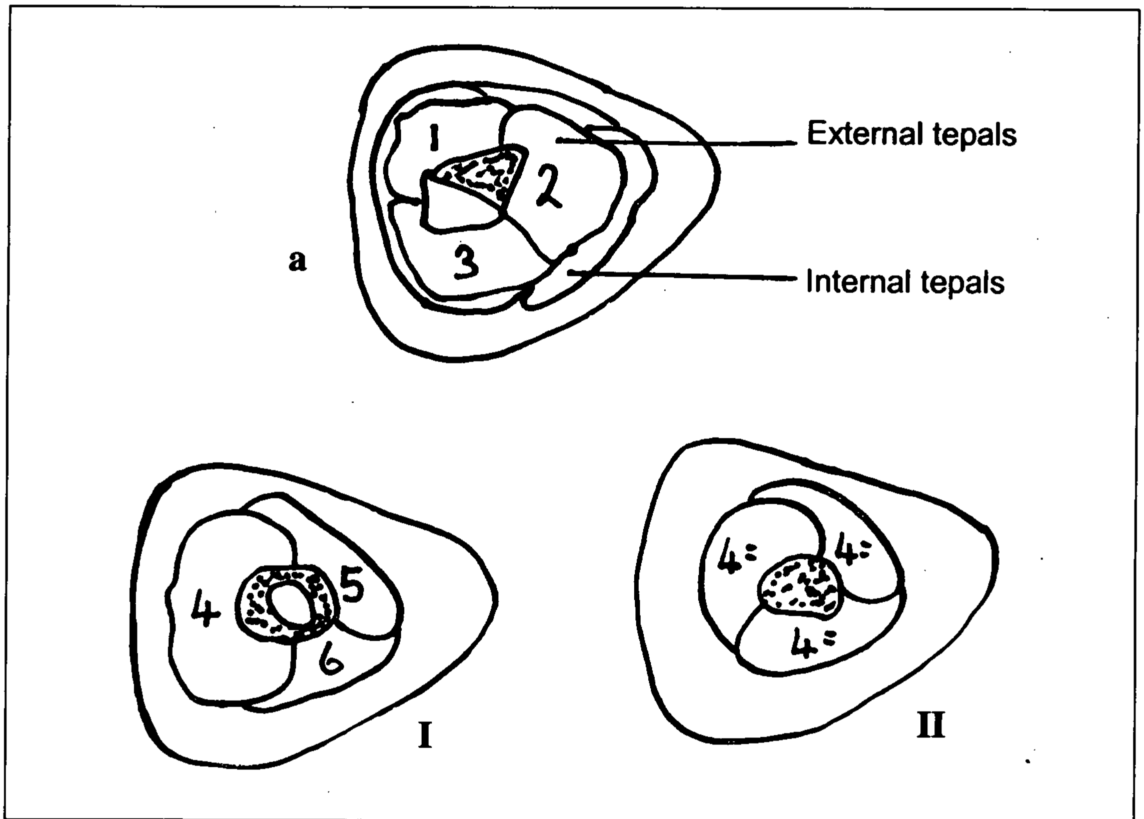

Fig. 1: Arrangement of tepals in the perianth.

(a) External and internal tepals
(b) External tepals removed to show inner tepals. Tepal arrangement I: one tepal (tepal 4) overlaps both of the other, tepal 5 is overlapped at one end and overlaps tepal 6 at the other, tepal 6 is overlapped at both ends II. Each tepal overlaps its neighbour at one end

Spread or Increased Susceptibility?

There appears to be a pattern with the coconut mite, with a sudden, devastating spread in new areas. In St Lucia major problems occurred in the early 1980s after a serious hurricane and the belief arose that the mite had been transported to the island by the hurricane. However, there were farmers who claimed to remember mite symptoms decades earlier, suggesting that the mite had been present but not as a pest and consequently suggesting that control features, previously effective, had broken down. The devastating effects of the hurricane may have weakened the trees or made them more susceptible. Another change in agricultural practice at that time was a major move to aerial application of Benomyl fungicide and spraying oils to the banana crop, which again may have predisposed the palms to the mite or removed a natural control agent (such as an entomopathogenic fungus) from the system. Anecdotal information from farmers in Dominica showed that they believed damage symptoms not to be caused by an arthropod but by the banana sprays.

If spread was induced by temporary features surely the equilibrium would soon be restored? The population dynamics of the pest may be an answer; normally the mortality of coconut mite transferring between trees will be very high. At small population levels the low chances of a fertilized female reaching a susceptible nut stage would ensure many trees escape while high populations may mean that almost every tree becomes infected, perpetuating the epidemic.

Has anything occurred in India and Sri Lanka to increase susceptibility of the trees to an endemic arthropod occurring at very low levels? This may be a global event, such as increased UV because of a diminishing ozone layer, or global warming. Or is the mite genuinely a newly introduced pest?

Either way, the potential for finding natural agents that would be effective classical biological control agents would appear to be remote. If recently introduced there appear to be no effective natural enemies in Africa or the Americas and if of long-term presence the natural enemies would appear to have failed.

Natural Enemies

Aceria guerreronis is reported from coconuts and *Cocos weddelliana* (Flechtmann, 1989). It is most unlikely that the mite was carried from the area of origin of the coconut to the Americas or Africa as mites are not found on mature nuts (Mariau, 1977), which would be those transported. The mite has not been reported from other continents until recently and consequently the mite probably has its original host amongst the indigenous flora of the Americas. If natural enemies were keeping the mite in check on the original host(s), they have not transferred successfully to coconuts. This may suggest a markedly different niche is occupied in the original host(s).

Predators and pathogens attack coconut mite, but under natural circumstances their known effects are minor. Consequently intervention in order to increase efficacy is required. Hall *et al.* (1980) observed predation of adults and eggs of *A. guerreronis* and *Colomerus novahebridensis* by two species of *Lupotarsonemus*, but these appeared to have only very minor effects on populations of either pest species. *Bdella* sp., two phytoseiids and another tarsonemid species were also found in association with *A. guerreronis*, but again seemed to have no practical effect on pest mite populations (Julia *et al.*, 1979; Howard *et al.*, 1990).

Hirsutella species of entomopathogenic fungi have attracted attention as control agents with the greatest potential of achieving effective control (Julia and Mariau, 1979), but this potential has yet to be realised. Work in Mexico with *Hirsutella thompsonii* (Espinosa-Becerril and Carrillo-Sanchez, 1986) and especially Cuba (Cabrera and Dominguez, 1987) with *H. nodulosa* has opened up new opportunities. A process for commercial production of *H. thompsonii* has been developed (Gillespie, 1988) so there is potential for large-scale development.

Both predators and pathogens are discussed by specialists in these proceedings, so will not be addressed here in specific terms. However I believe that, logistically, the use of pathogens is likely to be more satisfactory than the use of predators and that recent advances in mycopesticides make the development of an effective myco-acaricide a distinct possibility.

Myco-acaricide development

Natural epizootics demonstrate the devastating effect that pathogens can have on arthropod populations. However, biological pesticides have been slow to demonstrate their undoubted potential and they form less than 2% of the total pesticide market, mostly as *Bacillus thuringiensis* products. *Bt* is a good example; the first product was marketed as early as 1938 (Frankenhuyzen, 1993) yet it took over thirty years before products became reliable enough to obtain a consistent market share.

To a large extent development was impeded by the very efficacy of the biological agent, whether bacterial or fungal spore or virus etc. Early workers emphasized the agent and applied it to pest populations with little concern about factors such as application efficiency; consequently results were very variable, sometimes excellent and sometimes poor. In the 1960s with Bt and in the 1980s with fungi, attention began to be paid to application and formulation (the delivery system).

The greatest spur to this was given by a project on the biological control of locusts and grasshoppers (known as LUBILOSA, an acronym of the French title of the project): by development of a mycoinsecticide. Over a decade the delivery system became as fundamental to success as the agent (Bateman 1998; Bateman *et al.*, 1993). To this was added, during the 1990s a beginning of an appreciation of the importance of the host/pathogen/environment ecological characteristics (Fig. 2). These included the importance of features such as persistence of the agent in the environment, secondary cycling of the agent, degree of sporulation on the cadavers, host defenses, thermal ecology and so on (Thomas *et al.*, 1996, 1998, 1999; Blanford and Thomas, 1999). By the time LUBILOSA entered its fourth phase in 1999 many of the fundamental problems associated with mycoinsecticide development had been addressed. Of the most significant features notable was that the agent became one (instead of the only) component of a successful product and that virulence, previously considered the most important characteristic of an agent, became one of a number of attributes to consider. However, an effective agent is essential and more need to be sought, especially in areas long associated with the mite such as Mexico, Cuba and Trinidad and Tobago.

There is limited research indicating that nutrition of the coconuts has an effect on levels of *A. guerreronis* damage. Damage generally increased with increasing nitrogen levels and possibly decreased with potassium in St Lucia (Moore *et al.*, 1991). There is extensive literature demonstrating pest attack with plant nutrient imbalance (Chararas, 1979; Rodriguez, 1973; Hagen, 1976; Pant *et al.*, 1982) so this result would not be unexpected, but needs to be examined in detail.

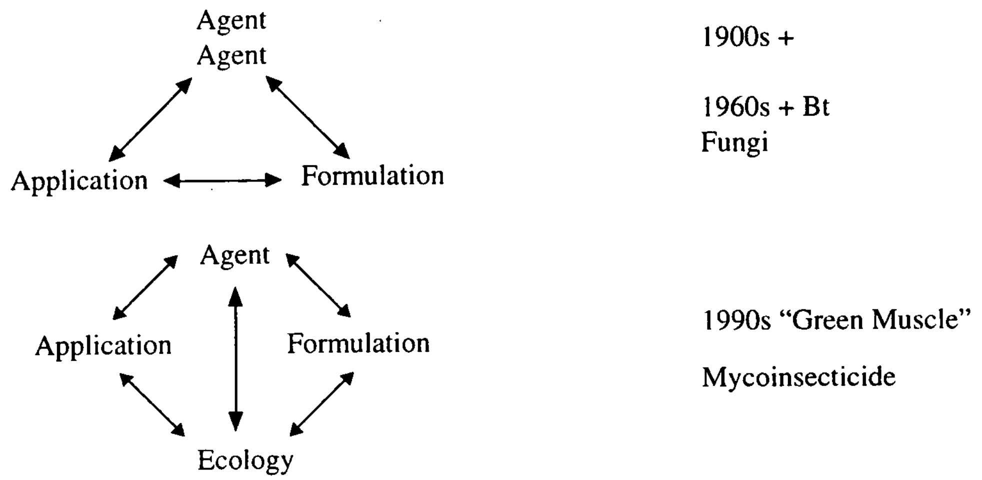

Fig. 2: The development of a more holistic view of biopesticide use. Biological pesticides have become more reliable as features other than the active ingredient have been considered.

Variety Resistance

Varietal differences in susceptibility to coconut mite have been demonstrated in Cuba (Suarez, 1991), Cte dIvoire (Mariau, 1977; Julia *et al.*, 1979; Julia and Mariau, 1979) and Costa Rica (Schliesske, 1988). With the exception of Mariau (1977) who attributed the low susceptibility of a Cambodian variety to the tightness of fit of the perianth, there are no mechanisms for resistance suggested. West African and varieties from the Americas tend to be more susceptible than varieties from Asia or Oceania. It is interesting that *Colomerus novahebridensis*, which causes minor damage on most Asian varieties, can produce much more serious damage on West African varieties (B. Zelazny, *pers. comm.*)

Integrated Control Following from Integrated Research

A fact of most coconut research is that it takes a long time for results to be known. It will be possible to breed cultures that are mite resistant, and this may be a long-term solution if the new cultures are as productive as the old. The breeding itself would take many years, as would subsequent replanting. There are other components of a management strategy that would not take so long to implement.

a) Modified dehusking equipment. A component of the pest status of the mite is the increased labour required for dehusking the coconuts. There may be an easy technical solution to this.

b) There is evidence that management practices influence coconut mite effects. In the early 1980s coconut mite as a pest was considered mainly a problem in poorly maintained plantations in Jamaica. In well maintained coconuts the symptoms of mite damage were still present, but the plants were tolerant and showed little yield loss. Fertilizer regimes are designed to optimise yields; not to control pests but detailed experiments should be carried out to determine if it is possible to maintain yields while reducing mite numbers. Long-term control may require a regular reduction of mites in the environment.

c) Development of a myco-acaricide. This may represent the most likely component for control in the next five years. The likely species to be developed are *H. thompsonii*, which has already formed the basis of a myco-acaricide product, *H. nodulosa* and possibly *Verticillium lecanii.*

d) Crop loss assessments do losses continue or are equilibria established? Crop loss assessments could be repeated in St Lucia and Trinidad and Tobago to see if losses moderate after 10-15 years. This may indicate the potential economic losses, which will be huge.

It may be possible to develop an effective, reliable myco-acaricide, but it will be neither easy nor cheap. Good isolates are available, but mass production, storage formulation and application issues need to be researched. Each component must work if a myco-acaricide is going to be reliable enough to protect the coconut industry.

Conclusions

The conclusions are stark. There is a serious threat to the livelihoods of many small farmers who rely heavily on the coconuts for income. Economic losses due to the mite may reach many hundreds of millions of dollars. The pest warrants serious research and no expectations of an overnight cure.

Fifteen years ago, in St Lucia, I advocated a research programme to develop a myco-acaricide and suggested that feasibility could take three years and further development another two. Five years was too long to wait, the research programme was not implemented and the pest remains. It would be a tragedy if the same sort of comments were to be made in another fifteen years. A major research programme to investigate integrated management of *A. guerreronis* is required and the commitment must be made to invest sufficient time and resources into the research.

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Eriophyoid mites : Special considerations in applied ecological research

Thomas M. Perring
Department of Entomology, University of California, Riverside, CA 92521, USA

Summary

The development of a suitable management program for ***Aceria guerreronis*** *on coconut relies upon an understanding of the ecology of the mite within the coconut ecosystem. We must consider the relationship of the mite with the seasonal growth cycle of the plant, and determine when and how damage from the mite occurs. Additionally we must gain information on other arthropods in the community and determine what role they play in population regulation of* ***A. guerreronis.*** *Unfortunately, the small size of this mite, coupled with the large size of the palm tree present special problems in ecological research.*

This presentation will draw from research conducted on other eriophyid mites and from tetranychid mites in the date palm system. Methods for rearing, sampling, studying dispersal and evaluating the seasonal growth of the mite will be discussed. Through this presentation, the author hopes to bring insight from other mite systems to bear upon the serious issue now facing coconut growers in Asia and Pacific.

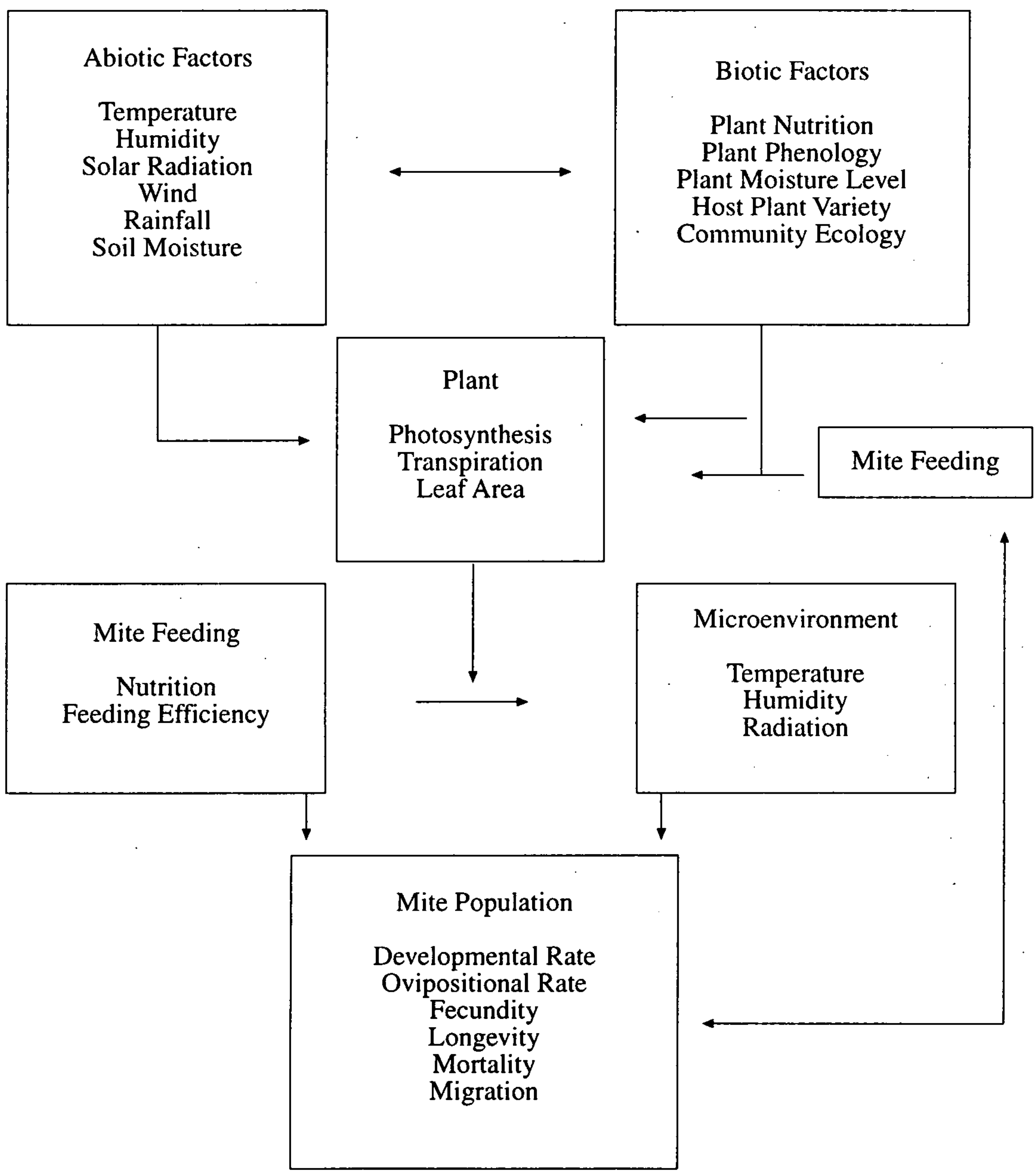
Introduction

The coconut mite, *Aceria guerreronis* Keifer, causes significant crop loss to coconut, *Cocos nucifera* L., growers in countries where it is established. Data from studies on the Isla de Espirito Santo, El Salvador, showed that in 1994, before the mite infested the island, 600,000 to 800,000 coconuts per month were produced. After *A. guerreronis* infested the groves, the yield dropped to 400,000 nuts per month (Dr. Ronald Ochoa, Systematic Entomology Laboratory, USDA, ARS, BA, PSI, Beltsville, Maryland, USA, *pers. comm.*). Where it has occurred, steps to develop IPM-based strategies have been only marginally successful. The recent introduction of this mite into Sri Lanka and India, and the threat of its occurrence in Asia and the Pacific have heightened an interest in management, because these are major coconut producing areas.

The Mite Ecological Model

The development of a sustainable management program for *A. guerreronis* is based upon an understanding of the ecology of the mite within the coconut ecosystem unique to the region of infestation. We are able to utilize this knowledge to disrupt the interactions that allow the mite to increase. An ecological approach to any pest situation begins by considering the theoretical underpinnings that may be functioning in the system (see Mite Ecological Model). The first consideration is the abiotic or physical factors that may impact the mite population. In this group we find ambient environmental factors such as temperature and humidity, which likely have a direct impact on the developmental rate of the mite. For many mites, high temperatures and low humidity accelerate population growth and pestiferous outbreaks follow these weather conditions. For *A. guerreronis* the impact of humidity appears to be dependent on where data have been collected (reviewed by Moore and Howard, 1996). Solar radiation also is important since it drives temperature, moisture loss directly from the mite, photosynthesis (and thus transpiration) of the plant, and evaporation from the soil surface, which can result in plant stress. Wind speed and direction is of major importance, because this is a primary means of dispersal of *A. guerreronis*, thereby influencing the distribution of the mite in coconut groves.

Mite Ecological Model



Reliable in-field sampling will be directly impacted by wind direction. Rainfall influences the humidity and temperature, and also can cause mortality or dispersal of *A. guerreronis*. Soil moisture contributes to plant health, which will have a direct influence on mite developmental rates.

Biotic factors are influenced by abiotic factors, and they, in turn, influence mite population growth. Plant nutrition will impact the feeding rate of mites, and there are many reports of mite increase or decrease with various plant constituents. Moore *et al.* (1991) reported that *A. guerreronis* damage on coconut increased with increased levels of nitrogen in the foliage. The phenology of the plant may play a critical role in the damage from *A. guerreronis*, since feeding appears to occur mainly to the young nut. The plant phenology will impact where the mites are distributed on the plant and when and how they cause damage. Adequate plant moisture level is required for plant health, photosynthesis, and transpiration. Plant variety is likely important as noted by Moore and Alexander (1990). Ochoa *et al.* (1994) showed that the Malayan green fruit sustained less damage from the mite than did the Pacific type. His observation was that the tepal on the Malayan fruit was not as tight as the Pacific nut, thus predators could effect better biological control (R. Ochoa, *pers. comm*). On the other hand, tight tepal is noted as one of the resistance mechanisms against *A. guerreronis* (Moore and Howard, 1996).

Perhaps the most complex biotic factor impacting *A. guerreronis* is the community of organisms sharing its niche. This includes natural enemies and competitive organisms. Indeed, several phytoseiid mites have been found in association with the coconut mite. These include *Amblyseius largoensis* Muma,*Neoseiulus mumai* Denmark, *Neoseiulus paspalivorus* DeLeon in Puerto Rico and Florida (Howard *et al.*, 1990), and mites in the genus *Typhlodromus*, and *Galendromus* found in El Salvador (R. Ochoa, *pers. comm.*). There likely are other mite and insect predators present in Sri Lanka and India, and these species should be explored for natural control. Other aspects of the community include competitors for resources important to the mite, and other organisms (such as fungi), which may cause mite mortality.

The abiotic and biotic factors, both independent and combined impact the mite through their influence on the plant. Through the process of photosynthesis, nutrients are available to the mite, which supports population growth. Transpiration puts moisture into the microenvironment, impacting the temperature, and humidity of this area immediately surrounding the mite. Plant growth builds leaf area, which provides feeding sites for herbivorous mites, and shades the microenvironment from incident solar radiation. These factors in the microenvironment support mite population growth, but also are affected by the feeding mite population. As damage occurs to plant cells, transpiration and photosynthesis are reduced. This may cause the mite to feed more, in an effort to compensate for the loss in nutritive value of the damaged plant tissue. In the absence of transpiration, the microenvironment temperature increases, as does the humidity, supporting rapid population growth. The direct impact is for increased developmental and ovipositional rates, higher fecundity and longevity. As the plant enters a period of decline due to mite feeding, there is high mite mortality and accelerated migration, typically of mated females. During this period large numbers of mites actively leave the plant on wind currents.

Thus the ecological considerations impacting mites are complex and circular. In ambient climatic conditions conducive to population growth, the mite can impart damage to the plant, further optimizing the conditions in the microenvironment. This will result in population explosions until resources are depleted, at which time the mites emigrate from the infested plant.

The date mite on date palms: A case study

This theoretical model serves as the framework from which we can set a research agenda toward developing management strategies. To illustrate this, I draw from another palm-mite system on which my laboratory has worked for the past 3 years. This system involves the damage caused by the Banks grass mite (BGM), *Oligonychus pratensis* Banks on the date palm, *Phoenyx dactilifera* L. Feeding by this tetranychid mite on date fruit can result in significant yield loss. In 1996, the $16 million date industry in southern California lost $2 million to *O. pratensis*. The accepted practice for dealing with this problem was to treat the dates with dusting sulfur on a calendar basis, treating up to 8 times per growing season. In recent years, the sulfur failed to control the mites, thus we implemented ecological research of the mite in the date palm ecosystem, with the intent of developing IPM strategies.

During our research, we determined that the mite is present in all stages throughout the year on fronds where it feeds and reproduces. On date bunches (where the fruit develop), mites are detectable in April and they reach the maximum peak by mid-July and start decreasing during fruit ripening in the fall. During this time on the fruit, they also remain on the fronds, although in very low numbers.

In a survey for natural enemies on fronds and date bunches, predatory mites, *Metaseiulus mcgregori* (Chant)) and thrips, *Scolothrips sexmaculatus* (Pergande) were collected frequently. These species have been shown to be important predators of BGM in other systems. Large numbers of the tydeid, *Pronematus* sp. nr *sextoni* were found on fronds and bunches. On Bermuda grass growing on the orchard floor, we found the predatory mite, *Neoseiulus commitatus* (DeLeon). We also collected a nitidulid beetle, *Cybocephalus californicus* which preys heavily on BGM. In field release studies, we have determined that *G. mcgregori* is able to reduce densities of BGM.

Studies to evaluate the effectiveness of sulfur on BGM and its natural enemies showed that sulfur had no consistent impact on reducing BGM, and in some cases caused fruit to develop higher BGM numbers. Data showed that sulfur reduced predatory mite populations, which in turn may have contributed to an increase of BGM in bunches. We found that orchards in the area had spider mites with different levels of pre-treatment sulfur resistance. Following sulfur applications, resistance levels in both fields was 3 times as high as pre-treatment levels. We suspect that resistance is a leading cause of field failures to sulfur dusting in the growing area. In laboratory trials, we determined that predatory mites are highly susceptible to sulfur application. Thus the accepted practice of dusting with sulfur had an opposite, detrimental impact on spider mite damage. The growers have stopped using sulfur for a more selective miticide that is sprayed only one time per season.

In further research, we identified mite webbing as a suitable sampling unit to be used in the development of a sampling plan. Because mites are so small and the date palm is so large, we had to identify a practical method of assessing the mite population. We learned that mite web ratings were closely linked to mite damage on the fruit. Since mite population growth (and webbing) is temperature driven, we developed a preliminary degree-day model to describe this growth. This model is intended to be a tool for informing individual growers when to apply miticides, depending upon when their grove blooms, and the daily temperatures of a particular growing season. This will result in more cost-effective use of the chemicals available for mite control.

Relevance of date mite to the coconut mite system

Several results from the Banks grass mite research described above are directly pertinent to the *A. guerreronis* problem in coconut palms in Sri Lanka. First it is imperative to determine the temporal and spatial distribution of the mite in the palms. Where is it, and when? In the process of this determination, other organisms in the community will be discovered; some of these may be suitable for augmentative control against the pest mite. What pesticides are being used, and are these helpful or harmful in controlling the mites. It could be that acaricides are doing more harm than good, as we determined in the date palm system. What aspects of the ecological system can we use to develop other management tools? Considering the mites disperse on the wind, can we use edges of coconut palm orchards in a sampling scheme? Do mite populations increase under dry conditions and can we use irrigation to ameliorate this impact? These and other questions can be answered through an understanding of the ecological components in the coconut ecosystem.

Techniques for Eriophyoid Studies

To conclude this paper, I will elucidate some techniques that may be useful to researchers studying the ecology and control of *A. guerreronis*. The small mite and large plant characteristic of this system requires special consideration.

Field Research

Sampling

One of the most difficult aspects of field studies is how to sample the mites. If *A. guerreronis* is like most eriophyoids it will not be distributed evenly throughout the coconut plant. Thus studies should be conducted to sample the various part of the coconut plant through the season to determine the intraplant distribution of the mite (see review by Perring *et al.* 1996). This research often leads to a sampling scheme in which only certain parts of the plant can be sampled to obtain a density estimate of the mites. In addition, it may be possible to use a density estimate, like the mite webbing we use in the date mite system, or damage to certain plant structures, to obtain population estimates. These estimates are necessary when treatment thresholds are being established.

When conducting research it may be necessary to count mites in the field. The advantage of this type of study is that the mite population can be subsequently counted to establish a time-density curve, without altering the natural population growth. With these data, mite-time units, designated as "mitedays", can be calculated from count data by computing the cumulative area under the mite population development curve. Of course the disadvantage of counting in the field is that considerable time must be spent there, and hand lenses or optivisors will be required. In the case of *A. guerreronis*, an aggravating factor is the very small size of the mite. Also useful can be specialized counting templates that can be used with plant material.

If in-field counting is not necessary, the advantages of destructive sampling outweigh those for non-destructive sampling described above. For this work, plant tissue can be collected in the field, and transported to the laboratory. Samples can be stored and counted with a dissecting scope, often much easier than counting in the field. A major consideration is determining which plant tissues should be collected. Once plant tissue is in the laboratory, mites can be counted directly on the affected plant part, or they can be removed and stored in alcohol. The mite brushing machine (Henderson and McBurnie, 1943) can be used effectively for this purpose. Mites also can be washed from the foliage (typically in alcohol), collected, and saved for later counting.

Measuring Mite Dispersal

Eriophyoids disperse by walking from plant to plant, by wind-aided "flight" and by phoresy on vertebrates and invertebrates which visit the host plant (Jeppson *et al.*, 1975). To monitor walking movement, various methods can be applied, making use of sticky barriers. One can wrap double-sided sticky tape around plant material or apply a band of commercially available Tack Trap to the plant. The predominant method of eriophyoid migration from plant to plant is with the aid of wind. Nault and Styer (1969) described mites standing erect with the aid of their anal suckers, facing the wind, and waving their legs. To measure this movement, a simple method is to use a sticky-coated or petroleum coated glass slides. After mites are trapped, they can be counted on the microscope slides with a dissecting microscope.

Laboratory Research

Requisite to conducting laboratory studies is the collection of mites, either for direct use from the field or to establish laboratory colonies. Collecting mites have been covered in other parts of this paper, and some of these techniques are perfectly suited for initiating lab studies. Mites can be collected from plant material by using the mite-brushing machine, by washing, by beating the mites from the plants, or by selecting individuals from infested tissue. One can also establish lab colonies by placing infested field material with clean laboratory plants, but there is a risk of moving natural enemies and competitors with the study mites. Thus it is advisable to establish lab colonies with individuals carefully selected.

Mite Rearing

The establishment of laboratory colonies provides the advantage of always having a population present on which to conduct research. The simplest method is to identify a suitable host plant on which the mites can be established. Once a colony is established, maintenance is done by placing clean plant stock among the infested material, removing the old, deteriorating material. Clean plant stock is necessary because the introduction of natural enemies of the target mite or competitors will cause problems in maintaining large number of test mites. For *A. guerreronis* Moore and Howard (1996) noted that mites can kill coconut seedlings by feeding on the meristematic tissues, thus seedlings may be a suitable host for rearing the mite. Other palm types (for example the queen palm) may be selected for rearing. Additionally, it may be possible to rear the mite on immature coconut fruit. Some eriophyoids (*Phyllocoptruta oleivora* Ashmead and *Aculus pelekassi* Keifer) have been reared on washed green lemon fruit that have been waxed on the ends (Reed *et al.*, 1964). This technique may be adaptable to young coconut fruit to sustain coconut mite populations.

Occasionally it becomes necessary to confine eriophyoids in small areas. This can be accomplished, most easily, by applying a ring of lanolin or Tack Trap to the leaf surface. However, mites frequently become stuck in the confining material. Thus many other confinement techniques have been developed. These vary with respect to materials used (for example tape and plastic), and with respect to using detached leaves or whole plants. These techniques are summarized by Oldfield and Perring (1996).

Conclusion

In this paper, I have outlined ecological interactions that impact plant-feeding mites. By understanding features of this model for *A. guerreronis* on coconut palms, scientists can move closer to establishing a sustainable management program for this devastating pest. I have used the date mite - date palm ecosystem to illustrate the success of this approach in a similar system. Clearly there are unique features of the coconut mite problem that must be elucidated through research. To assist in this effort, I also have discussed some of the techniques that are used to study eriophyoid mites.

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Use of predatory mites for the control of eriophyid mites

G.J. de Moraes and M.S. Zacarias
CNPq-Brazil Researchers; Departamento de Entomologia, Fitopatologia e Zoologia Agrcola;
ESALQ-Universidade de So Paulo; 13418-900 Piracicaba-SP; Brazil

Summary

Under an applied point of view, biological control refers to the use of natural enemies to reduce the population of a given pest species and consequently reduce the damage it causes to a particular crop. In practice, only pathogens and predators have been used in the biological control of pest mites. A relatively small number of projects have dealt with the possible use of predators to control Eriophoidae mites. Observations around the world have indicated significant effect of some species of predators of the families Stigmaeidae, Tydeidae and especially Phytoseiidae against eriophyid pest species. Almost 30 species of phytoseiids have been reported on coconut plants around the world, just a few of which knowingly associated with ***Aceria guerreronis*** *Keifer, an important eriophyid pest of coconuts. The actual type of relation of those predators with* ***A. guerreronis****, and their impact deserve further studies.*

It has been shown that Phytoseiidae mites avoid exposure to direct sunlight, hiding in protected areas of the plant. This fact might be considered positively significant in relation to the control of ***A. guerreronis****, because the latter lives under the bracts of coconut, where phytoseiids could conceivably have good chances of finding and controlling it. Conversely, places occupied by* ***A. guerreronis*** *may be too small for the larger stages of those predatory mites to occupy, except for small and or relatively flat species, as for example some species in the genus* ***Neoseiulus****. Predatory mites of other families cannot be discarded as prospective candidates for the control of the pest. Only field studies in countries where* ***A. guerreronis*** *is found may indicate the potential of the use of predators in controlling it.*

A concerted and comprehensive effort involving investigators from around the world may indicate specific prospective predatory mites to be used to control ***A. guerreronis****. Priority should be given to species associated with low populations of the pest. Those predators should be initially evaluated in the laboratory to determine the suitability of* ***A. guerreronis*** *as a food source for them. Most promising species should be further studied to determine techniques to conserve them in places where they are already present, the convenience of introducing them to areas where they are not found, and the most appropriate rearing and releasing techniques.*

Introduction

Applied biological control refers to the use of natural enemies to reduce the population of a given pest species and ultimately reduce its damage to a particular crop. Biological control has been used for centuries around the world, especially for the control of insect pests. It has been considered a very appropriate technique to control pest species that attack crops in areas that have not traditionally made extensive use of pesticides, for it prevents possible ecological disturbances that could occur with the use of those products, and which could lead to still other pest problems. It is also appropriate for the control of pests on crops of relatively low economic (but frequently high social) value, which could not pay for the use of pesticides.

Applied biological control is normally accomplished through three different strategies, namely conservation, augmentation or classical biological control. The former two refer to natural enemies that are already present in a given region, and correspond, respectively, to the use of agricultural practices that reduce negative impacts on the population of natural enemies or promote their increase in the field, and to the production of supplementary populations under controlled conditions for later field releases. Classical biological control corresponds to the importation, colonization and establishment of exotic natural enemies to control a given pest, which usually refers to a species previously introduced free of effective natural enemies.

Natural enemies of arthropods are generally classified as pathogens, parasitoids or predators. In practice, only pathogens and predators have been used in the control of pest mites.

Eriophyidae is a family of Actinedida, the suborder that contains most of the important mite pests (Krantz, 1975; Amrine and Stasny, 1994). Together with Phytoptidae and Diptilomiopidae, this family constitutes the superfamily Eriophyoidea, whose representatives are recognized by having two pairs of legs in all post-embryonic stages and elongate body. While many species of eriophyid mites live in secluded places, others live exposed onto the surface of different plant organs.

Biological control of eriophyoid mites

Tetranychidae has been the main mite group targeted for biological control, on orchard crops or on crops grown under protected situations (McMurtry, 1991). A recent successful major project involved a species of tetranychid attacking a root crop, cassava (*Manihot esculenta* Crantz), in Africa (Bellotti *et al.*, 1999). Relatively little effort has been dedicated to applied biological control of eriophyoid species, except for efforts toward the use of pathogens for the control of a few species. Other information refers mostly to reports of association of those mites with other natural enemies in the field, or laboratory observations on their suitability as food items to predators.

Few insect groups have been reported as natural enemies of eriophyoid mites. A few species of Chalcidoidea (Hymenoptera) loosely classified as parasitoids have been reported to feed on eriophyoids developing inside protective plant structures (Morgan and Hedlin, 1960; Mezei, 1995). Other groups of insects, especially Diptera (Cecidomyiidae), Coleoptera, Neuroptera, Thysanoptera and Hemiptera have been occasionally mentioned as predators of eriophyid mites, but are generally considered ineffective (Perring and McMurtry, 1996; Ocete and Skuhrava, 1996).

In general, the most common families of plant-inhabiting mites containing species known to prey on other mites are Phytoseiidae, Stigmaeidae, Bdellidae, Cunaxidae, Cheyletidae and Ascidae. Species most commonly reported in association with eriophyoid mites belong to Phytoseiidae, Stigmaeidae and Tydeidae.

Under an applied point of view, eriophyoid species have been mentioned to play a role as alternative prey, maintaining predator populations when the main prey is absent or scarce. One of the best known cases refers to the apple rust mite, *Aculus schlechtendali* (Nal.), an alternative prey of phytoseiid mites that attack important tetranychid pests on apple trees, as summarized by Laing and Knop (1983). A project for the practical use of a phytoseiid mite against an eriophyid mite was conducted in North America, and referred to the importation and establishment of *Typhlodromus rickeri* Chant for the control of the citrus rust mite, *Phyllocoptruta oleivora* (Ashmead) (McMurtry and Scriven, 1964). Several works have been conducted to evaluate the acceptability of different eriophyoid mites as food sources for phytoseiid species, as summarized by Sabelis (1996). Most of the tested eriophyids have been shown suitable food for those predators, while others have not. Sabelis (1996) discussed how eriophyoids survive, despite their vulnerability to predation by phytoseiid mites. Yet, relatively few comprehensive projects have been conducted to control eriophyoids with predatory mites. Just a handful of species have been even superficially studied, despite the major importance of those mites as pests.

Several references on the effectiveness of native stigmaeid species of the genera *Zetzellia*and *Agistemus* in controlling eriophyid mites have been reported by Laing and Knop (1983) and Thistlewood *et al.* (1996). Mites of another family, Tydeidae, have also been reported to prey on eriophyids, especially on orchard and vegetable crops (Knop and Hoy, 1983; Laing and Knop, 1983; Perring and McMurtry, 1996). Hessein & Perring (1986) concluded that the tydeid *Homeopronematus anconai* (Baker) had a significant impact on populations of *Aculops lycopercisi* (Massee) on tomatoes, under greenhouse condition. Perring and McMurtry (1996) considered *H. anconai* to be promising in the control of eriophyid mites.

Perspectives for the biological control of *Aceria guerreronis* Keifer

A. guerreronis is an eriophyid pest of coconut (*Cocos nucifera* L.) described from Mexico and now known to occur in different parts of the world. It has been reported to cause death of seedlings in northeast Brazil (Aquino *et al.*, 1968), but most losses around the world have been attributed to damages to meristematic tissues underneath the bracts on developing fruits (Moore and Howard, 1996).

The basics

Before considering approaches to control *A. guerreronis* biologically, a few questions should be answered. The first refers to the place of origin of *A. guerreronis*. This information is important to determine priority areas to be considered in the search for effective natural enemies. It is expected that those would be found in the place of origin of the pest, for there is where the pest and its enemies have had the longest contact, and where equilibrium between them should have evolved (Van Driesche and Bellows, 1996).

Another important question to be asked is why it became a pest. Moore and Howard (1996) discussed this matter. For many organisms, a definitive answer to this question is not possible. However, an effort in this sense is important, because it may first of all shed light on the possibility to control *A. guerreronis* biologically, and may ultimately indicate the most appropriate strategy to be adopted.

Considering the history of the distribution and damage caused by *A. guerreronis* around the world, the following possible explanations seem plausible. *A. guerreronis* could have been present and maintained under natural control on coconut in a given area for many years, having only recently become a pest, after transported to other areas without the concurrent transportation of effective natural enemies (which could be predators). If such is the case, than a classical approach to biological control would seem opportune, with search of effective natural enemies on coconut, in areas where the mite is found at low levels.

However, it could have become a pest because of a recent adoption of coconut as a new host somewhere in its area of distribution, because of genetic alterations of the mite or to alterations in the cropping systems. Still, the adoption of coconut as a new host could be the result of a recent contact between the mite and coconut. Alternatively, the mite could already have coconut as a host, but started damaging it significantly because of modifications of the environment or of the host plant.

Most eriophyoid mites are quite host-specific. Many species are reported from single hosts or from hosts within single genera. The severe type of damage caused by *A. guerreronis* to coconut, i.e., the death of young plants or the drop of immature fruits, concurrent with the rather quick spread of the mite around the world could indicate that its association with coconut is a relatively recent event.

If the adoption of coconut as a host was achieved because of a relatively recent genetic alteration of the mite, than effective natural enemies that have evolved with it may just not exist, although some natural enemies should eventually adopt the pest as a new host (or prey) at some point in time, and even control it successfully. There are several known cases of generalist predatory phytoseiid mites that play important role in keeping pest mites under control, especially in the Tetranychidae (McMurtry and Croft, 1997). Under those conditions, the study of predators already found on coconut plant, associated with other prey could be appropriate. In reviewing the literature, McMurtry (1992) concluded that in contrast to specialists, generalist phytoseiids seem to show closer association with plant substrates on which they are found, being affected both by their anatomical and physiological characteristics. Actually, because coconut is a perennial crop, the use of generalist predators would seem appropriate whenever the adopted cropping system allows their survival in the field.

In case it became a pest because of a recent adoption of coconut as a new host, due to the introduction of this crop to areas where the mite was attacking its original host, then effective natural enemies may most probably be found on the latter, although it does not mean that effective natural enemies on that host will perform well on coconut. In that case, it could have become a pest by adopting coconut as a new host somewhere in the Americas, spreading then to new areas, including the possible center of origin of the crop in Southeast Asia (Anderson, 1969). Oldfield (1996) reported two eriophyid species that occurred at low population levels on natural stands of native plant species, but reached damaging levels on cultivated plants of that species or on introduced plant species. A similar relationship was reported for the parasitic mite *Varroa jacobsoni* Oudemans and the European honeybee. The former adopted the latter as a new host in Asia and later spread to different parts of the world, including the place of origin of the bee (De Jong *et al.*, 1982).

Lytocaryum wedellianum (H. Wendland) Tol. is the only other plant on which *A. guerreronis* has been collected (Flechtmann, 1989); the mite was found in sheaths and buds of that plant. However, there is no assurance that the mite attacks this plant under natural condition, for it was collected by Flechtmann (1989) in a nursery, and not directly from plants in a natural stand. . *L. wedellianum* is native to the southeastern section of the Brazilian "Atlantic Forest". It is possible that other Arecaceae around the world may also harbor *A. guerreronis*. A project to determine phytophagous and predaceous mite species on Arecaceae in the "Atlantic Forest" of southeastern Brazil has been recently initiated.

However, if *A. guerreronis* became a pest because of changes in plant characteristics, cropping systems etc., then it is possible that effective biological control can only be achieved by turning back to the original situation or by promoting new changes to prevailing cropping systems in order to favor development of the natural enemies (including predators) found in each affected region, i.e., by conservation.

Natural enemies of *A. guerreronis*

Predatory insects and mites have been found associated with *A. guerreronis* in different parts of the world. The selection of natural enemies to be used in a biological control program should be based on ecological studies that demonstrate the species most significantly associated with the pest to be controlled, independently of the group to which they belong. Not too many insects have been reported associated with *A. guerreronis*. An undetermined species of Thysanoptera was reported by Hall and Espinosa Becerril (1981) in Mexico, but was not considered effective.

Mites have been most commonly reported in association with this pest. In the suborder Prostigmata, the Bdellidae mites *Bdella indicata* and *Bdella distincta* Baker and Balock were reported by Mariau (1977) in Benin and Howard *et al.* (1990) in Puerto Rico, respectively. *B. distincta* and *Spinibdella* sp. were reported by Otero Colina (1986) in Mexico. In the family Cheyletidae, a single unidentified species (*Paracheyletia* sp.) was reported by Otero Colina (1986). In the family Tarsonemidae, Estebanes Gonzalez (1976) reported an unidentified species of *Tarsonemus*, but was not able to determine its exact relationship with *A. guerreronis*. Hall *et al.* (1980) observed tarsonemids identified as *Lupotarsonemus* (junior synonym of *Tarsonemus*, according to Lindquist, 1986) from Ivory Coast and New Guinea, feeding on eggs and adults of *A. guerreronis*. The authors did not consider them promising predators of this pest. E.E. Lindquist (*pers. comm.*) believes that those mites could actually belong to the genus *Dendroptus*, which contains species that are suspected to prey on eriophyid mites (Lindquist, 1986). E.E. Lindquist (*pers. comm.*) also thinks that mites in this genus are not promising natural enemies of eriophyid mites. Howard *et al.* (1990) mentioned 3 tarsonemid species on coconut in Florida and Puerto Rico, but not as predators. Cabrera *et al.* (1992) reported a tarsonemid mite identified as *Steneotarsonemus*in Cuba. *Steneotarsonemus furcatus* DeLeon has been recognized as a pest of coconut, causing damages to the fruits that may be mistaken by damage caused by *A. guerreronis* (Ochoa *et al.*, 1991). However, because of considerable similarities, it is possible that some of the mites mentioned in the literature as *Tarsonemus* or *Steneotarsonemus* are actually *Dendroptus* species. Non-identified tarsonemid species were reported by Julia and Mariau (1979).

In the suborder Mesostigmata, Howard *et al.* (1990) mentioned an unidentified species of *Lasioseius* (Ascidae), but did not inform whether it was preying on the pest. Cabrera *et al.* (1992) reported an unidentified species in the same genus as well as the ascid, *Proctolaelaps bickleyi* (Bram). Estebanes Gonzalez (1976) also reported the occurrence of *P. bickleyi*, whereas an unidentified species of *Proctolaelaps* was reported by Otero Colina (1986). Estebanes Gonzalez (1976) found high population levels of *P. bickleyi* associated with high numbers of dead and low numbers of live *E. guerreronis* on coconut in Mexico.

Other Mesostigmata reported in the literature belong to the family Phytoseiidae. Howard *et al.* (1990) reported *Amblyseius largoensis* (Muma), *Neoseiulus mumai* (Denmark), *N. paspalivorus* (DeLeon) and *N. baraki* Athias-Henriot, the former three in Florida and the latter in Puerto Rico. The Florida species were actually observed to prey on the pest. *N. paspalivorus* was also mentioned by Cabrera *et al.* (1992) in Cuba. Estebanes Gonzalez (1976) reported *Typhlodromips sabali* (DeLeon) in Mexico, but believed it was not effective in controlling *A. guerreronis*. Other unidentified species of phytoseiid were reported by Julia and Mariau (1979), Hall and Espinosa Becerril (1981), Rai *et al.* (1991) and Cabrera *et al.* (1992).

Most promising predaceous groups for the control of *A. guerreronis*

Any representative of the groups mentioned in the previous section in association with *A. guerreronis* should a priori be considered for a control program, if additional studies indicate their consistent association with the pest.

Three species of Pronematinae, a tydeid subfamily, were reported on coconut, namely *Pronematulus perpulchus* Tseng and *Parapronematus formosanus* Tseng, by Tseng (1985), and *Pronematus* sp., by Otero Colina (1986). The former two species were on plants apparently not attacked by*A. guerreronis*. The latter species was on plants containing *A. guerreronis*, although the author did not clarify whether the tydeid was associated with it or with other food sources on the same plant. The Pronematinae contains known predatory species (Laing and Knop, 1983). Being commonly tiny, tydeids could have less difficulty than other predators in reaching secluded places occupied by *A. guerreronis* under the bracts of coconut fruits, and should thus be considered for further studies if more careful and extensive evaluations indicate their association with *A. guerreronis*.

However, from the available historic data, and from field observations so far conducted on coconut, it appears that major emphasis should be placed on the use of phytoseiid predators. It has been shown that Phytoseiidae mites avoid exposure to direct sunlight, hiding in protected areas of the plants. This fact might be considered positively significant in relation to the control of *A. guerreronis*, because of its apparent preference for living in secluded places, where phytoseiids could conceivably have good chances of finding and controlling it. Conversely, places occupied by*A. guerreronis* may be too small for the larger stages of those predatory mites to occupy, except for small and or relatively flat species, as for example some species in the genus *Neoseiulus*.

Which species of phytoseiid would be potentially useful in the control of *A. guerreronis*? Table 1 shows species of this family that have been reported on coconut plants around the world. In most cases, however, their exact roles on the plant are not known. They could be feeding on different mite species or on other sources of food as pollen, fungi, etc. (McMurtry and Croft, 1997). As observed on Table 1, some of those species seem to have limited distribution whereas others are rather widespread. Most species mentioned on Table 1 were most probably not associated with *A. guerreronis*, for they were found in regions where *A. guerreronis* was only reported years later, or where it has not been reported yet.

The identified *Neoseiulus* species reported by Howard *et al.* (1990) and Cabrera (1992) are distinctively flat and elongate phytoseiid species, concurring with the small spaces occupied by *A. guerreronis* under the bracts of coconuts. Schicha (1981) compared the morphology of a group of phytoseiids that contained those and 8 other closely related species, which are found mostly on monocotyledoneous and some low herbaceous plants. It would seem that phytoseiids of this group should have priority over other species, considering their activities under the bracts. However, this reasoning should not exclude from consideration other predaceous species, for regardless of having difficulties in reaching *A. guerreronis* on coconut fruits, they may be effective in attacking the pest during its migration. Moore and Alexander (1987) demonstrated experimentally that large numbers of *A. guerreronis* are found on the nut surface, mainly at night. The authors suspect that during the day mites on the fruit surface are more abundant in shaded areas, which are also areas preferred by predaceous phytoseiid mites.

In addition to a consideration of possible species of predators to be used based on literature information, new surveys should be conducted, searching specifically for natural enemies associated with *A. guerreronis*. Searches should consider the prevailing climatic condition at each site, so as to ultimately match source areas with most appropriate release areas, to promote higher chances of survival, establishment and good performance of candidates.

Initially, it is important to estimate the level of *A. guerreronis* in different regions of countries where it occurs, as an indication (though not an assurance) of the effect of the predators associated with it. Areas where *A. guerreronis* is present at low levels may contain efficient natural enemies, some of which may be predators. Conversely, areas with consistently high population of *A. guerreronis* may not have efficient predators under the prevailing cultivation techniques. It should be taken into account, however, that the inefficiency of a natural enemy may be due not to its intrinsic characteristics, but rather to the use of agronomic practices that hamper its action. Aspects that may interfere with the efficiency of a natural enemy present in a given area include morphological or phenological characteristics of the cultivar, presence of alternative plant substrates to the natural enemy in or around the cultivated area, use of pesticides for the control of different pest species etc.

The prioritization of natural enemies to consider in a biological control program is always subject to questioning. Because of the many aspects influencing the performance of a given natural enemy, it has been mentioned that the only way to determine the most effective natural enemy in any given situation is by introducing it to the new environment and analyzing its performance. The selection of natural enemies for a given project is particularly complicated when dealing with predators, given the fact that it is generally difficult to determine its real type of interaction with other organisms. In the case of predatory mites, field observations are often inconclusive because of their very small size. In the laboratory, understanding associations and preferences is difficult because of the artificial set ups that often have to be used for practical reasons. Regardless, some type of selection often has to be conducted because it is usually not possible to conduct extensive studies with wide arrays of candidates. Prospective predators should be evaluated to determine their potential effect on the pest mite, initially in the laboratory through simple tests of the acceptance of *A. guerreronis* as a food source, as indicated by the determination of standard biological parameters.

Table 1: Phytoseiidae mites from coconut plants (*Cocos nucifera* L.)

Species	Where Found	References
Amblyseiulella nucifera (Gupta)	India	1
Amblyseius caudatus Berlese	Mauritius	1
Amblyseius chiapensis DeLeon	El Salvador, Mexico	1
Amblyseius herbicolus (Chant)	Taiwan	1
Amblyseius largoensis (Muma)	Fiji, India, Mexico, New Caledonia, Papua New Guinea, Philippines, Puerto Rico, Tahiti, Thailand, Trinidad-Tobago, USA, US Samoa	1,2,3,4
Amblyseius paraaerialis Muma	India	5
Amblyseius santoensis Schicha	New Hebrides	1
Amblyseius tamatavensis Blommers	New Hebrides	1
Cocoseius elsalvador Denmark & Andrews	El Salvador	1
Euseius alatus DeLeon	Brazil	6
Euseius alstoniae (Gupta)	India	7
Euseius finlandicus (Oudemans)	Mexico	1
Euseius hibisci (Chant)	USA	1
Euseius ovalis (Evans)	India	1
Neoseiulus baraki Athias-Henriot	Puerto Rico	2
Neoseiulus masiaka (Blommers & Chazeau)	Tahiti	1
Neoseiulus mumai (Denmark)	USA	2
Neoseiulus paspalivorus (DeLeon)	Cuba, USA	2,8
Phytoseiulus macropilis (Banks)	Fiji, USA	1,4
Proprioseiopsis pubes (Tseng)	Taiwan	1
Proprioseiopsis solens (DeLeon)	USA	1
Typhlodromalus eucalypticus Gupta	India	5
Typhlodromips sabali (DeLeon)	Mexico	9
Typhlodromips tetranychivorus Gupta	India	1
Typhlodromips vestificus (Tseng)	Taiwan	1
Chanteius contiguus (Chant)	Philippines	1
Galendromus helveolus (Chant)	Mexico	1
Metaseiulus elliptica (DeLeon)	Brazil, Mexico, USA	1
Typhlodromina subtropica Muma & Denmark	USA	1

1- Several authors, as summarized by Moraes *et al.* (1986); 2- Howard *et al.* (1990); 3- Schicha and Gutierrez (1985); 4- Gutierrez and Schicha (1984); 5- Sathiamma (1993); 6- Santana and Flechtmann (1998); 7- Gupta and Gupta (1978); 8/ Cabrera *et al.* (1992); 9- Estebanes Gonzalez (1976).

The most promising species could be further studied to determine techniques to conserve them in places where they already exist, the convenience of introducing them to areas where they are not found, and the most appropriate rearing techniques to allow the production of adequate numbers of predators for releases. The most appropriate techniques will vary according to the intrinsic biological and physiological characteristics of each species.

Mass production of predatory mites

Special care should be taken in the mass production process of predators to prevent their inadvertent selection in the laboratory, which could lead to reduce genetic diversity. Thus, the rearing condition should be compatible with the condition prevailing at the region where the organisms where collected, which in turn should be similar to the condition where they could be released and to the optimal for their development. Thus, whenever possible, the prey used in this process should be the same as the one it is supposed to control in the field, developing preferably on the same plant substrate on which the prey is found on the site of release. Quite often, this is not possible, and an alternative prey or other type of food source has to be used for rearing the predator. In any case, and especially in the latter situation, it is always important to care for the frequent renewal of the stock colonies used for mass production, with populations recently collected in the field.

Phytoseiid mites may be mass produced by several different methods, which were reviewed by Overmeer (1985). The method to be adopted depends upon the biological characteristics of each species. Usually, methods that allow the production of larger amounts of predators are more prone to contamination by other species present in the environment, and thus, those methods are mostly indicated for the final phases of the rearing process, to obtain the individuals that will be released directly into the field. In the initial phases of the rearing process, when any contamination is extremely undesirable, the preferred methods are those that require more care and, consequently, higher maintenance costs.

Release Techniques

Releases should be conducted preferably in fields with a diversity of plant species, including weeds and or other associated or inter-cropped plant species, on which the predator could find refuge and alternative prey when the main prey becomes scarce. Releases should also be done in ecologically distinct areas, to facilitate the initial survivorship in the new environment. Special care should be taken in the case of predatory mites because they do not fly and thus have considerably more difficulties than insects, for example, in finding the opposite sex. Thus, it seems desirable that the releases be more or less concentrated in given fields, and repeated several times during the year. This was the strategy utilized in the project for the biological control of the cassava green mite in Africa (Yaninek *et al.*, 1991, 1998).

Soon after the first releases and repeatedly thereafter, a monitoring system should be initiated, to determine the establishment and dispersal of the released predator.

Conclusions

Not enough is known about the possible use of predators for the biological control of *A. guerreronis*. Available evidences indicate that coconut, the host plant on which the mite is targeted for control, is not its original host. The successful spread of the mite to a wide new area of distribution was possible because of the suitability of coconut as a new host, grown in many different parts of the world. Effective natural enemies, including predators, could be found on the primitive host(s) of *A. guerreronis*, but it is not certain that those will also perform well on coconut. Effective predators may have evolved in areas where the mites first transferred to coconut, and should be found in fields where the mite population is kept low. Where present, generalist predators of areas where the mite last invaded may be shown to play significant role in reducing the level of *A. guerreronis*, and should thus be conserved.

Suggested Priority Studies

- Determination of predators on coconuts, indicating the levels at which associated phytophagous organisms are found but selecting for study fields with both high and low levels of *A. guerreronis*.
- Study of the phytophagous mites and associated predators on other Arecaceae, particularly in the growing tip, flowers and fruits.
- Determination of techniques to rear predators under controlled conditions for initial screening tests and eventual field releases.
- In a second phase, promote field releases of promising species and establish a follow-up system.

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Biological control of the coconut mite *Aceria guerreronis* (Acari : Eriophydae) with the fungus H. *thompsonii* and its possible integration with other control methods

Reinaldo Israel Cabrera Cabrera
Institute for Citrus and other Fruits Research, Havana, Cuba

Summary

The mite ***Aceria guerreronis*** *Keifer is one of the main pests affecting coconut (****Cocos nucifera*** *Linné) plantations in many countries world-wide, including Cuba. This mite causes serious economical losses by reducing the amount and quality of the harvests and by the high levels of damage which in most cases reach up to 100 percent of fruits.*

Chemical control has been found to be too expensive to control this eriophyid, mainly in countries where yields are lower than one ton of copra per hectare.

This led to attempts since the 1980s to control ***A. guerreronis*** *biologically, using the fungus* ***Hirsutella thompsonii*** *and other bioregulators.*

This paper reports on the main features of the biology of ***H. thompsonii****, the influence of climatic factors on this fungus and the basic methods for its mass production, according to results obtained in Cuba. Methods and requirements for field application, its effectiveness as influenced by different factors are also analysed.*

This paper also discusses the integration of ***H. thompsonii*** *with other control methods and the results obtained with the use of this fungus in Cuba for the control of* ***A. guerreronis****.*

Introduction

The mite *Aceria guerreronis* Keifer is one of the main pests affecting coconut (*Cocos nucifera* Linné) plantations in many countries worldwide (Doresne 1963; Garca and Carmona 1968; Mariau 1969, 1977; Zuluaga and Sánchez 1971; Hernández 1977), including Cuba (Estrada and Gonzlez 1975; Cabrera 1982, 1991). The mite causes serious economical losses by reducing the amount and quality of the harvests.

This eriophyid (Fig. 1) produces considerable damage in the State of Guerrero and in other regions of Mexico, where 80 - 100% of the fruits have been affected by this mite (Ortega *et al.*, 1965).

Chemicals have been found to be too expensive to control this mite, mainly in countries where yields are lower than one ton of copra per hectare (Mariau and Tchibozo, 1973). This is basically due to the great number of applications required as a preventive measure, despite the efficacy of some pesticides.

This led to the initiation of a major effort to control *A. guerreronis* biologically, using the fungus *Hirsutella thompsoni* and other bioregulators (Julia and Mariau 1979; Becerra Leor 1983). *H. thompsoni* was considered the fungus with the greatest potential to control this pest successfully (Hall *et al.,* 1980; Cabrera 1982; Espinosa Becerril and Carrillo Sánchez, 1986)

The aim of this paper is to present and discuss the main aspects of the biology *of H. thompsonii*, the influence of climatic factors on its development, and methods to mass produce it, with emphasis on the results obtained in Cuba, requirements for its field application and its interaction with other environmental factors. Levels of effectiveness and factors influencing them are also analysed.

Biology of the fungus H. *thompsonii* Fisher

The biology of *H. thompsonii* has been studied by several authors (Mc Coy *et al.,* 1971; Gerson *et al.,* 1979; Kenneth *et al.,* 1979; Mc Coy 1980; Cabrera 1980; Tuverson and Mc Coy, 1982). The perfect phase of this fungus as well as its habitat where it might occur are unknown. As a non-hypogeous fungus, it is more likely determined by the location of its host mites in any aerial site of the plant.

a. Characteristics of H. thompsonii

The main characteristics of *H. thompsonii* were first described by Fisher in 1950, who illustrated the fungus and described it. According to Fisher, *H. thompsonii* has a white mycelium that later becomes greyish, without synnematas; decumbent and short-septated hyphae 1.7 to 3.3 µm wide; lateral, erect, rigid and hyaline conidiosphores 10.8 to 16.7 m long; phialides 3.3 to 4.4 µm wide and 5.4 to 9.9 µm long (typically attenuated in one or two sterigmas and, sometimes, three); sterigma 1.7 to 6.7 µm long; oval to round shaped apical, hyaline conidia (possibly showing a lemon-like shape due to a gelatinous capsule 2.1 to 3.3 µm wide).

In 1980, Samson *et al.,* , made a second description and illustration of the fungus, proposing three varieties within the same species, based mainly on the morphological characteristics of the fungus: *H. thompsoni* var *thompsonii, H.thompsonii* var *sinematosa* and *H. thompsonii* var *vinacea.* These varieties can show differences with regards to the description made by Fisher according to the coloration, the presence of synnemas, etc. The first two varieties are present in Cuba.

b. Taxonomic classification of H. thompsonii

According to Brady (1981), when Patouillard described the genus *Hirsutella* in 1892, he interpreted its small synnemata with its conidiogenous cells as the hymonium of a basidiomycete. Speare (1920) considered the genus as hyphomycete. This was monographed by Mains in 1951, including only those species bearing synnemas.

Minter & Brady (1980) considered divided the genus *Hirsutella* in two sections, based on the presence or absence of synnemas, and described and illustrated the mononematous (without synnematas), in which *H. thompsonii* was included. According to Roberts (1989),*Hirsutella thompsoni* is classified as:

Division:	Amastigomycotina
Subdivision:	Deuteromycotina
Class:	Deuteromycetes (Hyphemycetes)
Order:	Moniliales
Family:	Moniliaceae
Genus:	*Hirsutella*
Species:	*H. thompsonii* Fisher

c. Way of infection of H. thompsonii

The first symptoms of *Hirsutella* infection are difficult to observe, unless discolouration of mites is observed through bright field or phase contrast microscopy (340x), as at the beginning the fungus develops inside the mite (Fig. 2). The conidium adheres to any part of the mites body and germinates in contact with its cuticle, introducing a germinative tube that penetrates the haemocoel of the host. No preference for a specific kind of tissue is known (McCoy and Couch, 1978).

The conidium requires less than 4 hours to penetrate the integument of the rust mite *Phyllocoptruta oleivora* Ashm, and about 72 hours for the whole infection process to be completed and the fungus to produce conidia at 26 - 27° C (Mc Coy *et al.*, 1972) (Fig. 3). Approximately 9 hours are required for the fungus to develop and to sporulate at 26°C and 100% of relative humidity (Muttah, 1974). The process of infection is very fast and in less than 48 hours the mite dies at about 27° C and high relative humidity.

Maximun infection of mites takes place in the presence of free water on the leaves, but it also occur at 90-100% RH (McCoy, 1978). Mist, dew, frequent rain and a good vegetative development of plantations favours the performance of the fungus (Cabrera, 1980).

Further study on this regard should be made as data shown here are the results of studies carried out with the citrus rust mite *Phyllocoptruta oleivora* (Ash.) and the carmine mite *Tetranychus cinnabarinus* (Boisd.), as we have no reference in this regard in relation to infection on *A. guerreronis*.

d. Biocontrol potential

H. thompsonii is known to infect a great number of phytophagous mites (about 25 species) in different countries, playing an important role in reducing important agricultural pests. (Table 1). Of the five *Hirsutella* species known to attack mites, i.e., *H. brownorum* Minter and Brady; *H. kirchneri* (Rostrup); *H. tydeicola* Samson and Mc Coy; *H. nodulosa* Petch and *H. thompsonii* Fisher, the last four have been reported from Cuba (Cabrera, 1977; Cabrera and Dominguez, 1987a, 1987b, 1988). *H. nodulosa* and *H. thompsonii* have been found to infect *A. guerreronis* (Cabrea 1982; Cabrera and Dominguez, 1987).

Influence of environmental factors

As most fungi, species of *Hirsutella* , are subjected to the action of climatic factors that determine their behaviour and effectiveness; aspects that should be taken into consideration to any biological control or integral management program. There is little information about the influence that climatic factors have on *H. thompsonii* in coconut plantations, as most studies on this regards have been carried out in other kinds of plantation and on other mites; so further research is necessary to clarify what the real situation with *A. guerreronis*.

a. Air relative humidity (RH)

The action exerted by this environmental factor is one of the most important on the behaviour of *H. thompsonii.* High RH (higher than 90%) favours the infection of the host mite by the fungus (McCoy, 1978), while low RH is harmful to *RH. thompsonii*; but a RH between 3 and 8% for 8 hours does not hinder the performance of the fungus, if favourable conditions prevails later (Muttath, 1974; Kenneth *et al.*, 1979). Thus, the fungus has a high survival ability, even at extremely low RH.

b. Free water on plant leaves

According to McCoy *et al.* (1971), free water has a pronounced positive effect on both behaviour and effectiveness of a pathogenic fungus. However, this feature has a lower effect in *A. guerreronis* due to the locations where it develops on the coconut plant.

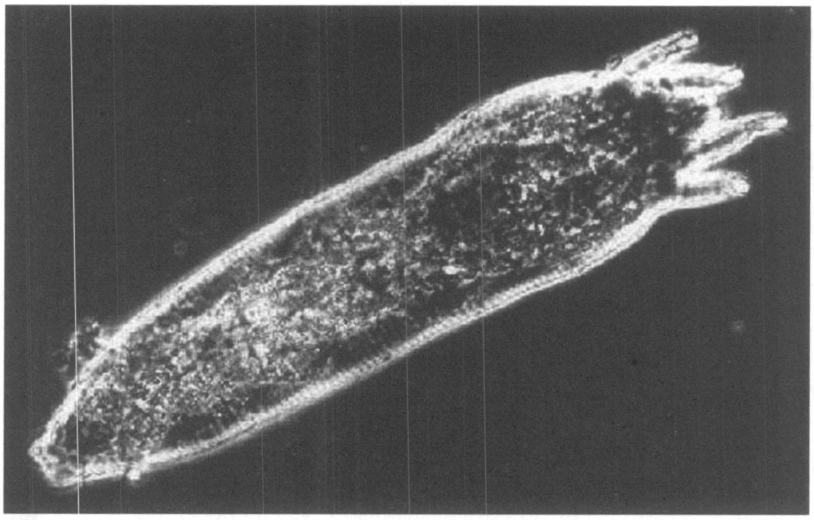

Fig 1. *Aceria gerreronis* under natural development conditions

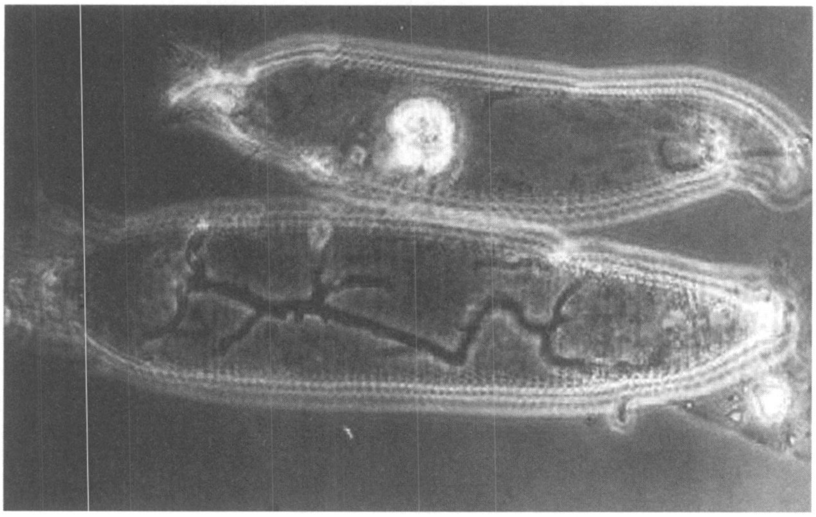

Fig 2. *Aceria gerreronis* with internal mycelium of *H. thompsonii*

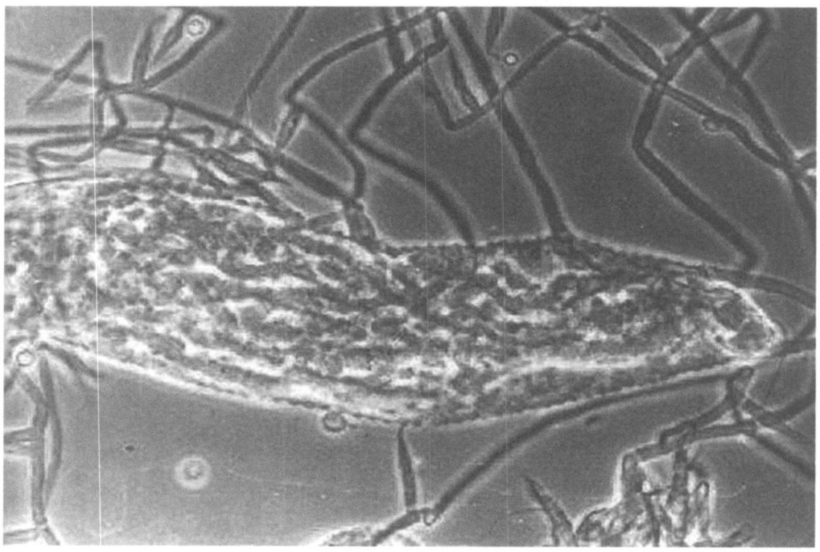

Fig 3. *Aceria gerreronis* with internal and external mycelium of *H. thompsonii*

Table 1: Species of mites infected by *H. thompsonii* under field conditions.

Mites	Host plants	Countries
Phyllocoptruta oleivora	citrus	Argentina, Brazil, Cuba, China, USA, Mexico, Surinam and Viet-nam
Brevipalpus phoenicis	citrus	Cuba and Mexico
Brevipalpus obovatus	citrus	Mexico
Aceria sheldoni	citrus	Cuba
Eutetranychus banksi	citrus	USA
Eutetranychus sexmaculatus	citrus	USA
Lorryia formosa	citrus	Cuba
Tydeus californicus	citrus, guava and mango	Cuba
Aceria guerreronis	coconut	Ivory Coast, Cuba, Mexico and Jamaica
Panonychus citri	citrus	USA
Polyphagotarsonemus latus	citrus	Cuba
Colomerus novahebridensis	coconut	New Guinea
Dolichotetranychus sp.	coconut	Sri Lanka
Ttetranychus cinnabarinus	french bean	Israel
Eutetranychus orientalis	french bean	Israel

c. Dew and mist

Those two factors, along with the good vegetative development of of the plants, also favours the development of infection (Cabrera, 1980).

d. Rain

This factor has not been adequately studied. It is known, however, to affect the fungus by modifying air RH and affecting plant phenology . The effect of rain is conveyed by increased evapotranspiration and the self-shadow of the plants (Cabrera, 1980).

e. Temperature

H. thomsonii is mesothermophyl, with an interval of development between 25-30° C, with optimum at 27 C, although this may vary according to the strain under consideration. The growth of this fungus stops at a minimum of 5° C or at a maximum of 37° C (when its death occurs) (Kenneth *et al.*, 1979 and Mier *et al.*, 1989). Below 5° C or above 37° C, conidiation on dead mites does not occur (Gerson*et al.*, 1979). A rapid conidiation occurs between 18 and 30° C, at adequate humidity. Infection of the mites by *Hirsutella* can occur at 13 and 35° C, although slower than at 27° C (Gerson *et al.,* 1979).

f. Effect of light

According to Kenneth *et al.* (1979), *H. thompsonii* has the ability of regrow, although slowly, after exposed to desiccation and to irradiation with potentially harmful doses of the far spectrum of ultraviolet rays (200-300 nm). This could apparently be the result of the presence of melanin in the cell walls of the fungus. That is why its colonies show no morphological changes when subjected to desiccation and exposed to a far spectrum of ultraviolet rays (200-300 nm) and, after 24 hours, sporulation can occur if they are incubated under common light conditions.

It is essential not to study each factor separately, but the result of their interactions as well as the direct or indirect actions that can occur, what would lead to a complete assessment allowing more precise determination of the causes influencing behaviour of the fungus and its host.

Methods for culturing *H. thompsonii*

Traditionally, *H. thompsonii* has been cultured in many countries, for its study and/or use in the biological control of several phytophagous mites (Mc Coy *et al.*, 1972, 1975; Cabrera and Sampedro, 1992; Cabrera, 1978, 1992, 1995; Latgé *et al.*, 1988). Until now, the most efficient method for culturing or mass producing the fungus is by using the two-phase culture. This method consists of growing *H. thompsonii* first in a liquid medium (submerged culture) (McCoy *et al.*, 1984; Van Winkelhoff and Mc Coy 1984; Latgé *et al.* 1988; Cabrera, 1992; 1995; Rosa *et al.*, 1994), when an abundance of mycelial growth can be observed, and then in a solid medium, where all the strains of this fungus produce conidia (McCoy *et al.* 1978; Gerson *et al.* 1979; Cabrera, 1980; Pereira and Roberts, 1990; Cabrera and Sampedro, 1992). Some strains of the fungus can even produce conidia in the liquid medium.

a. Characteristics of the liquid phase (submerged culture)

In this phase the fungus requires abundant oxygenation, and its production in continuous shaker should be conducted between 180 - 200 rpm (Cabrera, 1995). In the fermentation agent, agitation should be conducted between 900 - 600 rpm, with an aeration between 0,6 and 10,5 litres of air per minute for fermenting agents of 2 and 20 litres of capacity respectively (Latgé *et al.* 1988), although for each kind of fermenting agent and of strain, a particular study should be required. In this phase the fungus requires a carbon source, which could be mainly dextrane or sucrose and a nitrogen source, using peptone and yeast extract (McCoy *et al.*, 1972). An anti-foam agent should also be added (silicon-antischaummittel 426 or another) (Latgé *et al.*, 1988), and the process should run at 25 and 28° C, and pH between 6,0 and 7,5.

b. Characteristics of the solid phase (on solid medium)

During this phase the fungus requires a substrate that is able to absorb the rest of the medium that accompanies the mycelium. After the liquid fermentation the mycelium is exposed to the environmental oxygen that exists between the particles of the solid base (space between solid particles) (Cabrera *et al.*, 1991; 1992; Cabrera and Sampedro, 1992). Some nutrients are needed for the production of conidia, but not at such high contents as in the liquid phase. Good asepsis to avoid contamination, temperature between 25 and 28 C and a pH between 6.0 and 7.5 are required although those conditions could vary slightly according to the strain.

Studies carried out in Cuba have produced promising results in large production of *H. thompsonii* in submerged culture at reduced cost (Figs 4, 5 and 6). High production of conidia have been achieved (3.06×10^8 conidia per millilitre) in 96 hours after fermentation when using the sporulating H77 strain in liquid media, beer must and cane sugar as nitrogen and carbon sources, respectively (Cabrera, 1992). Also up to 1.51 g of mycelium (dry weight) per each 100 ml of the media was obtained after 4 days of fermentation. This led to a reduction of production costs as relatively cheap nitrogen and carbon sources were used.

c. Results of the liquid phase (submerged culture) in Cuba

The following results were obtained in studies carried out in Cuba for large-scale production of *H. thompsonii* and for reduction of production cost. Fig. 4 shows the maximum production of conidia at must concentrations between 50 and 60% volume/volume (V/V) when a sporulating strain is used in a liquid medium. The greatest production of conidia was observed at cane sugar concentrations between 2 and 3% of weight/volume (W/V) (Fig. 5).

Must has a marked effect on conidia production, but yield starts to decrease from the must concentration of 70% (Fig. 6).

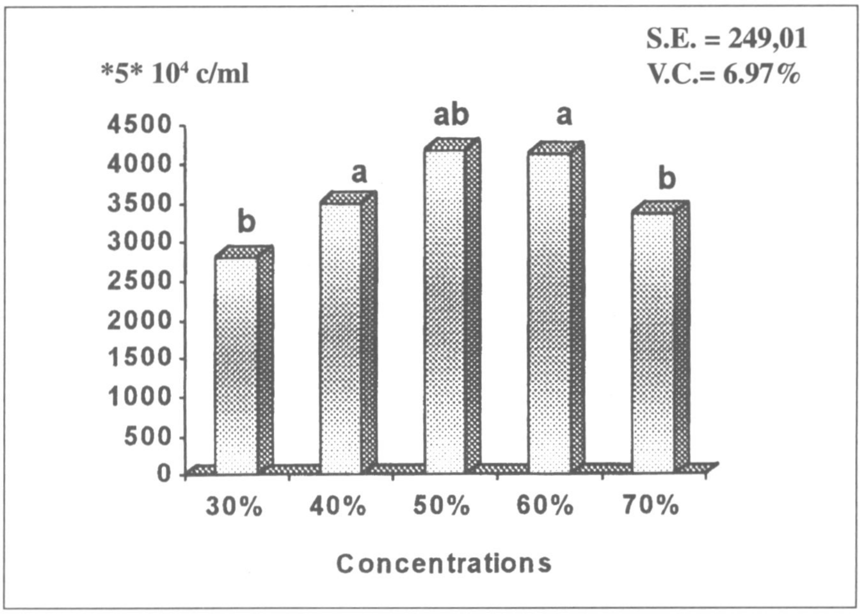

Fig 4. Comparison of different must concentrations during conidiation of *Hirsutella thompsonii* var *thomsopnii* in submerged culture.

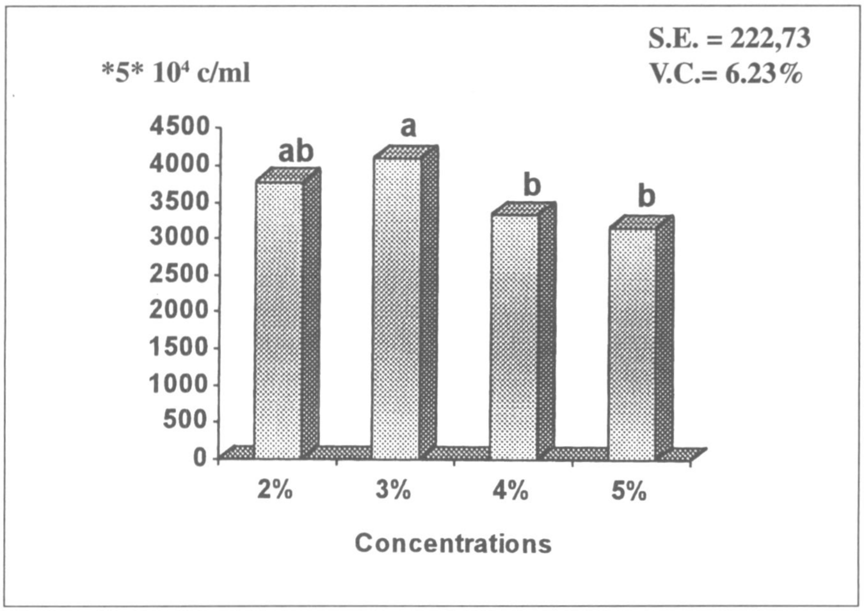

Fig 5. Comparison of different cane sugar concentrations during conidiation of *H. t.* var *thompsonii* in submerged culture

These results showed that;

a. nitrogen source (peptone and yeast extract) can be replaced by beer must; cane sugar can be used to replace dextrose and sucrose to obtain a more economical and efficient culture medium for the production of *H. thompsonii*.

b. beer must-based medium between 40 and 60% v/v and cane sugar between 2 or 3 % w/v can be used for the production of the fungus in submerged culture, which corresponds with the first phase of the two-phase culture (a two-stage fermentation process).

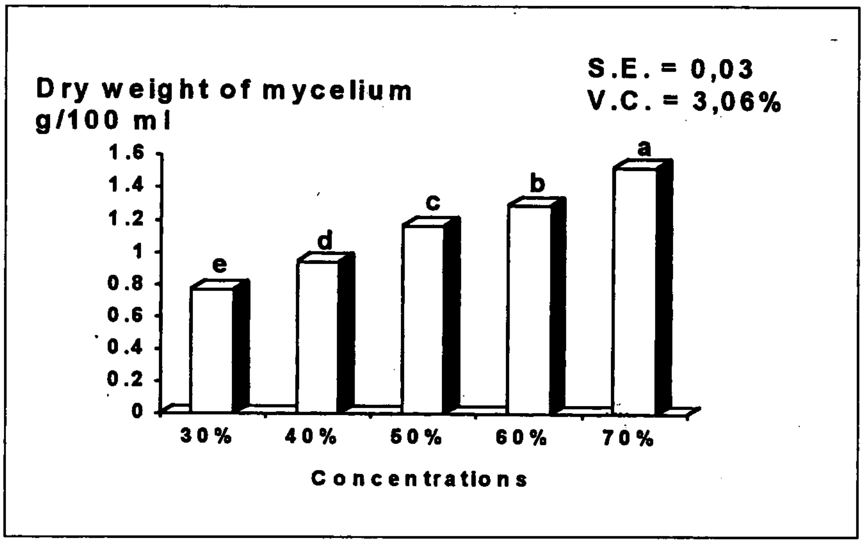

Fig 6. Comparison of different must concentrations in the dry weight of the mycelium of H. t. var thompsonii in submerged culture.

d. Results of the solid phase (on solid medium) in Cuba

The study carried out on large number of solid substrates has proven that their nutritional contents were less important than their structural characteristics and their ability to extract the liquid from the medium next to the fungus' mycelium, once it has been transferred from the submerged to the solid culture in the fermentation process in the solid phase (Cabrera *et al.,* 1991; 1992; Cabrera and Sampedro, 1992) (Table 2).

The results obtained led us to the conclusion good conidiation was obtained in all media (over 10^9 conidia/1 l flask), between 6 and 12 days after inoculation of the fungus. Besides, combination of substrates can be done to reduce the use of expensive reagents; bran can be used as a culture medium for the mass production of this fungus in fermenting agents of solid phase.

Table 2: Solid media with agar and bran without agar used in the production of *H. thompsonii.*

1		2		3		4
Barley	10%	Barley	10%	Barley	4%	Bran
Molasses	8%	Sugar	3%	Must	500 ml	(Barley
Must	500 ml	Clay	5%	Starch	2%	residue in
Agar	0,5%	Agar	0,5%	Agar	1%	beer
Water	500 ml	Water	1000 ml	Water	500 ml	production)

Field application of *H. thompsonii*

This fungus has been applied in the field mainly to control the citrus rust mite, *P. oleivora* (McCoy *et al.*, 1971; 1975; 1982; Cabrera *et al.,* 1981) and less commonly to control *A. guerreronis* (Espinosa and Carrillo, 1986; Súarez González *et al.*, 1989). The fungus has been applied as mycelial fragments or mainly as conidia.

a. Field application of the fungus

According to the formulation, fragmentation and filtration of the fungus, it can be applied by any of the following ways:

I. hand gun or motor spray systems in new plantations; ground-based high-pressure sprayers equipped with hoses and trigger handguns; airplanes or helicopters mainly for large plantations.

II. The fungus will be sprayed as a conventional chemical pesticide; the unique requirement for this procedure is that the equipment used be provided with a constant agitation system (Cabrera and Sánchez, 1992).

b. Requirements for field application

The requirements for application of *Hirsutella* are very similar to those for other fungi used in biological control or integrated pest management programs. In the case of this mycoacaricide, applications should be carried out preferably late in the afternoon to avoid the initial effects of ultraviolet rays, high temperatures, etc. The biopreparation should not be mixed with any chemical pesticide (until its compatibility with this fungus is proven). The product should be filtered so that it can be applied with any conventional application technique. The addition of an adjuvant such as nu-film or any other to protect the fungus from adverse climatic conditions is desirable (Cabrera and Sanchez 1992; Suarez Gonzalez *et al.,* 1992).

c. Dosage of the biopreparation (mycoacaricide)

The dosage of any biopreparation will depend on the content of its active ingredient (infective particles or colony/ml-forming units) and the goal is to achieve sufficient colonization for microbial action. In Cuba, Suárez González and Almaguel (1992) recommended a dose of 109 conidia per plant in a final solution of 1.5 to 2 liltres/plant for the control of *Aceria guerreronis* (Cabrera and Sánchez, 1992). For air applications it is necessary to study the final solution as well as its effectiveness.

d. Time of the application

The time of application of *H. thompsonii* should be determined through the study of the mite's population dynamics, so that the biopreparation is used when the mite population is rising and conditions are favourable for the development of the fungus.

Under the Baracoa conditions, Cuba, the time of application for *A. guerreronis* is from May to August, if necessary (Suárez González and Almaguel 1992).The biopreparation is used as a common mitecide or it is applied to colonize and/or to restore the fungus in areas requiring it.

e. Index of application

The index of application of *Hirsutella* against *A. guerreronis* is an average of one or more mites per bract or fruit, when natural infection is lower than 20% of the mites. Such index is subject to change, according to the time of the year, the climatic conditions and the susceptibility of the coconut variety (Súarez González and Almaguel, 1992).

f. Calculation of the effectiveness of the fungus

There are many ways, formulae and scales to calculate the efficacy or effectiveness of an application, but the percentage of infection is still a practical way to evaluate the performance of any bioregulator. It can be calculated as:

Percentage parasitism = A/B x100 (A = total of parasitized mites, B = total number of mites observed)

Effectiveness of the fungus to control mites

Espinosa Becerril and Carrillo Sanchez (1986), made applications of Mycar® (a biopreparation of *H. thompsonii*) in Mexico and concluded that a 36,7% of the fruits tested showed infected mites, with a mortality rate varying from 25 to 75%.

Suarez *et al.* (1989) obtained an infection rate of up to 75% (85.6 - 97.5%) in Cuba, after 60 days of the application of a biopreparation based on *H. thompsonii* produced by Cabrera and others. A subsequent reduction of the intensity of attack by *A. guerreronis* followed, with an increase in yield and fruit quality.

There is still much to be clarified about the effectiveness of the fungus under field conditions. Even though promising results have been achieved in certain regions, the performance of the fungus may be different in other regions, depending on factors such as *H. thompsonii* strains used, the prevailing climatic conditions, variety of coconut plants, cultivation practices (monocrop or intercrop), the flora and fauna of each region and the time of application of the fungus.

Survival of *H. thompsonii* in the field

Sampedro and Rosas (1988) pointed out that under Acapulco conditions (Mexico), this fungus persisted in the field for more than 5 months in both 1988 and 1989. Not enough information is available in this regard, and in our opinion, a broader research is needed to determine the real survival of the fungus under conditions of different regions or countries.

Integration of *H. thompsonii* with other control methods

In 1991, Cabrera pointed out that biological control, selective chemical control, phytotechnics, intercalated culture and varietal resistance should be taken into consideration for a complete study of this mite. The author based his suggestions on his practical experiences in Cuba.

The greatest difficulty relates to the considerable number of applications required of otherwise effective pesticides, as Morestan and Nuvacron effective (Mariau and Tchibozo, 1973). Repeated applications have been shown necessary because of the characteristics of the pest and the crop.

Modified cultivation techniques were proposed by Súarez González *et al.* (1989) in Cuba, involving the removal of remains of previous harvests (old leaves, dry parts of plants, and bunchs with more than 50% of the fruits damaged by the mite), intercrop with cacao, improved culturing techniques and application of *H. thompsonii*.

Promising results were achieved, with remarkable reduction of the mite population and an outstanding quantitative and qualitative improvement of the harvest. Higher percentage of parasitism of the mite by *H. thompsonii* was obtained, what lead us to consider this experience as very positive, mainly in the most humid areas of Cuba.

Subsequent research carried out by Cabrera and Diaz (1995) consisted of selecting a coconut plantation to subject to different measures, viz. removal of dry parts of the plants and fruits affected by the mite, one application of chemical pesticides (Neoron 50 EC) and maintenance of traditional culturing techniques. When the first bunch were ready to be harvested and recollection began every one or two months in each plant, undamaged fruits and fruits damaged by A. *guerreronis* were evaluated to determine the level of damage. The results of this study are shown in Figs. 7 and 8.

The number of fruits damaged by *A. guerreronis* was reduced from 82.7% to 33% after 18 months. In addition, the level of damage of the fruits was much lower than before. The number of damaged fruits varied with time. Figure 8 shows that the percentage of damaged fruits was different for each plant, with values fluctuating from 3 to 5% during the 22 months that the test lasted. There were coconut palms that did not show damaged fruits for almost a year, and after two years damage by the mite was minimal. The level of infection by *Hirsutella* was enough to contribute to the reduction of the increase of the population of *A. guerreronis*. Those results indicated that the application of the fungus within a program of integrated management can play an important role in controlling the mite, in association with the effect of other natural enemies.

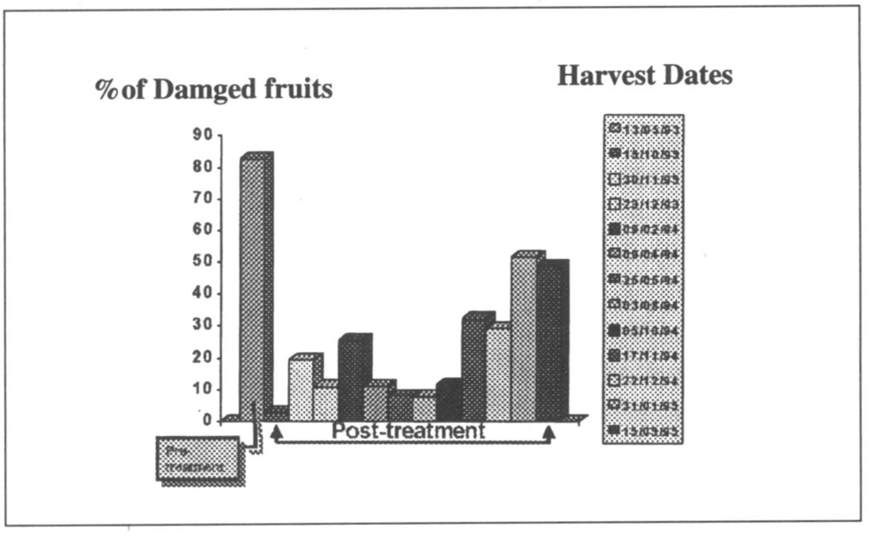

Fig 7. Percentage of the number of fruits damaged by *A. guerreronis* before and after the test (22 months)

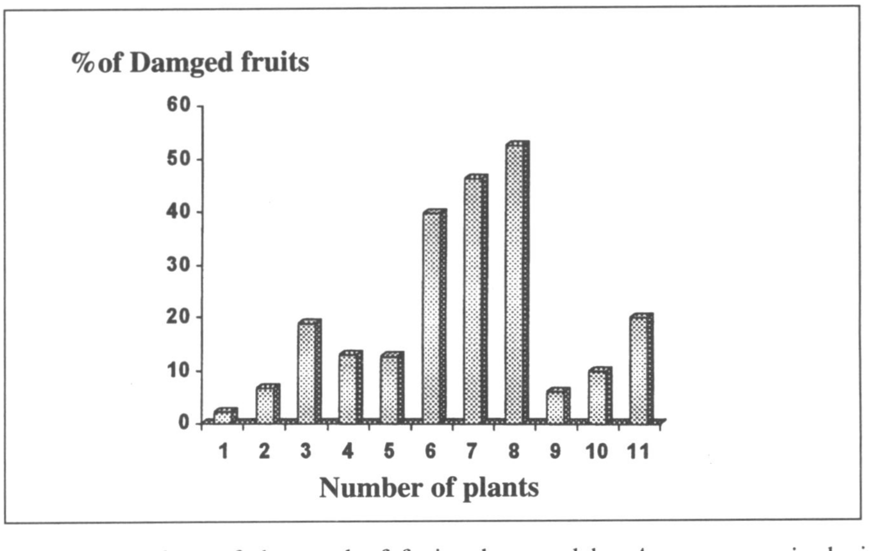

Fig 8. Percentage per plant of the total of fruits damaged by *A. guerroronis* during the test (22 month)

Natural enemies of A. *guerreronis* in Cuba

Table 3 shows the natural enemies of *A. guerreronis* which represent very important biological restraint to this pest in Cuba (Cabrera *et al.* 1992).

Table 3: Natural enemies of A. *guerreronis* in Cuba

Fungi	Insects	Mites
H. thompsonii Fisher *H. nodulosa* Petch	*Entomobrya* sp.	*Neoseiulus paspalivorus* (DeLeon) *Neoseiulus sp.* *Lasioseius sp.* *Amblyseius* (probably)

Conclusions

- After 37 years of its first appearance in Mexico, the mite *A. guerreronis* continues to be a serious coconut pest in America and Africa. Its recent appearance in Sri Lanka and India represents an important threat for the coconut plantations in those countries.
- The characteristics of both pest and crop make it difficult to establish an economical Integrated Pest Management (IPM) or an Integrated Crop Management (ICM).
- Most research on *H. thompsonii*, with regards to field applications, have been carried out on citrus and to a lesser extent on coconut mites; more research is needed in relation to the latter pest.
- Aspects such as the real effectiveness and persistence of this fungus under field conditions in each country, its presence as well as that of other biological control agents in each territory, the regulating effect that these agents have within the integrated management programs require a deeper and complete study.
- Advances in the knowledge of *H. thompsonii*, especially in relation to techniques for its mass production at low cost and its integration with other control methods broaden the perspectives of using the bioacaricide against *A. guerreronis*.
- Until now, the use of this mycoacaricide in the most humid regions of each country, alone or combined with other measures or methods of control, represents the most promising alternative for the control of *A. guerreronis*.
- Drier zones will require a set of measures and methods of control, including selective chemicals, which allow the preservation of natural enemies of *A. guerreronis*.
- Establishment of a research program will be required to focus on the study of this mite in an integral way as well as on the most effective and economical ways of controlling it. Features such as natural enemies, fertilising, varietal resistance, culturing techniques and the study of new chemical pesticides, among others should also be studied.

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Questions and discussion : Papers by experts

Paper: D. Moore

U. Pethiyagoda : Considering the nature of pollination in coconut, each nut is the result of a different pollination and hence breeding for resistance to *Aceria* is far from reality.

P. K. Koshy : The hybrid coconut variety Chowghat Green Dwarf x West Coast Tall is tolerant to Root Wilt disease but in turn it is more susceptible to *Aceria*. Therefore, breeding for resistance has to be carried out in a larger context.

W. Modder : It looks like breeding for resistance to *Aceria* is out of scope. Is mycopesticides feasible? Is it economical?

T. Perring : Use of mycopesticides has a good potential and breeding too is a good long-term strategy.

Paper : T. Perring

W. Modder : The need for developing an ecological model of *Aceria* is important to develop an effective control strategy by disrupting its ecosystem.

K. Ramaraju : There are two types of eriophyid mites. How can you differentiate between the two types by the damage?

T. Perring : The best way is to look at the morphology of the mite.

K. Ramaraju : *Aceria guererronis* lives underneath the perianth. Therefore the damage is visible after few months of infestation. In such a situation how could you detect an infested nut?

T. Perring : It is not easy, unless you detach the perianth and look for the mite underneath it. Otherwise, you have to wait until the damage starts to appear.

M. A. Haq : Is there any possibility of identifying the nut infestation before the damage symptoms appear as triangular patches?

T. Perring : Damage is the only method of identifying the infestation, unless you detach the perianth of the fruits you want to check.

C. P. R. Nair : After 5-6 months of continuous infestation the mites often disappear even without any control measures. How can this be explained?

T. Perring : It is likely that too much damage to the palm triggers the mite to leave the host. DNA technology can be used in this instance to check single or multiple infestations.

Paper : G. de Moraes

P. K. Koshy : What are the chances of using entomophilic nematodes as biological control agents? They may be good because they can easily enter the perianth because of their small size, and they have the capacity to search for prey. They can survive better under humid tropical conditions.

G. de Moraes : There are no reports of any such attempts. However, it looks a possibility that could be explored.

C. P. R. Nair : What are the symptoms of *Aceria* infestation on *Cocos weddelliana* palms?

G. de Moraes : There was actually no clear symptoms. The mite was accidentally found when nematologists were examining some samples of this plant.

K. Ramaraju : There are three factors that limit the use of predators for the control of eriophyid mites: viz *Aceria* lives inside the perianth, they are very small size and produce toxic compounds.

G. de Moraes : These factors could probably limit the use of predators for the control of *Aceria.* Looking for predators that require less food is a possible way of solving the problem. *Aceria* come out from the perianth at certain times of the day. The predators can attack them in those instances. Hence, should look for a predator with potential to feed on *Aceria guerreronis*

K. Ramaraju : Can you give an example of a predator that can do well on an eriophyid mite?

G. de Moraes : Yes. We have conducted some studies on tomatoes concluding that *Euseius concondis*, a predatory mite of the family Phytoseiidae, feeds well on the tomato russet mite in Brazil.

K. Ramaraju : Is the prey an exposed mite?

G. de Moraes : Yes.

C. P. R. Nair : Coconut is not the primary host of *Aceria guerreronis.* Is *Cocos weddelliana* its primitive host?

G. de Moraes : We cannot say anything in this regard. It would have been excellent if we had had the chance to study the mite fauna in the native vegetation before the problem with coconut first appeared.

M. A. Haq : Is there a possibility of host switching?

G. de Moraes : No evidence in literature that this happened in this case, but it seems possible.

M. A. Haq : The idea of using nematodes as biological control agent is a welcome venture because there are evidences of two species of nematodes acting as control agents for vector mites.

D. Ahangama : Can you comment about the race specificity of predatory mites.

G. de Moraes : Species in the genus *Phytoseiulus* seem to be the most specific, preying only on Tetranychidae mites. Most other species studied so far have shown to be generalists. Good information on this regarded was recently published by Croft & McMurtry.

M. A. Haq : What are the common predatory mites found under the bracts in Brazil?

G. de Moraes : No detailed study has been conducted so far in Brazil.

P. Fernando : What is the possibility of using *Neoseiulus. paspalivorus* as a biological control agent?

G. de Moraes : *N. paspalivorus* or a species similar to it has been mentioned in several places as a common associate of *A. guerreronis*. This seems to be an important species to be conserved in places where it is already found, for being so common on coconut in different places.

J. Edirisinghe : Could you comment on methods for conservation of predatory mites.

G. de Moraes : Have to use less chemicals and strategies differ for each species.

Paper : R. I. Cabrera

D. Ahangama : What is the effect of *H. thompsonii* on the predatory mites of *A. guerreronis.*

R. I. Cabrera : Sufficient information is not available.

K. Ramaraju : How many applications of *H. thompsonii* are required to contain the mite?

R. I. Cabrera : In Cuba since it is more humid one application is sufficient, but in dryer conditions more applications may be needed. However, it is necessary to try all possible methods of control.

R. Rajapakse : Although several fungi have been found to be effective under laboratory conditions, it has not been effective in controlling the pest under field conditions. Based on this evidence, have we come across any fungus in Sri Lanka that is infectious to *Aceria*?

P. Fernando : Yes. We have found *H. thompsonii*. However, this was parasitic on *Dolichotetranychus* sp., another mite infesting coconut.

R. Rajapkse : Is it possible to combine the fungi with other pesticides to make the control programme more effective?

R. I. Cabrera : Fungi are very susceptible to most acaricides but it can be used in combination with some of them.

C. Jayasekara : Under Sri Lankan conditions, in areas where the mite infestation is prevalent the temperature rangeis 17 35° C and during the daytime it can be as high as 40° C. Can the fungus survive under such drastic conditions?

R. I. Cabrera : The fungus can survive under the given temperature range. Survival is possible even at 37° C in the general environment, because the microenvironment underneath the bract is maintained at a lower temperature.

N. Kumarasinghe : In sugar cane, mite is an occasional pest and was found first in 1987 and again in some areas as pockets. The mite was contained by collecting and burning. A fungus *H. citroforma* was isolated and cultured. In case of coconut mite it is important to find whether it is indigenous or not. It is also worthwhile to study the distribution in all coconut plantations even if the damage is not visible.

K. Ramaraju : In Tamil Nadu we have isolated a strain of *Hirsutella* fungus and studies on these are in progress.

G. M. Nair : We are also proceeding with similar studies.

D. Ahangama : Are there any commercial preparations of the fungus?

R. I. Cabrera : Few years ago there were but not at the moment.

D. Ahangama : What is the shelf life of the harvested spores?

R. I. Cabrera : In solid preparation it is 10 - 15 days.

T. Perring : Is *Entomobrya* sp. a predator?

R. I. Cabrera : Yes. It is a predator which can attack the mites when it is outside the perianth. It is a very strong feeder of *A. guerreronis.*

U. P. de S. Waidyanatha : Can removal of the harvest and sanitation reduce the infestation by 50%?

R. I. Cabrera : Removal of all infested and suspected nuts can reduce the infestation by a considerable extent.

Plenary Discussion

T. Perring : It is important to study the biology of coconut mite at the time of dispersal i.e. when it leaves the perianth. There may be many physiological factors involved. Based on this, control strategies could be developed in two ways. (1) to avoid mites getting back under the perianth and (2) to avoid them leaving the infested nut. The latter has a very low possibility. Therefore, it is important to find answers for the following: How many mites develop under the perianth and how long are they going to be there? What would be the population remaining inside the perianth when the mite leaves the fruit?

P. Fernando : Dr. Moore, U.K. has observed that mites come out of the perianth every day between 2 6 a.m. and do not get back. This occurs continuously almost every day. The reason for this is not known but could be due to physiological factors.

K. Ramaraju : The previous comment that mites leave the perianth around 2 - 6 a.m. is doubtful because it was based on a laboratory investigation. Our observation also shows that they leave the nuts, but more field level studies are needed to confirm this.

T. Perring : Is there a distribution curve or a population curve?

P. K. Koshy : When nuts become mature the mites go in search of fresh, tender nuts. The tissues in the mature nuts become lignified with high tannin content, making it unsuitable for feeding.

C. P. R. Nair : In a single bunch all nuts do not show the same degree of infestation. The number of lesions varies from 1 - 8.

C. Jayasekara: The size of the nut at the time of infestation can have an impact on the damage, because the photosynthesis that takes place in the nut itself is contributing for its development. The nut size can be reduced as a result.

M.A. Haq : Preference of mites for a specific tissue depends on different components of the meristematic tissue. A correlation with cellulose is likely to exist.

C. Jayasekara: Another factor that may be contributing to the above behaviour (leaving nuts between 2 - 6 a.m.) of mites may be the saturation of the nut with food and water during the night providing sufficient food for the nuts. As a result, the mites may become more active.

R. I. Cabrera : The infestation depends on many factors such as variety, physiological status, age of the plantation, age and shape of fruits etc. Wind conditions and sunlight also affect the dispersion of mites. Mites leave the nut six months after the infestation, during which both vertical and horizontal dispersion may occur. In a plantation the horizontal dispersion may occur almost every day. Infestation may not occur at all places in a similar manner. Where natural enemies exist, infestation may not occur. Same factors could also effect the dispersion of natural enemies.

K. Ramaraju : What is the shape of the nut in resistant coconut cultivars in Cuba?

R. I. Cabrera : Round in shape. In Cuba this variety is called Yellow Indian Coconut. It is important to look at the specific characters of the variety and also local conditions in which it is grown.

K. Ramaraju : Infestation can be seen in both well-managed and neglected plantations.

R. I. Cabrera : The most important factor is the combined effect of variety and the environment i.e. the natural enemies.

R. Rajapakse: We should study the population curve with the growth of the nut.

P. K. Koshy : Chaughat Orange Dwarf, which is mainly used as tender nuts, has more resistance. Its hybrids too show more resistance to *A.guerreronis*.

D. Ahangama: Is there a relationship between the palm height and mite population? Why is *A. guerreronis* spread more rapidly in India than in Sri Lanka?

R. I. Cabrera : The reason may be the differences in varieties, natural enemies and level of the mite population.

G. M. Nair : Yes. Height does have an effect on the dispersion as all tall palms of West Coast Tall have escaped the infestation. However, we have to be very cautious in making generalizations.

G. de Moraes : In Brazil there is a belief that Tall varieties are more resistant than Dwarfs and also that their hybrids are relatively resistant.

U. P. de S. Waidyanatha: Is the stress predisposing or aggravating the mite infestation?

C. P. R Nair : In India the symptoms are more intense. Can this be due to the variety?

P. Fernando : The symptoms are similar in Sri Lanka and India but different to that in Cuba.

J. Edirisinghe : As we know the mite is wind-borne and climatic conditions may be main factors affecting the dispersal. What are the factors other than wind barriers that control the dispersion?

M.A Haq : Temperature has a linear relationship with the dispersal.

P. Fernando : In addition, humidity and shade are predisposing factors for the infestation in Kalpitiya area.

S. Vitharana : This looks very complex and you cannot single out any factor because many factors interact. Thats why the expression of the problem differs in different countries. The microclimate definitely plays a major role in mite infestation. The behavior of predator mites in relation to movements of pest inside the perianth is also an important aspect to study.

U. P. de S. Waidyanatha: The climate is more or less constant inside the perianth. The mite decides to leave the bract when there are no resources inside. Is there any impact from environment factors to cause the mite coming out of the bract?

T. Perring : There is a tremendous amount of academic issues in the dispersal of mites that has to be considered. Do they migrate at specific times? Is it a continuous stream? What time the mites come out of the fruit? Is there a difference at certain times compared to a specific time?

Recommendations

At the plenary discussion, considering the gradual spread of the mite over the past two decades and thus the potential threat to the coconut industry in future, the participants agreed on the urgent need to launch a collaborative research programme at an international level to develop effective control strategies. Accordingly, the specific areas for further studies were identified and priorities were set up as given in the proceeding section with a view to drawing up a suitable research programme. The group emphasized the need to seek the support of international funding bodies to obtain financial assistance to launch the research programme.

SESSION 3
RESEARCH PRIORITIES

CHAIRPERSON : J. P. EDIRISINGHE

Discussion on priorities for future research needs

The following themes were discussed by four groups of participants to identify priorities.

a. Biology and ecology of *A. guerreronis*
b. Use of predators in the control
c. Use of pathogens in the control
d. Crop loss/damage assessment and chemical control

Biology and ecology

Many gaps in the knowledge of biology and ecology of *A. guerreronis* exist. Therefore important areas were discussed.

Rearing of *A. guerreronis* in the laboratory would be required for many biological studies. Possible techniques using button nuts, immature leaf tissues and meristematic region were identified. Knowledge of the relationship of mite migration with the age of nuts, stage of the pest and the time of the day were identified as useful in designing control methods. The techniques to assess migration were discussed. This included use of sticky traps, spore traps, pollen traps and washing of nuts and examining mites. Aspects related to the feeding of mites such as causes of necrosis due to damage, influence of nut colour on feeding and estimation of mite population on a nut with respect to the area damaged was found important. It was identified that development of field sampling techniques to determine population dynamics and select suitable infested nuts for different studies will be extremely important. Studies on inter-palm and intra- palm distribution of mites will be a prerequisite for such studies.

Use of predators

Use of predators for the control of *A. guerreronis* has not been addressed in the past, hence would be a new area of study. The studies would involve local surveys in infested and uninfested areas, identification of predators, selection of prospective candidates, mass rearing and field releases of predators. Methodologies for the studies were discussed. It was suggested to explore the possibilities of introducing exotic predators if local predators are not successful.

Use of pathogens

The prospects of using entomopathogenic fungi has been encouraging and studies overseas are progressing. It was suggested to identify local strains of *Hirsutella thompsonii*. Several aspects on culturing the fungus, pathogenecity studies and field application were discussed.

Yield loss assessment and chemical control

Methods are available to assess crop loss based on harvest records. However, determination of economic threshold level would be important in application of control measures. It was suggested that development of user-friendly application techniques such as soil application, root feeding and convenient methods for spray applications are extremely necessary, since the present practices of chemical control is environmentally hazardous, uneconomical and impractical in the long term. Studies of other associated factors viz. nutrients, stress, secondary infections and ecological issues were discussed.

Priorities

Laboratory work

1. Laboratory culturing of *A. guerreronis*
2. Laboratory culturing of predatory mites
3. Laboratory culturing of pathogens
4. Damage scoring of nuts
5. Determination of the efficacy of predators and pathogens

Field work

1. Field surveys
   a. for predators and pathogens
   b. distribution of mites
2. Field sampling
   a. *A. guerreronis* and predator
   b. Nut loss assessment
3. Application techniques of chemicals
4. Determination of economic threshold level

Appendix: List of Participants

Professor Thomas M. Perring
Professor of Entomology
Department of Entomology,
University of California,
Riverside, CA 92521
USA
Tel.: (909) 787-4562
Fax: (909) 787-3681
E-mail: perring@mail.ucr.edu

Professor G. J. de Moraes
Depto. de Entomologia,
Fitopatologia e Zoologia
Agricola, ESALQ-USP, 13418-900
Piracicaba, SP
BRAZIL
Tel.: (55) 19-429-4260
Fax: (55) 19-429-4338
E-mail: gjmoraes@carpa.ciagri.usp.br

Dr. R. I. Cabrera Cabrera
Ave. 7ma No 3005, entre 30 y 32
Playa La Habana
Codigo postal 11300
CUBA
Tel.: (53 7) 293585
Fax: (53 7) 246794
E-mail: iicit@ceniai.inf.cu

Dr. C.P.R. Nair
Principal Scientist
Central Plantation Crops Research
Institute, Regional Station
Kayangulam 690533, Kerala
INDIA
Tel.: (91) 0479-442160, 442104
Fax: (91) 0479-445733
E-mail: cpcri-kygm@x400.nicgw.nic.in

Dr. K. Ramaraju
Associate Professor (Entomology)
Department of Agricultural Entomology
Centre for Plant Protection Studies
Tamil Nadu Agricultural University
Coimbatore - 641 003
INDIA
Tel.: (91) 0422-431222
Fax: (91) 0422-431672
E-mail: drtnau@md3.vsnl.net.in

Dr. P. K. Koshy
Head, Central Plantation Crops Research
Institute, Regional Station
Kayangulam 690533
INDIA
Tel.: (91) 0479-442160, 442104
Fax: (91) 0479-445733
E-mail: cpcri-kygm@x400.nicgw.nic.in

Dr. G. Madhavan Nair
Professor and Head
Department of Agricultural Entomology
Vellayani P.O. Trivandrum 695 522,
INDIA
Tel.: (91) 0471- 480158/ 322397
Fax: (91) 0471-480239
E-mail: kauvly@giasmd01.vsnl.net.in

Dr. M.A. Haq
Professor, Division of Acarology
Department of Zoology
University of Calicut
Kerala 673635
INDIA
Tel.: (91) 0494-400505
Fax: (91) 0494-400269
E-mail: haq@md3.vsnl.net.in

Dr. K. Arulmozhi
Director of Agriculture
Chepauk
Chennai- 600 005
Tamil Nadu
INDIA
Tel.: (91) 044- 8521998
Fax: (91) 044- 8524894
E-mail: diragri@hotmail.com
diragri@sectt.tn.nic.in

Dr. U.P de S Waidyanatha
Chairman, Coconut Research Institute
Lunuwila
SRI LANKA
Tel.: (94) (0)31-55300/ (0)1- 253795
Fax: (94) (0)31-57391
E-mail: dircri@sri.lanka.net

Dr. C. Jayasekara
Acting Director
Coconut Research Institute
Lunuwila
SRI LANKA
Tel.: (94) (0)31-55300/ (0)1- 253795
Fax: (94) (0)31-57391
E-mail: dircri@sri.lanka.net

Dr. L.C.P. Fernando
Head, Crop Protection Division
Coconut Research Institute
Lunuwila
SRI LANKA
Tel.: (94) (0) 31-55300/ (0)1- 253795
Fax: (94) (0) 31-57391
E-mail: rescri@sri.lanka.net

Mr. I. R. Wickramananda
Entomologist
Crop Protection Division
Coconut Research Institute
Lunuwila
SRI LANKA
Tel.: (94) (0)31-55300/ (0)1- 253795
Fax: (94) (0)31-57391
E-mail: rescri@sri.lanka.net

Mr. H.T.R. Wijesekara
Pathologist
Crop Protection Division
Coconut Research Institute
Lunuwila
SRI LANKA
Tel.: (94) (0)31-55300/ (0)1- 253795
Fax: (94) (0)31-57391
E-mail: rescri@sri.lanka.net

Mrs. N.S. Aratchige
Entomologist
Crop Protection Division
Coconut Research Institute
Lunuwila
SRI LANKA
Tel.: (94) (0)31-55300/ (0)1- 253795
Fax: (94) (0)31-57391
E-mail: rescri@sri.lanka.net

Professor J. P. Edirisinghe
Department of Zoology
Faculty of Science
University of Peradeniya
Peradeniya
SRI LANKA
Tel.: (94) (0) 8-388018/ 388693
Fax: (94) (0) 8 389126
E-mail: jpe@zoology.pdn.ac.lk

Dr. G. K. Manuweera
Registrar of Pesticides
P.O. Box 49, Getambe
Peradeniya
SRI LANKA
Tel.: (94) (0) 8-388076
Fax: (94) (0) 8-388135
E-mail: PEST@SLT.LK

Dr. D. Ahangama
Senior Lecturer
Faculty of Agriculture
University of Peradeniya
Peradeniya
SRI LANKA
Tel.: (94) (0) 8-388375
Fax: (94) (0) 1-865053
E-mail: daya@agbio.pdu.ac.lk

Mrs. Sushila I. Witharana
Entomologist
Tea Research Institute of Sri Lanka
Low Country Station, Ratnapura
SRI LANKA
Tel.: (94) (0)45 32350
Fax: (94) (0)45-22428
E-mail: triratnapura@lanka.ccom.lk

Professor Rohan Rajapakse
Professor of Agricultural Biology
Department of Agricultural Biology
University of Ruhuna
Matara
SRI LANKA
Tel.: (94) (0) 41-27029
Fax: (94) (0) 41-92384/22683

Mr. C.N. Fernando
Regional Manager
Coconut Cultivation Board
Mudukatuwa, Marawila
SRI LANKA
Tel.: (94) (0) 32 54237
Fax: (94) (0) 32 54237

Dr. N.C. Kumarasinghe
Head, Pest Management Division
Sugarcane Research Institute
Udawalawe
SRI LANKA
Tel.: (94) (0)7-33233/33281
Fax: (94)(0)47-33233
E-mail: kumara@sugar.ac.lk

Mr. Canute Anthony
Assistant Regional Manager
Coconut Cultivation Board
Mudukatuwa, Marawila
SRI LANKA
Tel.: (94) (0) 32 54237
Fax: (94) (0) 32 54237

Dr. H.C.E. Wegiriya
Senior Lecturer
Department of Agricultural Biology
University of Ruhuna
Matara
SRI LANKA
Tel.: (94) (0) 41-27029
Fax: (94) (0) 41-92384/22683

Mr. J.K.F Keerthisinghe
Udayarthoppu Mawatha
Negombo
SRI LANKA
Tel.: (94) (0)31-24350