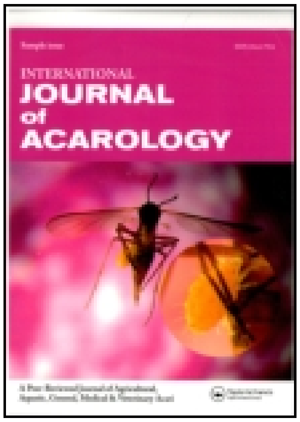

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Impact of climatic factors on leaf roll-inducing mite, *Floracarus perrepae* (Acari: Eriophyidae) feeding on the Old World climbing fern, *Lygodium microphyllum* (Pteridophyta: Lygodiaceae)

B. Muthuraj [a] & R. W. Alexander Jesudasan [a]

[a] Department of Zoology, Madras Christian College, Tambaram East, Chennai, Tamil Nadu, 600 059, India

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IMPACT OF CLIMATIC FACTORS ON LEAF ROLL-INDUCING MITE, *FLORACARUS PERREPAE* (ACARI: ERIOPHYIDAE) FEEDING ON THE OLD WORLD CLIMBING FERN, *LYGODIUM MICROPHYLLUM* (PTERIDOPHYTA: LYGODIACEAE)

B. Muthuraj and R. W. Alexander Jesudasan
Department of Zoology, Madras Christian College, Tambaram East, Chennai, Tamil Nadu 600 059, India
(e-mail: alexjesu62@gmail.com)

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ABSTRACT – The Old World climbing fern *Lygodium microphyllum* is native to Asia but has become a category I weed in the Everglades ecosystem of Florida, USA. The eriophyid mite *Floracarus perrepae* induces leaf rolls on the subpinnae of *L. microphyllum* through its feeding and has been found throughout the year in the host plant, with varying prevalence. The impact of weather parameters such as temperature, rainfall, and relative humidity on the phenology of leaf rolls and mite density has been studied under natural conditions at two locations: Thomaiyarpuram (Nagercoil, Tamil Nadu, India) and Ithikkara (Quilon, Kerala, India). The trend of % leaf roll at both the sites was high during the months of August, September, October, and December in both study years. The density of mites per leaf roll varied considerably during the study, peaking in August 2003 (44.2 and 33.1 mites per roll at Nagercoil and Quilon, respectively). Statistical analysis revealed that there was no significant interaction or impact between weather variables and the % leaf roll (Nagercoil, $r = 0.077$ and Quilon, $r = 0.025$) but in Quilon the rainfall played a role in reducing the mite population. However, a significant positive correlation was found between mite density and abiotic factors (Nagercoil $r = 0.6457$; Quilon $r = 0.9514$), i.e. all the abiotic factors such as temperature, rainfall and relative humidity can influence mite density.
Key words – Eriophyidae, *Floracarus perrepae*, *Lygodium microphyllum*, weather factors, phenology, population dynamics.

INTRODUCTION

The Old World climbing fern, *Lygodium microphyllum* (Cav.) R. Brown (Pteridophyta: Lygodiaceae) is native to Asia and is naturalized in the United States; it has spread widely throughout the tropics and subtropics extending from 18°E in Senegal to 150°W in Tahiti and between the latitudes of 29°S in Australia to 27°N in northern India (Alston, 1959; Holttum, 1968; Copeland, 1994; So, 1994). This fern is found in a variety of habitats, including mesic forests, rain forests, and open swamp. In recent years, it has become a weed in various parts of the world including Australia, Singapore, and the USA. The old, thick skirt of the fern mat acts as a "fire ladder", carrying the fire into the tree canopy and spreading fire to new areas; as a result it is classified as a category one invasive species by the Florida Exotic Pest council (Pemberton and Ferriter, 1998).

The eriophyid mite, *Floracarus perrepae* Knihinicki and Boczek (2002), is a minute (about 0.1–0.3 mm in length), slow-moving, worm-like mite, feeding exclusively on *L. microphyllum* (Goolsby *et al*., 2005) and is distributed over tropical and subtropical regions including Australia, China, India, Indonesia, Malaysia, New Caledonia, Singapore, Sri Lanka, and Thailand (Goolsby *et al*., 2002), and they recommended this mite as a key biological control agent to control the invasive fern *L. microphyllum*. The continuous feeding of these mites leads to leaf

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curl, and a severe attack by *F. perrepae* causes stunted growth and leaf necrosis, which lead to premature leaf fall and ultimately to suppressed growth of the fern. The aim of the present study done during 2002–2004 is to investigate the influence of climatic factors on the phenology of leaf curl and the density of the mite under natural conditions.

MATERIALS AND METHODS

Nature of study sites and field survey – The study sites were located in the southern tip of India at Thomaiyarpuram, Nagercoil, Tamil Nadu (8°′11′24″N, 77°15′0″E) and Ithikkara, Quilon, Kerala (8°30′36″N, 76°24′36″E) where the occurrence of this fern were in abundance when compared to other areas in southern India. Both the sites are known to receive heavy rainfall during the south-west monsoon, i.e. from May to November. The mean maximum temperatures were 32.59 and 32.18°C at Nagercoil and Quilon, respectively. In Nagercoil, the fern was found in the shadow of coconut palms and also under areca nut shade, while in Quilon it was found along the roadside ditch, directly exposed to the sun. The two-year study started in July 2002 and was completed in June 2004. The specimens were identified by experts in the United States Department of Agriculture, and in the Agricultural Research Service, Australia.

Seasonal phenology of leaf curls under field conditions – For phenology studies, the intensity of leaf curl was estimated based on counts of sterile subpinnae of *L. microphyllum*. Each month 100 moderate subpinnae were collected at each site and the number of infested and uninfested subpinnae were counted to assess the proportion of infestation (leaf rolls). Temperature and humidity at the study sites were recorded using a field thermohygrometer (Goolsby *et al*., 2005), and additional weather data pertaining to the study sites were obtained from the Meteorology Station, Thiruvanathapuram and the Horticultural Research Station, Peechiparai, Nagercoil.

Population dynamics of *F. perrepae* – Leaf samples were collected monthly over a period of 17 months (from February 2003 to June 2004) from two study sites: Thomaiyarpuram and Ithikkara. Each sample consisted of 10 curled leaves plucked from the main rachis at random, secured in plastic bags, and/brought to the laboratory for further observations. Individual mites were counted under a Nikon stereo zoom microscope (SMZ 1000) by uncurling the leaves.

Statistical analysis – Data were fitted to a multiple regression analysis through SPSS 10.1 to assess the impact of abiotic variables on the population of *F. perrepae*. Student's *t*-test was performed using the % population of mite within a site and between the sites to understand the trend in the mite population for the 2-year period (2002–2004).

RESULTS

Impact of weather factors on phenology of *F. perrepae* – The results of the investigation on the seasonal incidence and population dynamics of *F. perrepae* on *L. microphyllum* are presented in Tables 1 and 2. The mite was found to be active throughout the period of observation. The trend of % leaf roll in both sites was high during August, September, October, and December. The % mite infestation was always higher in Nagercoil than Quilon. In Nagercoil, the peak infestation (68.67%) was observed in December 2003 and the lowest (4.14%) in July 2003, whereas in Quilon the peak infestation (66.1%) was noted in September 2002 and the lowest (4.35%) in November 2002. In general, there was a sharp decline in the mite infestation immediately after rainfall; however, the onset of new growth of the fern pinnule had a greater role in increasing the mite population. The trend was similar within a site (*t*-test for equality of means: Nagercoil $F = 1.679$, $df = 22$, $P = 0.805$; Quilon $F = 5.331$, $df = 22$, $P = 0.869$) in both years (2002–2003 and 2003–2004), whereas it differed between the sites ($F = 7.964$, $df = 46$, $P = 0.004$). Statistical analysis revealed that there was no significant interaction between weather variables and the proportion of mite infestation (Nagercoil, $r = 0.077$ and Quilon, $r = 0.025$; Figs. 1A, B).

Population dynamics of *F. perrepae* – The population dynamics of *F. perrepae* in two experimental sites are presented in Tables 1 and 2. The numbers of all stages of mite varied considerably during the study. At both sites, the peak was recorded in August 2003. In Nagercoil, the mean number was less (3.1 per leaf curl) in May 2003, whereas in Quilon the average was only 2.0 per leaf curl in May 2004. However, higher densities of mite were noticed in mid-July to mid-December in 2003 in the 2-year study: 44.2 and 33.1 mites per curl at Nagercoil and Quilon, respectively. Nymphs and adults of *F. perrepae* were found in low numbers between January and May of 2004 and numbers started to build up from June. The mite population was generally high after the monsoon. This investigation indicates that the population of *F. perrepae* increased from a low level after the onset of the monsoon, which usually commenced in the first week of May in Kerala and the Nagercoil area of Tamil Nadu. The multiple regression analysis revealed that there was a significant positive correlation between the

Table 1. Weather parameters, phenology and density of *F. perrepae* at Nagercoil (from July 2002 to June 2004).

	Temperature		RH				
Month	Mean maximum	Mean minimum	a.m.	p.m.	Rainfall	% Leaf curl[a]	Mean mite ± SEM[b]
July	31.13	23.67	88.12	69.03	16.50	62.20	–
August	30.46	23.85	87.22	69.90	3.07	43.80	–
September	34.05	26.16	81.46	59.41	1.62	63.28	–
October	30.67	22.61	92.41	79.90	19.48	14.42	–
November	30.88	21.93	92.03	80.10	10.32	45.49	–
December	32.08	22.96	85.35	72.58	0.30	68.67	–
January	34.06	23.00	81.90	66.22	–	54.09	–
February	34.96	23.51	87.89	70.00	0.61	32.22	8.4 ± 2.064
March	34.91	23.29	87.41	64.93	2.16	29.00	4.3 ± 0.51
April	33.48	23.40	88.83	69.06	6.97	6.03	7.1 ± 0.87
May	33.22	25.01	82.41	69.90	1.13	18.71	3.1 ± 0.54
June	32.71	22.93	82.83	68.83	4.13	7.35	3.8 ± 0.62
July	31.08	23.62	86.70	70.52	2.59	4.14	12.9 ± 2.17
August	31.54	23.79	84.80	72.58	1.83	50.65	44.2 ± 10.19
September	33.70	21.80	78.46	59.06	1.17	45.28	12.1 ± 1.81
October	30.11	22.96	91.61	80.19	13.6	56.60	18 ± 4.47
November	30.46	22.76	86.76	74.13	4.50	43.67	17.4 ± 1.92
December	33.00	20.61	86.64	60.96	0.03	45.41	14.9 ± 2.30
January	34.45	21.69	86.12	60.00	–	45.05	4.5 ± 1.74
February	34.93	20.48	86.00	62.68	0.19	44.66	4.4 ± 0.56
March	35.25	21.45	85.41	60.01	3.23	17.64	6.1 ± 1.73
April	33.50	21.67	87.93	69.50	8.04	9.79	5.7 ± 1.58
May	30.95	23.54	88.64	75.64	11.83	33.37	3.8 ± 0.86
June	30.63	23.25	87.70	75.66	8.58	24.61	4.2 ± 1.29

[a]Percentage of leaf curl (infestation ratio) was calculated by counting 100 subpinnae in random manner; [b]Mean mite was calculated by averaging the mites presented in 10 infested leaves.

population dynamics of *F. perrepae* and abiotic factors (Nagercoil $r = 0.6457$; Quilon $r = 0.9514$), i.e. all the abiotic factors such as temperature, rainfall, and relative humidity influenced mite density.

DISCUSSION

The eriophyid mite, *F. perrepae* is one of the key arthropods associated with the climbing fern, *L. microphyllum* from tropical and subtropical regions. The biology of *F. perrepae* includes egg, larva, nymph, and adult stages with two inactive stages, the nymphochrysalis and imagochrysalis. The eggs are white and measure 0.041 mm in diameter according to Knihinicki and Boczek (2002), who also reported that the larvae and adults of *F. perrepae* were transparent and similar in their appearance (173–226 mm long) and that the adult females were larger than the males. The entire life cycle is completed in 9–12 days. The female adult preferred newly emerged subpinnae for feeding and oviposition and continuous feeding by immature stages and adults resulted in leaf rolling as a response to the feeding pressure imposed by the mites. The epidermal cells become significantly enlarged in the rolled areas of leaves, either upward or downward, with one to three rollings (Goolsby *et al*., 2002).

A 2-year field study on the impact of abiotic factors on the phenology of *F. perrepae* showed no significant relationship between them, except on the population dynamics of *F. perrepae*. In general, it was found that the abiotic factors played a key role on population size of the mites, *Schizotetranychus nanjingensis* Ma and Yuan, *Aponychus corpuzae* Rimando, and *Aculus bambusae* Kuang (Zhang *et al*., 2000), and rainfall played a key role in *Aculus bambusae* and *S. nanjingensis*, as also relative humidity and temperature (Zhang *et al*., 2000). Gonzalez *et al*. (1984) reported that relative humidity had a negative impact on the population dynamics of *Phyllocoptruta oleivora* in Havana, Cuba. Hossain *et al*. (2002) found no significant relationship between these factors and the population dynamics of *Aceria dalbergiae*

Table 2. Weather parameters, phenology and density of *F. perrepae* at Quilon (from July 2002 to June 2004).

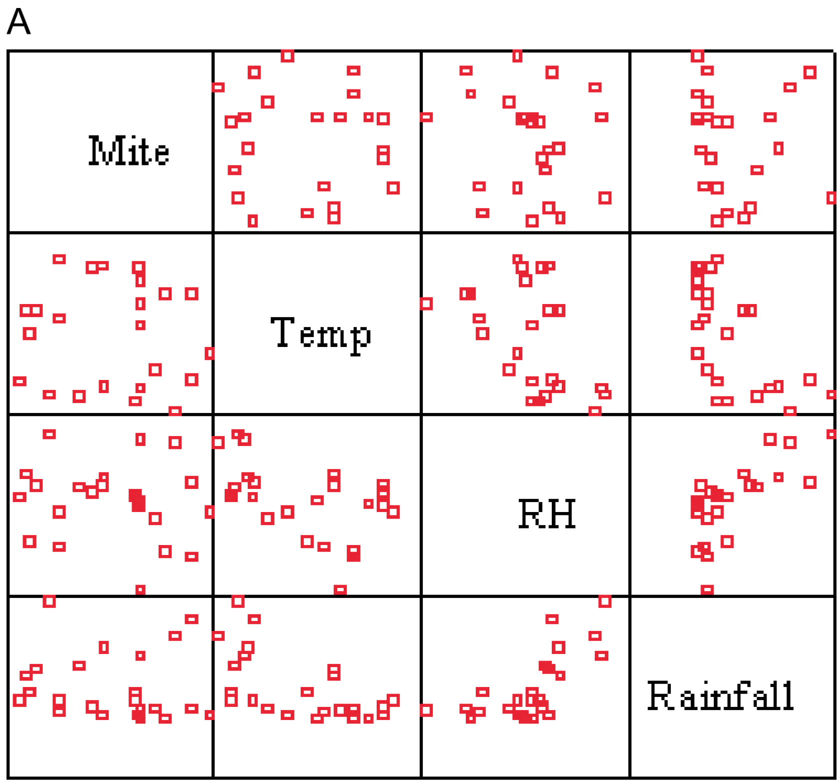
	Temperature		RH				
Month	Mean maximum	Mean minimum	a.m.	p.m.	Rainfall (mm)	% Leaf curl[a]	Mean mite ± SEM[b]
July	31.17	23.46	85.60	77.83	8.12	42.30	–
August	30.78	22.70	86.74	77.96	3.31	28.00	–
September	30.81	22.28	86.35	76.12	7.77	66.10	–
October	32.58	22.39	76.86	70.50	2.35	6.15	–
November	30.97	22.30	87.35	82.41	15.94	4.35	–
December	31.01	22.35	87.66	79.66	4.27	15.81	–
January	32.36	21.70	76.29	66.00	–	30.59	–
February	32.84	22.02	77.06	65.25	–	20.05	6.4 ± 0.69
March	31.40	21.41	85.28	68.07	1.11	13.43	5.1 ± 0.91
April	33.05	21.54	81.77	67.22	2.73	6.90	6.5 ± 0.98
May	33.80	23.63	77.86	75.10	5.52	19.39	8.1 ± 1.26
June	32.49	24.26	78.83	73.03	3.58	13.50	4.3 ± 1.31
July	31.20	22.80	84.00	78.00	8.32	10.62	7.9 ± 3.71
August	31.50	23.00	86.00	76.00	6.94	17.34	33.1 ± 9.08
September	33.00	23.10	79.00	71.00	2.56	29.50	11 ± 1.98
October	31.60	22.80	88.00	81.00	14.95	25.65	5.8 ± 1.61
November	31.60	22.50	85.00	80.00	2.69	17.25	11.7 ± 1.81
December	32.90	21.30	79.00	65.00	2.70	19.85	6.7 ± 1.23
January	33.00	21.40	81.00	64.00	0.22	21.58	7.4 ± 1.53
February	33.90	21.90	77.00	60.00	2.25	21.58	3.8 ± 1.16
March	34.40	23.60	81.00	66.00	1.65	35.37	3.6 ± 0.96
April	34.00	23.90	78.00	74.00	3.76	17.49	6.6 ± 1.50
May	31.30	22.60	86.00	79.00	20.24	23.91	2.0 ± 0.67
June	30.70	23.20	87.00	81.00	13.83	15.50	6.1 ± 1.73

[a]Percentage of leaf curl (infestation ratio) was calculated by counting 100 subpinnae in random manner; [b]Mean mite was calculated by averaging the mites presented in 10 infested leaves.

Channabasavanna (temperature $r = -0.28$; and rainfall $r = -0.36$). In contrast, the population dynamics of the cassava mite, *Mononychellus tanajoa* (Bondar) was greatly influenced by the wet season, being low as the mites were washed off the leaves by the rainfall (Nukenine *et al*., 2002). Goolsby *et al*. (2005) has reported that higher temperature had a significant negative impact on the population of *F. perrepae* and found no leaf roll formation when the temperature rose above 35°C. They also claimed that the climate did not play a pivotal role in the establishment of the *F. perrepae* population, and the results of the present study also confirm their observations, and we believed that the leaf roll prevented the direct effect of abiotic factors on the population of the mite and such a characteristic is e ideal for establishment of any biocontrol agent.

Apart from phenological studies, the overall density of the adult and nymphal population of *F. perrepae* fluctuated throughout the year and increased steadily between June and December, with a peak during August 2003 (44.2 and 33.1 mites per leaf curl in Nagercoil and Quilon, respectively) in both study sites, however, Ozman and Goolsby (2005) found a maximum of 12.11 ± 1.56 *F. perrepae* per leaf roll and a minimum of 7.11 ± 1.08 mites and observed a number of peaks during the study period. They believed that the presence of predatory mites such as *Tarsonemus* sp. (Tarsonemidae), *tydeid* sp.1, *tydeid* sp.2 (Tydeidae), *Agistemus* sp. (Stigmaeidae), and one species each of *Cheyletidae* and *Ascidae* also had a significant impact on the density of the eriophyid mite.

In Quilon, though the rainfall played a role in reducing the mite population, in the present study, we also noticed that the onset of the monsoon in May enabled the formation of new pinnae of *L. microphyllum*, which in turn assured the foraging material for the establishment of mite population. Similarly, Meyer (1981) found fluctuation in the population of *Calacarus citrifoli* Keif., which fed on *Citrus* spp., and Bacic and Petanovic (1995) noted a similar trend in the population of *Aculus euphorbiae* feeding on



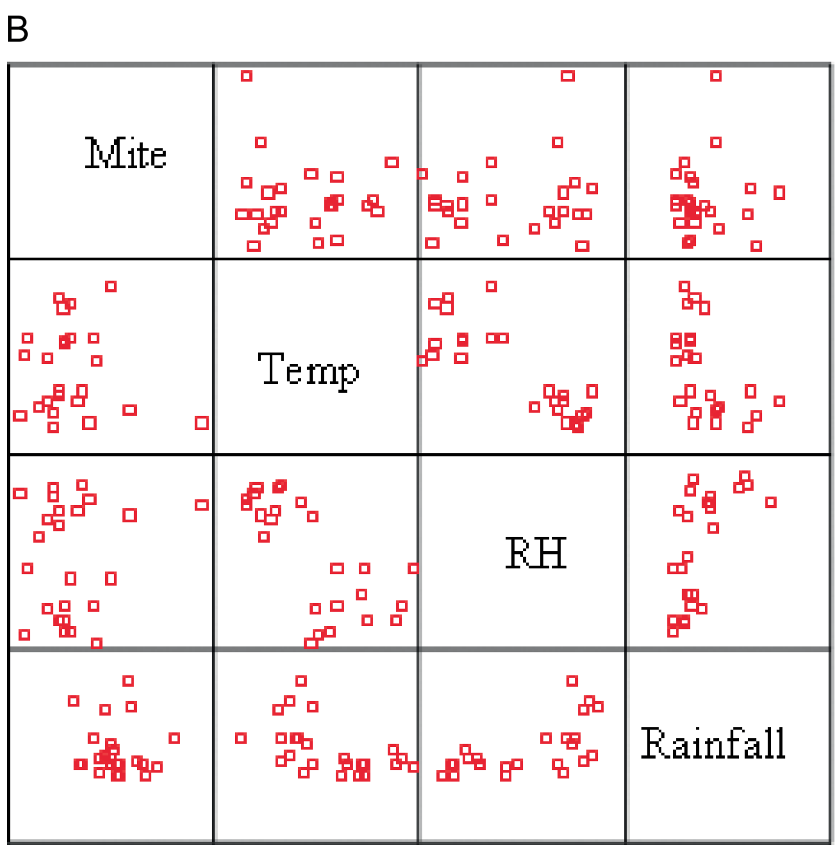


Fig. 1. Scatter plot showing relationship between weather parameters and mite incidence. More assemblage of dots indicates the impact. A – Nagercoil; B – Quilon.

Euphorbiae spp., recording a lower population in winter, which is characterized by slow plant tissue growth and the presence of a predator population.

Considering the harmful effects of use of synthetic herbicides in the control of weed *L. microphyllum* on the environment, the releasing of *F. perrepae* on *L. microphyllum* lead to the formation of leaf roll which ultimately suppresses the growth of the weedy climbing fern. From the present study we conclude that the population density of the eriophyid mite was independent and not influenced directly by temperature and humidity of the study sites. As a result of the shelter given to the mites by the leaf rolls, the direct effects of temperature and rainfall on the population were limited and such a study gains importance in the biocontrol of this weedy fern.

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