Bulletin of Entomological Research (2008) **98**, 83–96
doi:10.1017/S0007485307005421

Printed in the United Kingdom

Exploration of the acarine fauna on coconut palm in Brazil with emphasis on *Aceria guerreronis* (Acari: Eriophyidae) and its natural enemies

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Abstract

Coconut is an important crop in tropical and subtropical regions. Among the mites that infest coconut palms, *Aceria guerreronis* Keifer is economically the most important. We conducted surveys throughout the coconut growing areas of Brazil. Samples were taken from attached coconuts, leaflets, fallen coconuts and inflorescences of coconut palms in 112 localities aiming to determine the occurrence and the distribution of phytophagous mites, particularly *A. guerreronis*, and associated natural enemies. *Aceria guerreronis* was the most abundant phytophagous mite followed by *Steneotarsonemus concavuscutum* Lofego & Gondim Jr. and *Steneotarsonemus furcatus* De Leon (Tarsonemidae). Infestation by *A. guerreronis* was recorded in 87% of the visited localities. About 81% of all predatory mites belonged to the family Phytoseiidae, mainly represented by *Neoseiulus paspalivorus* De Leon, *Neoseiulus baraki* Athias-Henriot and *Amblyseius largoensis* Muma; 12% were Ascidae, mainly *Proctolaelaps bickleyi* Bram, *Proctolaelaps* sp nov and *Lasioseius subterraneus* Chant. *Neoseiulus paspalivorus* and *N. baraki* were the most abundant predators on attached coconuts. Ascidae were predominant on fallen coconuts, while *A. largoensis* was predominant on leaflets; no mites were found on branches of inflorescences. Leaflets harboured higher mite diversity than the attached coconuts. Mite diversity was the highest in the state Pará and on palms surrounded by seasonal forests and Amazonian rain-forests. *Neoseiulus paspalivorus*, *N. baraki* and *P. bickleyi* were identified as the most promising predators of *A. guerreronis*. Analyses of the influence of climatic factors revealed that dry ambient conditions favour the establishment of *A. guerreronis*. *Neoseiulus paspalivorus* and *N. baraki* have differing climatic requirements; the

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former being more abundant in warm and dry areas, the latter prevailing in moderately tempered and humid areas. We discuss the significance of our findings for natural and biological control of *A. guerreronis*.

Keywords: coconut, *Aceria guerreronis*, natural enemies, diversity, biocontrol

(Accepted 19 April 2007)

Introduction

Coconut palm, *Cocos nucifera* L. (Palmales: Arecaceae), also called 'Tree of Life' in the Indian Ocean, has a key importance to the livelihoods of farming communities in coastal areas of tropical and subtropical regions in the world (Foale, 2003). All parts of the plant are used in different consumption forms. The dried coconut kernel, also called Copra, is a significant cash crop throughout the tropics. The leaves are used to thatch or are woven into baskets, mats and clothing. The trunks are used for construction. The mesocarp is widely used as domestic fuel or as planting medium (Vietmeyer, 1986).

Among the mites that infest coconuts, *Aceria guerreronis* Keifer (Acari: Eriophyidae) is the only species considered a serious pest. It has been reported from many coconut-growing regions in the Americas, West Africa, Tanzania and, most recently, from the Indian sub-continent, often causing enormous damage (Mariau, 1977; Fernando *et al*., 2002; Seguni, 2002). Despite the variable measures used to control this pest, none has been proven sufficiently effective, making this mite the most intractable coconut pest. Chemicals considered for use are hazardous to either humans (directly or indirectly), pollinators or natural enemies of potentially damaging organisms (Moore *et al*., 1989). Considerable attention is being given to the pathogenic fungus *Hirsutella thompsonii* Fisher to be used as biopesticide against this pest; however, there is not enough information about the influence of climatic factors on the effectiveness of that pathogen in coconut plantations (Sreerama Kumar & Singh, 2000; Cabrera, 2002).

Aceria guerreronis has been shown recently to be most probably of South American origin (Navia *et al*., 2005). Classical biological control may, hence, offer a sustainable solution to the problem caused by this pest in regions outside of South America, such as Africa and Asia (Moore, 2000; Moraes & Zacarias, 2002). Brazil is the largest coconut producer in South America (FAO, 2005) and falls within the likely native home of *A. guerreronis*. However, to date, little is known about the acarine fauna of coconut palms in that country, in particular the predatory mites associated with *A. guerreronis* (Santana & Flechtmann, 1998; Gondim & Moraes, 2001; Arruda Filho, 2002; Navia & Flechtman, 2002). The present work is part of a multi-institutional project with the broad objective of developing a biological control program against *A. guerreronis* in Africa and elsewhere. The specific objectives of this study are: (i) to determine the abundance and distribution of *A. guerreronis* and other phytophagous mites on coconut throughout the major coconut growing regions of northern and north-eastern Brazil; (ii) to determine simultaneously the abundance and distribution of natural enemies associated with *A. guerreronis* with the aim of identifying potential candidates for introduction into Africa; and (iii to determine the relationship between the predominant vegetation adjacent to coconut palms and climatic factors – temperature, humidity and rainfall – on the presence and abundance of *A. guerreronis* and associated natural enemies.

Material and methods

Sampling routes and methods

Three collecting routes were initially established through the coconut growing areas in northern and northeastern Brazil, each starting from the city of Recife. Those routes were mapped out to cover, as much as possible, the range of ecological conditions under which coconut is grown in Brazil.

Three surveys were conducted along each of those routes between August 2004 and September 2005; sampled sites were visited once every four months, in an attempt to cover the range of climatic changes during that period. For logistical reasons, an average distance of 50 km between sampling sites was initially set. However, the actual distance between sampling sites varied according to the availability of coconut fields along the routes. In addition, in areas showing high concentration of coconut fields, the distance between sampling sites was reduced to approximately 20 km. After the first survey, some sites were revisited and new fields situated between two previously visited sites were visited at the following sampling occasions. Geographical coordinates at each sampling site were recorded. The most relevant localities are listed in table 1. The sampling sites were sorted in classes established for each of five parameters (table 2) according to information obtained from IBGE (Instituto Brasileiro de Geografia e Estatística; www.ibge.gov.br) and INMET (Instituto Nacional de Meteorologia; www.inmet.gov.br) databases compiled from 1931 to 1999.

Table 1. Relevant localities visited in nine states in northeastern Brazil and one in northern Brazil during surveys from August 2004 to September 2005.

States from North to Northeast	Relevant localities
Pará	Moju, Santa Isabel, São Caetano de Odivelas, Salinopólis
Maranhão	Carutapera, Guimarães, Pinheiro, Barreirinhas
Piauí	Pedra do Sal
Ceará	Acaraú, Itapipoca, Caponga, Ibicuitaba
Rio Grande do Norte	Muriú, Búzios
Paraíba	Mataraca
Pernambuco	Itamaracá, Ipojuca, Petrolina
Alagoas	Maragogi, Paripueira, Miaí de Baixo
Sergipe	Neopólis
Bahia	Juazeiro, Una

Table 2. Description of vegetation and climate-related parameters.

Parameter	Description	Source
Predominant surrounding vegetation	**1.** Tropical Amazonian rain-forest **2.** Seasonal forest (semi- or deciduous forest) **3.** 'Caatinga' (thorn forest, cacti thick stemmed plants, arid adapted grasses) **4.** Tropical Atlantic rainforest **5.** Restingas (mangrove, beach, dunes, shrubs)	IBGE
Average period of drought per year	**1.** 0 month **2.** 1–3 months **3.** 4–5 months **4.** 6–8 months	IBGE
Average range of temperature per year	**1.** 21–24°C **2.** 24–27°C **3.** 27–30°C	INMET
Average range of humidity per year	**1.** 50–70% **2.** 70–80% **3.** 80–90%	INMET
Average range of precipitation per year	**1.** 300–600 mm $year^{-1}$ **2.** 600–1500 mm $year^{-1}$ **3.** 1500–2400 mm $year^{-1}$ **4.** 2400–3000 mm $year^{-1}$	INMET

In each site 30, two- to five-months-old, coconuts and 30 leaflets taken from two–four randomly selected palms were collected. In addition, ten branches of inflorescences, bearing male flowers and female flower-buds, and ten recently fallen coconuts (if present) were collected. For logistical reasons, coconuts were cut so that only the part carrying the bracts was collected.

Mite evaluation

Due to time limitation, only 10% of the sampled coconuts were examined in the field. All leaflets were examined directly in the field with hand lenses at 15× magnification. The remaining coconuts and branches of inflorescences were placed in separate plastic bags, stored in cool boxes and transported to the Laboratory of Acarology at UFRPE (Universidade Federal Rural de Pernambuco, Recife) for further processing. Immediately before mite collection, coconut parts carrying bracts were cut in several sections during processing and the bracts were gradually removed. All mites other than *A. guerreronis* were collected individually with a paint brush and placed in 70% ethanol for later mounting and identification. All specimens of *A. guerreronis* from each sample (30 coconuts) were brushed into vials containing 10 ml of 70% ethanol.

The numbers of *A. guerreronis* on fallen and attached coconuts were estimated using a methodology similar to that described by Siriwardena *et al*. (2005). A 1:10 dilution of the eriophyids' suspension was prepared, shaken and an aliquot (1 ml) drawn into a counting chamber. The chamber was similar to the one used by Seaman *et al*. (1996) and consisted of a thick glass slide with a U-shaped trough forming a counting area of 3×2 cm divided into 24 squares. The edges of the trough are raised to support a thinner cover slide. The aliquot was introduced into the chamber with a pipette and was allowed to settle for two minutes before counting. Mites were counted in six of the 24 squares. The number obtained was multiplied by four and the coefficient of dilution (10) to estimate the total number of mites per 30 coconuts. The same counting technique was applied to Tarsonemidae.

All individual mites other than *A. guerreronis* and Tarsonemidae and a subsample (50 individuals) of the latter two groups were mounted in Hoyer's medium for subsequent identification or confirmation of identification to species level when possible.

Data analyses

The diversity and uniformity of the acarine fauna on coconuts and leaflets were assessed using the Shannon diversity index (H) (Shannon & Weaver, 1949) and the Evenness index (E) (Pielou, 1966), respectively. The Shannon index describes the relationship between the number of individuals of each species and the total number of individuals of all species present. It is calculated according to the formula

$$H = -\sum_{i}^{S} P_i \log P_i$$

where P_i is the number of specimens of species i divided by the total number of specimens of all collected species and S the species richness. H is zero if there is only one species in the system ($\log 1 = 0$). H reaches its maximum (theoretical maximal diversity) when the individuals are equally distributed among the species present in the system ($H_{max} = \log S$).

The Evenness index describes the uniformity in the abundance of different species prevailing in a given system and is calculated according to the formula

$$E = \frac{H}{\log S}$$

where H is the Shannon index and S is the species richness.

Statistical analyses of mite diversity and abundance was carried out using SPSS 12.0 for Windows (Bühl & Zöfel,

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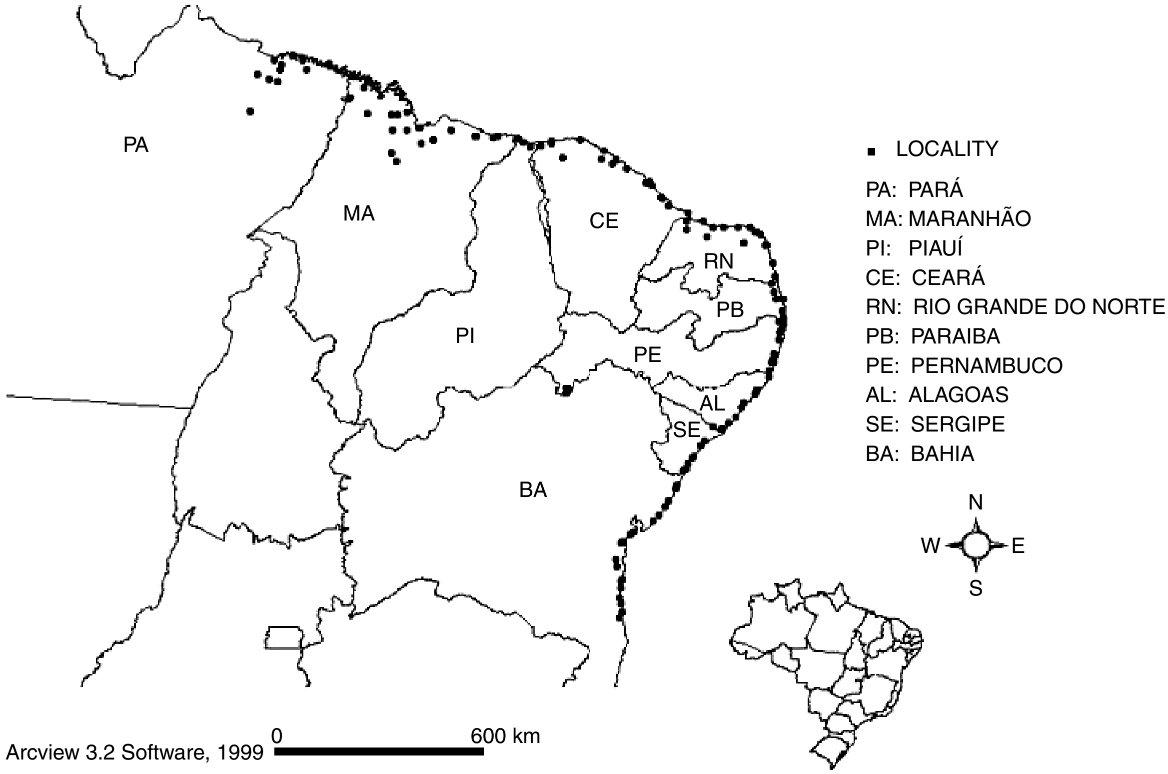

Fig. 1. Sites sampled from August 2004 to September 2005.

2004). Univariate analyses of variance (ANOVA) were used to compare: (i) the mite diversity and evenness indices among plant parts (attached coconuts and leaflets) and the predominant surrounding vegetation types; (ii) the occurrence and abundance of *A. guerreronis* and tarsonemids per state; and (iii) the effects of climatic factors on the number of *A. guerreronis*, tarsonemid mites and the most important predatory mites on attached coconuts. If univariate ANOVAs revealed significance, Bonferroni post-hoc tests were used to separate the means. Log-transformed values of the dependent variables were used in the ANOVAs where needed to correct heterogeneity and/or heteroskedasticity of the variances. Means ($\pm$standard error) of untransformed data are presented in the figures. All statistical analyses were conducted at $p = 0.05$ significance level.

Results

Species survey

Sampling was conducted in a total of 163 sites in nine states of northeastern Brazil (Alagoas, Bahia, Ceará, Maranhão, Paraíba, Pernambuco, Piauí, Rio Grande do Norte, Sergipe) and one state in northern Brazil (Pará) (fig. 1). A total of 4890 coconuts, 4080 leaflets and 500 branches of inflorescences from 300 palms, as well as 307 fallen coconuts, were examined in this study. Mites were found on attached and fallen coconuts and leaflets but not on the branches of inflorescences.

Aceria guerreronis was by far the most abundant phytophagous species on attached and fallen coconuts, followed by the tarsonemids *Steneotarsonemus concavustucum* Lofego & Gondim Jr and *Steneotarsonemus furcatus* DeLeon (table 3). No *A. guerreronis* or tarsonemid mite was found on leaflets. *Notostrix nasutiformes* Gondim Jr, Flechtman & Moraes was the only eriophyid mite found on leaflets, but this species was not found on coconuts. A few specimens of Tetranychidae and Tenuipalpidae were found on attached coconuts. Mites of the latter two families were, however, the predominant species on leaflets. Among the phytophagous mites listed in table 3, *Dolichotetranychus* sp (Tenuipalpidae) is the most relevant finding since this is the first report of this genus on coconut in Brazil. Individuals of this genus were collected from attached coconuts sampled in Itapipoca (Ceará), showing no visible damage. Other non-phytophagous mites were also found on coconut palms. The most important species in this group were *Lorryia formosa* Cooreman (Tydeidae) and *Tyrophagus aff. putrescentiae* Schrank (Acaridae); the latter was common on fallen coconuts (table 4).

By far the largest numbers of predatory mites found in this study were Phytoseiidae, followed by Ascidae (table 5). Phytoseiids were found on both coconuts and leaflets, whereas ascids were only found on coconuts. The most abundant phytoseiid species was *Neoseiulus paspalivorus* DeLeon, which was only found on coconuts, followed by *Amblyseius largoensis* Muma, mainly present on leaflets and, to a much lesser extent, on attached and fallen coconuts. Only two other predatory species, the phytoseiid *Neoseiulus recifensis* Gondim Jr. & Moraes and *Bdella distincta* Baker & Balock (Bdellidae), were found on both coconuts and leaflets. *Neoseiulus baraki* Athias-Henriot was only present on

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Table 3. Phytphagous mites found on attached coconuts, leaflets and fallen coconuts of coconut palms in northern and northeastern Brazil.

FAMILY	Ac	Lf	Fc	STATE
Eriophyidae				
Aceria guerreronis Keifer	6643177	–	27112	Alagoas, Bahia, Ceará, Maranhão, Pará, Paraiba, Pernambuco, Piaui, Rio G. Norte, Sergipe
Notostrix nasutiformes Gondim Jr, Flechtmann, Moraes	–	78	–	Pernambuco
Phytoptidae				
Retracrus johnstonii (Keifer)	–	55	–	Bahia
Tarsonemidae				
Steneotarsonemus furcatus DeLeon	8785	–	–	Alagoas, Bahia, Ceará, Maranhão, Pará, Paraiba, Pernambuco, Piaui, Rio G. Norte, Sergipe
Steneotarsonemus concavustucum[1] Lofego & Gondim Jr.	35950	–	–	
Tenuipalpidae				
Brevipalpus phoenicis (Geijskes)	2	113	–	Alagoas, Bahia, Maranhão, Pernambuco, Sergipe
Dolichotetranychus sp[1]	4	–	–	Ceará
Tenuipalpus sp	–	12	–	Pernambuco
Tetranychidae				
Oligonychus sp	1	19	–	Ceará, Maranhão, Pernambuco, Rio G. Norte Paraiba
Tetranychus mexicanus (McGregor)	1	2	–	
Tetranychus neocaledonicus André	–	23	–	Alagoas, Bahia, Pernambuco
Tetranychus sp	–	139	–	

[1] New record in Brazil; Ac, attached coconuts; Lf, leaflets; Fc, fallen coconuts.

Table 4. Other groups of mites found on attached coconuts, leaflets and fallen coconuts of coconut palms in northern and northeastern Brazil

FAMILY	Ac	Lf	Fc	STATE
Ameroseiidae: *Ameroseius* sp	1	–	–	Maranhão
Astigmata				
Glyciphagidae	8	–	–	Alagoas, Ceará, Pernambuco, Sergipe
Histiostoma sp	42	–	–	Alagoas, Bahia, Ceará, Pará
Tyrophagus aff. putrescentiae Schranck	85	–	1600	Alagoas, Bahia, Ceará, Maranhão, Pará, Paraiba, Pernambuco, Piaui, Rio G. Norte, Sergipe
Camerobiidae: *Neophyllobius* sp	–	1	–	Piaui
Digamasellidae	–	–	4	Ceará
Eupalopsellidae: *Peltasellus* sp	1	–	–	Pernambuco
Eupodidae: *Eupodes* sp	2	10	–	Alagoas, Bahia, Céara, Pará, Piaui
Macrochelidae	2	–	5	Bahia
Oribatida	12	17	9	Alagoas, Bahia, Ceará, Pará, Paraiba, Pernambuco, Rio G. Norte Alagoas
Podapolipidae	1	–	–	
Raphignatidae: *Neoraphignathus* sp	–	1	–	Maranhão
Sejidae	–	–	2	Alagoas, Rio G. Norte
Trombidiidae	–	1	–	Maranhão
Tydeidae				
Lorryia formosa Cooreman	139	41	–	Alagoas, Bahia, Ceará, Maranhão, Pará, Paraiba, Pernambuco, Sergipe
Pronematinae	16	12	–	Bahia, Ceará, Pará, Pernambuco, Sergipe
Uropodidae	–	–	2	Bahia, Ceará

Ac, attached coconuts; Lf, leaflets; Fc, fallen coconuts.

coconuts and was the second most numerous predatory mites on this plant part. The phytoseiids *Euseius concordis* Chant, *Iphiseoides zuluagai* Denmark & Muma, *Amblyseius operculatus* DeLeon and *Amblyseius saopaulus* Denmark & Muma were exclusively found on leaflets. *Neoseiulus gracilis* Muma and *Typhlodromus transvaalensis* Nesbitt were only found on fallen coconuts. *Proctolaelaps bickleyi* Bram (Ascidae) was found on both attached and fallen coconuts. Overall, *P. bickleyi* was the most numerous species on fallen coconuts, on which it represented 46% of all predatory mites (table 5).

Table 5. Predatory mites found on attached coconuts, leaflets and fallen coconuts of coconut palms in northern and northeastern Brazil.

FAMILY	Ac	Lf	Fc	STATE
Ascidae				
Asca foxi DeLeon	3	–	1	Maranhão, Pará, Pernambuco
Blattisocius keegani Fox[1]	1	–	–	Maranhão
Gamasellodes sp nov *aff. adrianae* Athias–Henriot[1]	–	–	1	Ceará
Lasioseius subterraneus Chant	34	–	14	Alagoas, Bahia, Ceará, Maranhão, Pará, Paraiba, Pernambuco, Piaui, Rio G. Norte, Sergipe
Melichares aff. agilis Hering[1]	1	–	–	Pernambuco
Proctolaelaps bickleyi Bram	178	–	77	Alagoas, Bahia, Ceará, Maranhão, Pará, Paraiba, Pernambuco, Piaui, Rio G. Norte, Sergipe
Proctolaelaps coffeae Karg & Rodriguez[1]	1	–	–	Pernambuco
Proctolaelaps intermedius Athias–Henriot[1]	1	–	–	Pernambuco
Proctolaelaps sp nov[1]	42	–	11	Alagoas, Bahia, Ceará, Maranhão, Pará, Paraiba, Pernambuco, Rio G. Norte, Sergipe
Proctolaelaps sp	4	–	–	Alagoas, Paraiba, Pernambuco, Rio G. Norte
Phytoseiidae				
Amblyseius adhatodae Muma[1]	–	1	–	Bahia
Amblyseius aerialis Muma	–	9	–	Bahia, Maranhão, Pará, Pernambuco
Amblyseius herbicolus Chant		1	–	Rio G. Norte
Amblyseius largoensis Muma	96	566	2	Alagoas, Bahia, Ceará, Maranhão, Pará, Paraiba, Pernambuco, Piaui, Rio G. Norte, Sergipe
Amblyseius operculatus DeLeon	–	5	–	Bahia
Amblyseius saopaulus Denmark & Muma	–	9	–	Bahia, Ceará
Amblyseius sp	–	20	–	Bahia, Maranhão, Pará, Sergipe
Amblyseius tamatavensis Blommers	3	18	–	Bahia, Ceará, Pará, Rio G. Norte, Sergipe
Cocoseius elsalvador Denmark & Andrews	–	4	–	Bahia, Pará, Pernambuco
Euseius alatus DeLeon	26	174	1	Alagoas, Bahia, Ceará, Maranhão, Pará, Paraiba, Pernambuco, Rio G. Norte, Sergipe
Euseius concordis Chant	–	49	–	Bahia, Ceará, Maranhão, Rio G. Norte
Iphiseoides zuluagai Denmark & Muma	–	49	–	Alagoas, Bahia, Ceará, Maranhão, Paraiba, Pernambuco, Rio G. Norte, Sergipe
Neoseiulus baraki Athias–Henriot	350	–	–	Alagoas, Bahia, Ceará, Maranhão, Pará, Paraiba, Pernambuco, Rio G. Norte
Neoseiulus gracilis Muma	–	–	3	Bahia, Paraiba
Neoseiulus paspalivorus DeLeon	821	–	16	Alagoas, Bahia, Ceará, Maranhão, Pará, Paraiba, Pernambuco, Piaui, Rio G. Norte, Sergipe
Neoseiulus recifensis Gondim Jr. & Moraes	41	17	8	Alagoas, Ceará, Paraiba, Pernambuco, Rio G. Norte
Prorpioseiopis canaensis Muma	1	–	1	Alagoas, Bahia
Typhlodromina subtropica Muma & Denmark	1	1	–	Bahia, Pernambuco
Typhlodromips cananeiensis Gondim Jr. & Moraes	4	4	–	Bahia
Typhlodromips mangleae DeLeon	–	4	–	Maranhão
Typhlodromus transvaalensis Nesbitt	–	–	1	Pernambuco
Typhlodromus aff. vulgaris Ehara[1]	4	1	–	Alagoas, Pernambuco, Rio G. Norte
Cheyletidae				
Cheletomimus sp	5	–	–	Piaui
Hemicheyletia sp	22	8	–	Alagoas, Bahia, Ceará, Maranhão, Pernambuco, Piaui, Rio G. Norte
Mexecheles sp	1	–	–	Ceará
Bdellidae				
Bdella distincta Baker & Balogh	78	42	2	Alagoas, Bahia, Ceará, Maranhão, Pará, Paraiba, Pernambuco, Piaui, Rio G. Norte, Sergipe
Spinibdella sp	3	1	–	Alagoas, Pernambuco, Rio G. Norte, Sergipe
Cunaxidae				
Armascirus sp	2	12	–	Ceará, Maranhão, Pernambuco
Cunaxoides sp	–	1	–	Pará
Neocunaxoides sp	–	–	1	Pará
Pulaeus sp	–	–	1	Maranhão
Stigmaeidae				
Agistemus floridanus Gonzalez	–	13	–	Bahia, Maranhão, Pernambuco

[1] New record in Brazil; Ac, attached coconuts; Lf, leaflets; Fc, fallen coconuts.

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Table 6. Univariate analyses of variance of the effects of plant parts and predominant vegetation on the diversity of mites on coconut palms in the surveyed areas.

	Source of variation					
	Plant parts			Predominant vegetation		
	df	F	*P*	df	F	*P*
Overall diversity	1	67.05	0.000	4	2.40	0.05
Diversity predatory mites	1	93.87	0.000	4	39.16	0.000
Diversity phytophagous mites	1	2.64	0.105	4	0.76	0.55
Overall evenness	1	400.97	0.000	4	5.59	0.000
Evenness predatory mites	1	264.79	0.000	4	33.56	0.000
Evenness phytophagous mites	1	4.22	0.042	4	0.55	0.696

$P > 0.05$ (ANOVA) denote no significant differences within source of variation for the given parameter.

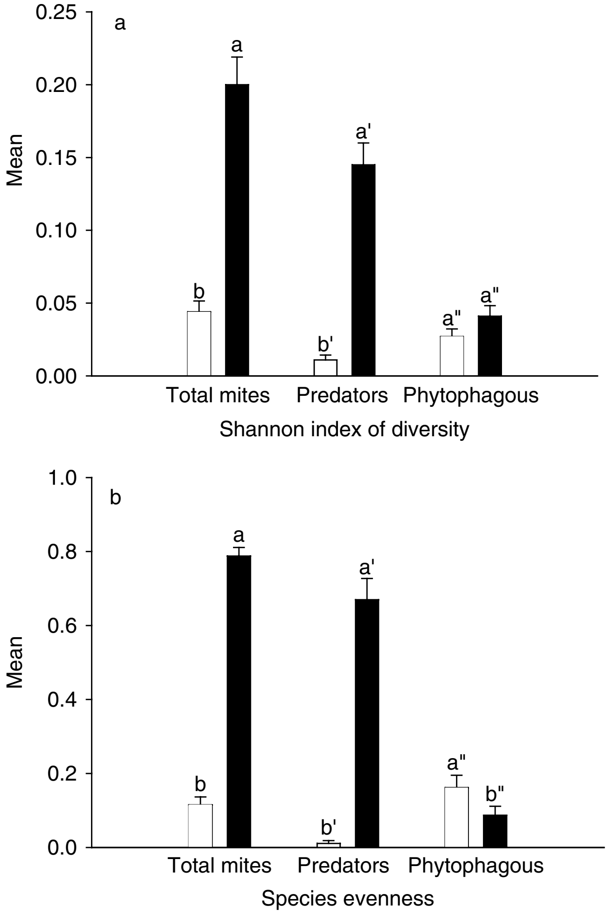

Fig. 2. (a) Mean diversity (±SE) and (b) mean species evenness (±SE) of all mites together, predatory mites and phytophagous mites on (■) leaflets and (□) attached coconuts. Different letters on top of bars indicate significant differences at $P < 0.05$.

Species diversity

The overall mite diversity according to the Shannon index and species evenness differed significantly between plant parts (table 6). The index was higher on leaflets than on attached coconuts. Similarly, the diversity of predatory mites (as a functional group) was significantly higher on leaflets than coconuts. The diversity of the other main functional group – the phytophagous mites – was similar on coconuts and leaflets (fig. 2a). The highest overall mite diversity was found in the states Pará (0.172±0.06 SE), Alagoas (0.113±0.03 SE) and Maranhão (0.086±0.03 SE), whereas the diversity was the lowest in the states Piauí (0.004±0.01 SE) and Pernambuco (0.006±0.01 SE). Based on the evenness index, the numbers of predatory mites were significantly more evenly distributed among species on leaflets than on coconuts, whereas the evenness of phytophagous mites was higher on coconuts than on leaflets (fig. 2b). The overall mite evenness was the highest in the states Pará (0.484±0.15 SE) and Maranhão (0.255±0.10 SE). Likewise, the evenness of phytophagous mites was highest in these states and lowest in Piauí (0.007±0.01 SE) and Pernambuco (0.009±0.01 SE). Predatory mite diversity and evenness on attached coconuts varied significantly with the predominant surrounding vegetation. In contrast, the corresponding indices of phytophagous mites were not influenced by the predominant surrounding vegetation (table 6). Mite diversity and species evenness were higher in fields surround by tropical Amazonian rainforest and seasonal forest and lower in the type Caatinga (fig. 3).

Geographic distribution and influence of predominant surrounding vegetation and climatic factors

Aceria guerreronis

Aceria guerreronis was present in all surveyed states and infestation was recorded in 87% of the sampling sites with on average 40,756±4724 (SE) mites per 30 coconuts (1358±157 SE, mites coconut^{-1}). Differences in the average densities of *A. guerreronis* were significant among states (df=9, F=4.12, $P = 0.001$). The average number of *A. guerreronis* per coconut was higher in the state Pernambuco (2909±736 SE, mites coconut^{-1}), followed by Rio Grande do Norte and Ceará (1933±536 SE, mites coconut^{-1}) and Piauí (1518±280 SE, mites coconuts^{-1}) (fig. 4). Maximum infestation was recorded in Ipojuca-Pernambuco with *ca.* 8000 mites coconut^{-1}. Circa 6000 and 7000 mites coconut^{-1} were recorded in Acaraú and Ibicuitaba, respectively, both in Ceará, and 4000–5000 mites coconut^{-1} in Muriú and Búzios (Rio Grande do Norte) as well as in Mataraca in the state of Paraíba. Minimum infestation levels were recorded in the states of Pará (158±139 SE, mites coconut^{-1}) and Maranhão (360±131 SE, mites coconut^{-1}) (fig. 4). Fields in the localities Santa Isabel, São Caetano de Odivelas and Salinóplolis in the

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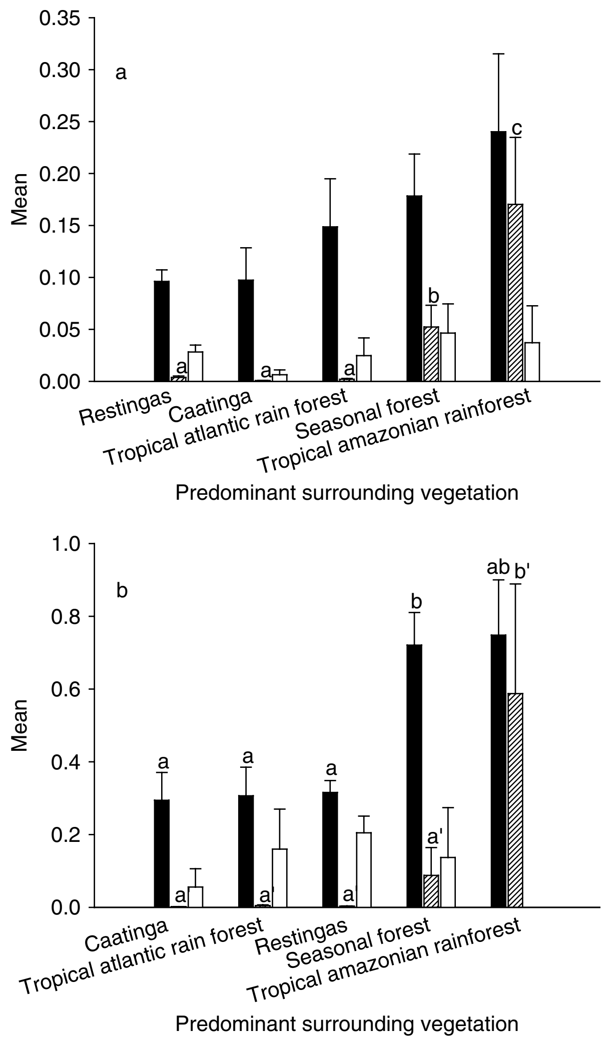

Fig. 3. (a) Mean diversity (±SE) and (b) mean species evenness (±SE) of (■) all mites together, (▨) predatory mites, and (□) phytophagous mites in dependence of the predominant surrounding vegetation. Different letters on top of bars indicate significant differences at $P<0.05$ within species; if no letters are given the difference is not significant.

state Pará and the localities Carutapera, Guimarães, Pinheiro in the state Maranhão were free of infestation by *A. guerreronis*. The highest mean densities of *A. guerreronis* were observed in sites with the following characteristics: dry period of 6–8 months; average annual temperature of 27–30°C; average annual relative humidity of 50–70%; average annual precipitation of 300–600 mm; as well as in periods between the rainy and the dry seasons. The lowest mean densities of *A. guerreronis* were observed in sites with the following characteristics: dry period of 4–5 months; average annual relative humidity of 80–90%; average annual precipitation of 2400–3000 mm (figs 5, 6a,b,c).

Other phytophagous mites

Infestation by tarsonemids was often associated with that by *A. guerreronis*. The densities of tarsonemid mites did not significantly differ among states (df = 9, F = 1.39, $P=0.21$). Coconut plantations in Miaí de Baixo and Paripueira, in the state Alagoas, had the highest infestation levels by the two tarsonemid species (1339 ± 622 SE, mites coconut^{-1}). Very few specimens of this family were collected in Piauí and Pará (9 ± 7 SE, mites coconut^{-1}) (fig. 4). The average length of drought period significantly affected the densities of tarsonemid mites (df = 3, F = 3.47, $P=0.02$).

Predatory mites

Among the three most abundant predatory mites, *N. baraki*, *P. bickleyi* and *N. paspalivorus*, only the densities of the latter were significantly affected by temperature and precipitation (table 7). *Neoseiulus paspalivorus* was collected in all states except Pará; with the highest densities per coconut – 7 mites coconut^{-1} – occurring during the dry season in Caponga (Ceará) and Pedra do Sal (Piauí) (fig. 7). This mite was abundant in localities characterized by six to eight dry months per year, an average temperature of 27–30°C, a relative humidity between 70–80% and precipitation from 600 to 1500 mm year^{-1} (figs 5, 6a,b,c). In contrast, *N. baraki* was found in all states except Piauí and was most abundant – 4 mites coconut^{-1} – in Itamaracá (Pernambuco), Maragogi (Alagoas) and Pitimbu (Paraiba) (fig. 7). The mite was predominant in areas characterised by one to three dry months per year, temperature between 24–27°C, relative humidity between 70–80% and precipitation between 2400–3000 mm year^{-1} (figs 5, 6a,b,c). *Proctolaelaps bickleyi* was found in higher numbers in Sergipe and Pará; but, unlike *N. paspalivorus* and *N. baraki*, *P. bickleyi* abundance did not depend on any particular climatic condition (figs 5, 6a,b,c). *Amblyseius largoensis* was found on coconuts in all states but occurred in relatively higher numbers in Maragogi and Neópolis (Sergipe), although this mite species was predominant on leaflets (table 5). Other species – *Proctolaelaps* sp nov, *Lasioseius subterraneus* Chant (Ascidae), *B. distincta*, *N. recifensis* and several other species – accounted for 17% of the total number of predatory mites collected on coconuts (table 5).

Discussion

Our work shows that *A. guerreronis* is widely distributed on coconut palms in Brazil, where it is clearly the most important phytophagous mite on attached coconuts. We, furthermore, found that numerous predatory mite species occur on coconut palms. A few of them occur under the bracts of attached coconuts in association with *A. guerreronis* and seem promising natural enemies of this pest. Our survey revealed *N. paspalivorus* along with *N. baraki*, *P. bickleyi* and *Proctolaelaps* sp nov, as well as *N. recifensis*, as predators that deserve further investigations as potential biocontrol agents of *A. guerreronis* and as potential candidates for introduction into other continents. The diversity of predatory mites was higher on leaflets than on attached coconuts and the predominant surrounding vegetation and climate related factors influenced the occurrence of these predators. Several species of phytophagous and predatory mites were found for the first time on coconut palms in Brazil. Other antagonistic organisms of *A. guerreronis*, such as fungi, were not found on coconut palms during our survey. However, the emphasis of the present work was placed on predatory mites and only minor attention was given to the detection

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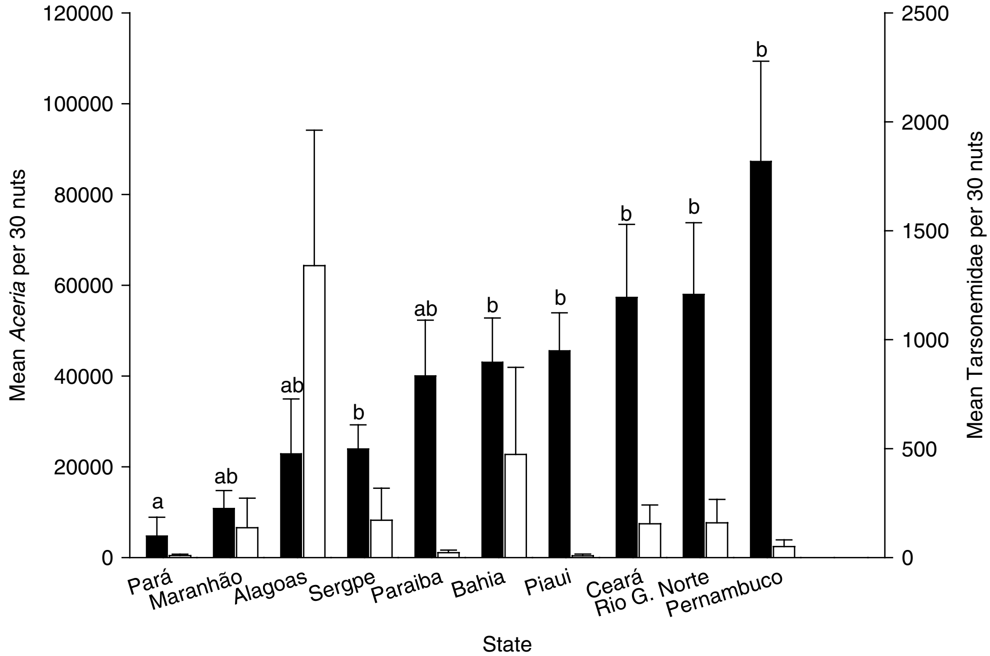

Fig. 4. Mean number per 30 coconuts (±SE) of (■) *Aceria guerreronis* and (□) Tarsonemidae per state. Different letters on top of bars indicate significant differences at $P < 0.05$ within species; if no letters are given the difference is not significant.

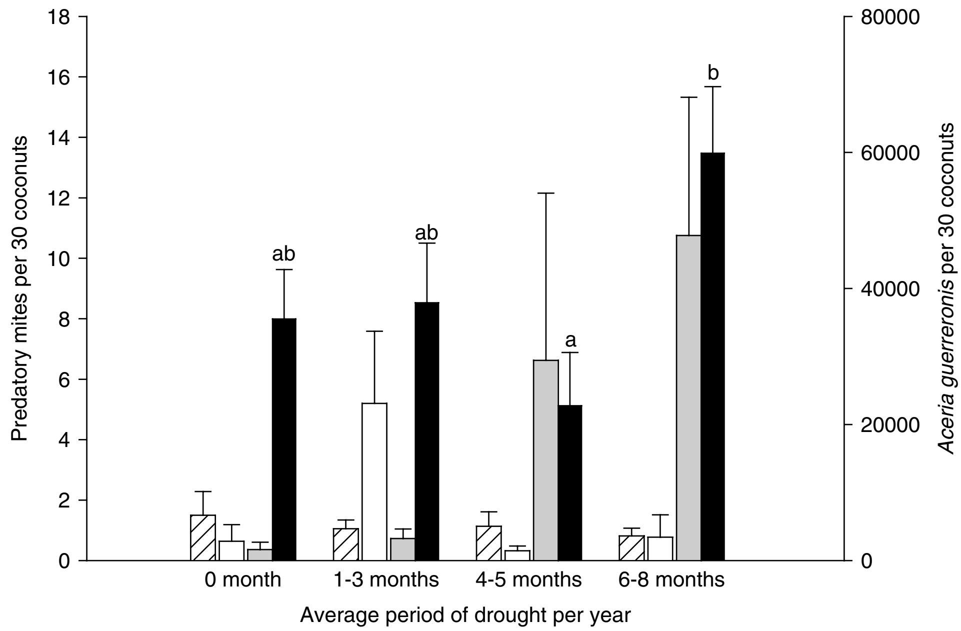

Fig. 5. Mean number per 30 coconuts (±SE) of (■) *Aceria guerreronis* and the predatory mites (▩) *Neoseiulus paspalivorus*, (□) *Neoseiulus baraki* and (▨) *Proctolaelaps bickleyi* in dependence of the average period of drought per year. Different letters on top of bars indicate significant differences at $p < 0.05$ within species; if no letters are given the difference is not significant.

of entomopathogenic fungi. Fungi of the order Entomophtorales were previously recorded from palms in Brazil (Van der Geest *et al.*, 2002), India (Sreerama Kumar *et al.*, 2001), Cuba and Mexico (Cabrera, 2002). Only one specimen of the family Ameroseiidae was found on coconut palms during our survey in Brazil. This contrasts sharply with findings from Benin (Koffi Negloh, personal communication), India (Haq, 2001) and Sri Lanka (Ramaraju *et al.*,

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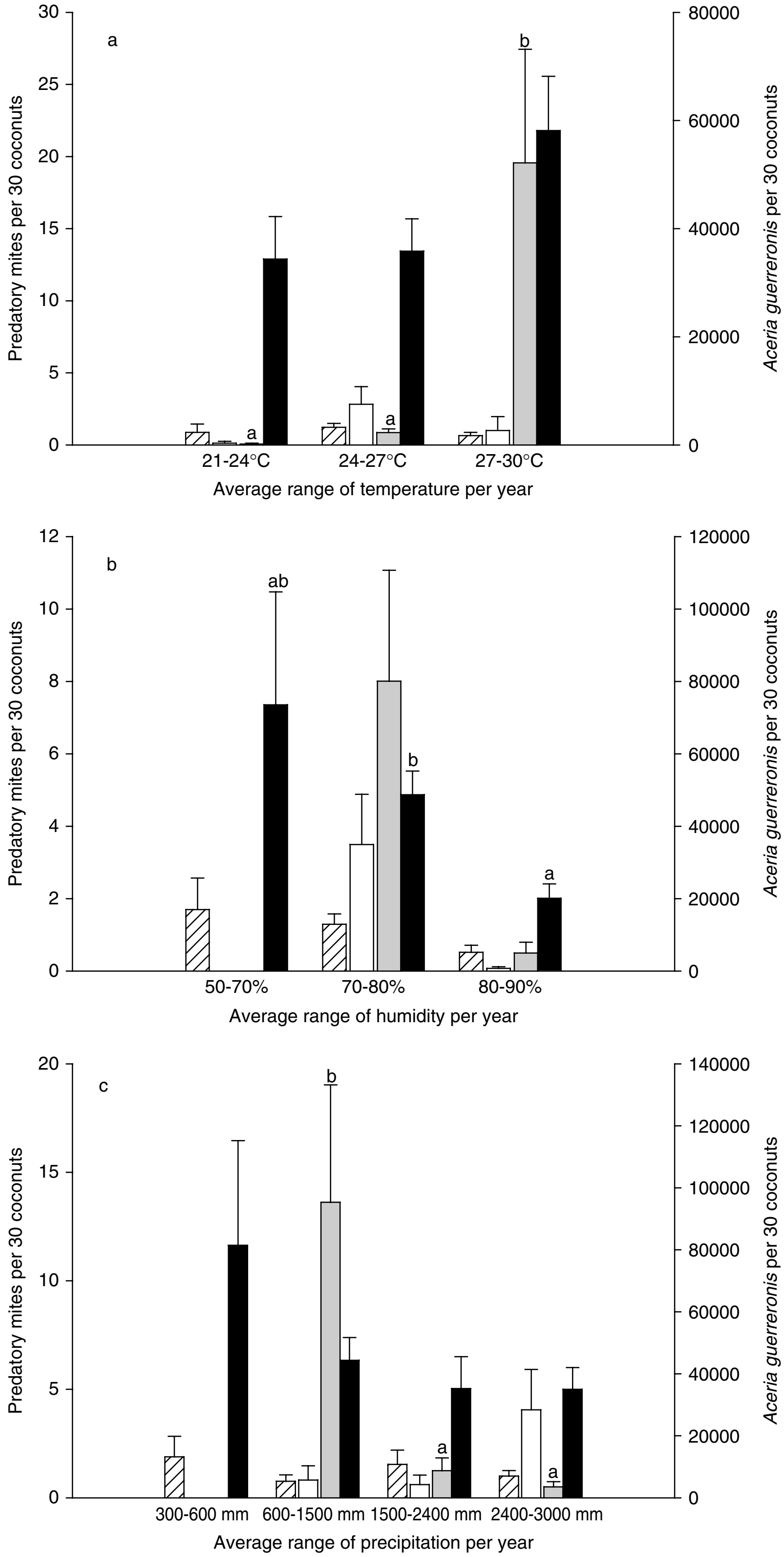

Fig. 6. Mean number per 30 coconuts (±SE) of (■) *Aceria guerreronis* and the predatory mites (■) *Neoseiulus paspalivorus*, (□) *Neoseiulus baraki* and (▨) *Proctolaelaps bickleyi* in dependence of the average range of (a) temperature, (b) humidity, and (c) precipitation. Different letters on top of bars indicate significant differences at $p < 0.05$ within species; if no letters are given the difference is not significant.

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Table 7. Univariate analyses of variance for the effects of drought, temperature, humidity and precipitation on the abundance of *Aceria guerreronis*, *Neoseiulus paspalivorus*, *Neoseiulus baraki* and *Proctolaelaps bickleyi*.

Source of variation	*A. guerreronis*			*N. paspalivorus*			*N. baraki*			*P. bickleyi*		
	df	F	*P*	df	F	*P*	df	F	*P*	df	F	*P*
Average drought	3	3.01	0.03	3	2.27	0.10	3	0.99	0.42	3	0.40	0.76
Average temperature	2	2.02	0.14	2	5.52	0.01	2	0.70	0.50	2	0.80	0.45
Average humidity	2	3.43	0.04	1	1.52	0.23	1	3.03	0.10	2	0.96	0.39
Average precipitation	3	1.75	0.16	2	6.81	0.00	2	0.94	0.41	3	1.90	0.14

$P > 0.05$ (ANOVA) denote no significant differences within source of variation for the given species.

2002) where ameroseiids are abundant on coconut inflorescences.

The very high number of *A. guerreronis* and Tarsonemidae on attached coconuts reduced the Shannon index, i.e. the diversity of mites associated with coconut palms in the surveyed areas. Contrarily, the higher evenness index on leaflets indicates uniformity in the repartition of the number of mites among the different species present. The lower number of predatory mites and low mite diversity on coconuts seems to be a consequence of the secluded environment occupied by *A. guerreronis* under the coconut bracts. *Aceria guerreronis* and the slightly larger tarsonemid mites seem well adapted to live in such tight spaces, which are not readily accessible to larger herbivorous competitors and/or larger natural enemies. The high diversity and number of potential natural enemies outside the bracts may have been an important selective force for *A. guerreronis* to move under the bracts. The theory of enemy-free space predicts that selection favours herbivores that escape from their natural enemies by shifting to a novel host plant or a certain site of the original host plant where they are better protected from natural enemies than before (Jeffries & Lawton, 1984). Only morphologically flattened predatory mites were present in high numbers under the bracts. The relatively large size of *A. largoensis*, *B. distincta* and *P. bickleyi* hampers access under the bracts of young coconuts compared to the three *Neoseiulus* species. The new species of *Proctolaelaps* may overcome that obstacle because of its smaller size and body shape resembling that of the most common *Neoseiulus* species found.

Interactions between climatic factors and surrounding vegetation apparently play a key role in the diversity of predatory mites on coconut palms, especially on leaflets, as they may allow the establishment and the development of a larger number of organisms, including mites and plants (Perring, 2002). High plant diversity in the region of Pará and Maranhão offers suitable conditions for various predatory mites in comparison to the vegetation of the littoral, which is composed of beaches, dunes and shrubs, with strong human influences on the original vegetation. Fields are very contiguous along the littoral from Piauí towards Bahia but isolated in most parts of Pará and Maranhão. Neighbouring vegetation certainly influences the mite fauna in monocultures and may represent a reservoir of beneficial

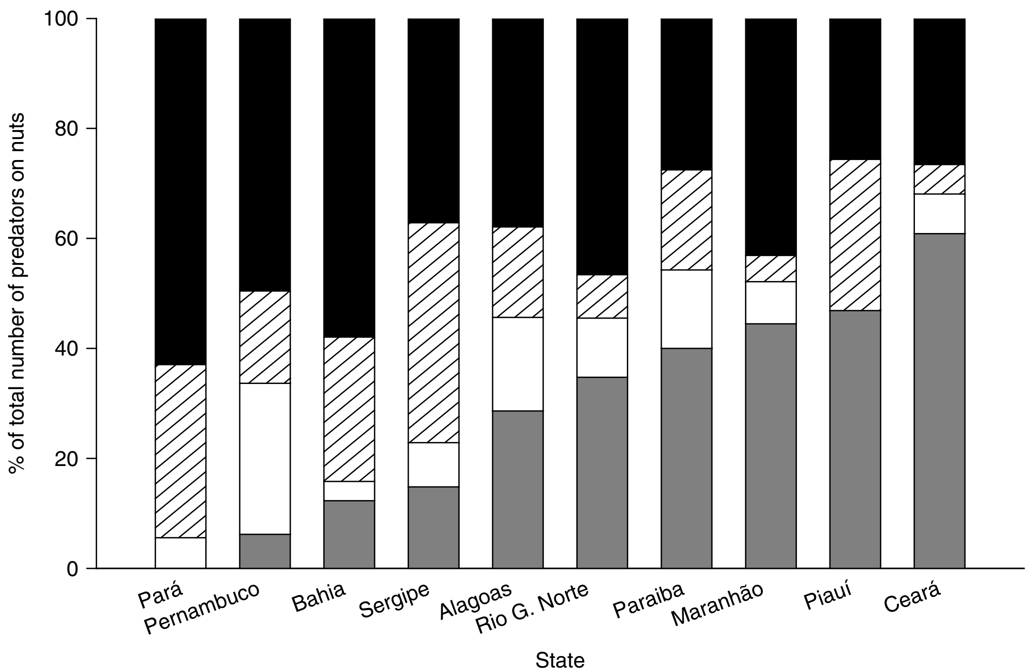

Fig. 7. Proportional distribution of (■) *Neoseiulus paspalivorus*, (□) *Neoseiulus baraki*, (▨) *Proctolaelaps bickleyi* and (■) other predatory mites per state.

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arthropods especially phytoseiid mites, may provide alternative food, or may be a temporal refuge before they move from there to cultivated plants (e.g. Tuovinen, 1994; Demite & Feres, 2005; Tixier *et al*., 2006).

The occurrence of *A. guerreronis* was highly variable in the surveyed areas. Long drought periods and elevated temperature seem to be decisive factors favouring the occurrence and establishment of *A. guerreronis*. Plant water and nutrition status are widely known to affect the abundance of herbivores and at times their associated natural enemies on coconut palms (Perring, 2002). Plant water stress could lead to separation of the bracts from the coconut surface and, thus, allow entry of the mites. Although coconut palm tolerates extended drought periods, coconut production is low and the maturation period of young coconuts is prolonged when adequate precipitation or irrigation is lacking (Foale, 2003). Young coconuts from fields in areas with dry ambient conditions would be exposed to drought that would allow in turn a better settlement of the mite in dry areas such as Moju (Pará), parts of Maranhão from Barreirinhas to the states Piauí, Ceará and Rio Grande do Norte, as well as in dry regions of Pernambuco (Petrolina) and Bahia (Juazeiro). Moreover, it is negatively affected by heavy rain fall (Mariau, 1969; Zuluaga & Sanchez, 1971; Griffith, 1984). Regular rainfalls probably disrupt the spread and establishment of *A. guerreronis* in the dispersal phase, washing off mites migrating between bunches and dislodging them onto unsuitable vegetation or places with high incidence of natural enemies (Howard *et al*., 1990).

Ambient climatic conditions clearly have an effect on the prevalence and abundance of predatory mites. Our results showed clear trends in the distribution of the most important predatory mites according to the prevailing climatic factors: *N. paspalivorus* predominates in dry regions; and *N. baraki*, and especially *N. recifensis*, predominate in humid regions. This ecological zoning is ascribed to the innate physiological characteristics of each strain and the adaptation to the climatic factors prevailing in the respective regions. The absence of the *Neoseiulus* species in the driest regions of Moju, Petrolina and Juazeiro indicates their preference for areas in which the direction of the prevailing winds plays a dominant role (littoral climate). There was no trend in the distribution of *P. bickleyi* and *A. largoensis*. The former was most common on fallen coconuts, while the latter is apparently adapted to a wide spectrum of ecological conditions as it is a pan-tropical species (Moraes *et al*., 2004).

Aceria guerreronis is present in all coconut-producing states in Brazil, but its level of incidence is certainly low compared to Africa and Asia. According to regular evaluations conducted by the largest coconut producer in Brazil, in the state of Pará, the average level of incidence of *A. guerreronis* is about 12% of all coconuts. During this work, the highest levels of incidence of *A. guerreronis* seemed to occur in the fields that were apparently not properly maintained by growers (Lawson-Balagbo, personal observations).

In this study, we were most interested in identifying natural enemies that could serve as potential candidates for introduction to Africa and elsewhere where *A. guerreronis* is thought to have invaded. The suspected place of origin of *A. guerreronis* is the Americas, but the original host plant is still unknown (Navia *et al*., 2005). The present work was the first of that amplitude conducted on this continent on coconut palms. The present prevailing thought is that the original host of *A. guerreronis* could be a palm (or some other type of host plant) native to the Americas, from which *A. guerreronis* switched to coconut palm (Moraes & Zacarias, 2002). The mite was reported on other palms of the family Arecaceae since its original description from coconut (Keifer, 1965) – on buds of *Lytocaryum weddellianum* H.A. Wendl in Brazil (Flechtmann, 1989) and queen palm *Syagrus romanzoffiana* (Cham.) Glassm in California, USA (Ansaloni & Perring, 2002), as well as on fruits of *Borassus flabellifer* L. in Sri Lanka (Moraes, personal communication) and India (Ramaraju & Rabindra, 2002). Surveys were conducted on many native and introduced palms in Brazil but *A. guerreronis* was never found, not even on the alternative hosts from which it had been reported previously (Gondim *et al*., 2000; Arruda Filho, 2002; Navia & Flechtmann, 2002). The presumed place of origin of the coconut palm is South-East Asia to the Pacific Islands of Papua New Guinea (Persley, 1992; Lebrun *et al*., 1998), but *A. guerreronis* has never been reported from these regions. Although some observations have been made on natural enemies associated with *A. guerreronis* on coconut palms in Colombia, Mexico, Cuba, Puerto Rico, and Florida (Zuluaga & Sánchez, 1971; Estébanes, 1976; Howard *et al*., 1990; Rodríguez, 1990; Moore & Howard, 1996), very little is known about them in these or any other country of the Americas. It would, therefore, be interesting to continue the search for natural enemies on coconut and other palms in other parts of the Americas. Nonetheless, the predominant predators found in our survey on attached coconuts, i.e. *N. baraki*, *N. paspalivorus* and *P. bickleyi*, are the same in American, African and Asian coconut growing regions (Howard *et al*., 1990, Moraes *et al*., 2004; Koffi Negloh, personal communication). At least the former two species seem morphologically adapted to live under the perianth, making them promising natural enemies of *A. guerreronis*. Life history studies, as well as predation tests, are on the way to evaluate the biocontrol potential of each of the predator species found in this study.

Acknowledgements

The authors thank the climber J.F. de Queiroz for his readiness and excellent work. We thank A. Walzer and K. Fiaboe for the comments on this paper. We are also are grateful to C. Araujo, W. Melo, D. Amorin, F. Rodriguez, G. Vasconcelos, E. Britto, J. de Souza, A. Galvão, A. Reis, students at the laboratory of acarology of UFPRE for their technical support and to the secretariat of UFRPE for the helpful logistic provided during this work. This work was supported by the International Institute of Tropical Agriculture (IITA) through a grant from the Austrian Ministry of Finance and by in-kind contribution from IITA, FEALQ, Fundação de Estudos agrarios Luiz de Queiroz, Piracicaba-Sao Paulo, Brazil and BOKU. This work is part of the PhD thesis of the senior author.

References

Ansaloni, T. & Perring, T.M. (2002) Biology of *Aceria guerreronis* (Acari: Eriophyidae) on queen palm *Syagrus romanzoffiana* (Areaceae). *International Congress of Acarology* **30**, 63–70.

Arruda Filho, G.P. (2002) Ácaros em Arecaceae da mata Atlântica do estado de São Paulo, com êmfase na família

Stigmaeidae (Acari: Raphignatoidea). Master study, Piracicaba-SP, Brazil, 89 pp.

Bühl, A. & Zöfel, P. (2004) SPSS Version 12. Einführung in die moderne Datenanalyse unter Windows. Pearson Studium, Germany, 744 pp.

Cabrera, R.I.C. (2002) Biological control of the coconut mite *Aceria guerreronis* (Acari: Eriophyidae) with the fungus *H. thompsonii* and its possible integration with other control methods. pp. 89–100 *in* Fernando, L.C.P., Moraes, G.J. & Wickramananda, I.R (*Eds*) *Proceedings of the International Workshop on Coconut Mite* (Aceria guerreronis). Coconut Research Institute, Sri Lanka. 6–8 January 2000, Coconut Research Institute, Sri Lanka.

Demite, P.R. & Feres, R.J.F. (2005) Influência de vegetação vizinha na distribuição de ácaros em seringal (*Hevea brasiliensis* Muell.Arg., Euphorbiaceae) em São José do Rio Preto, SP. *Neotropical Entomology* **34**, 829–836.

Estébanes, M.L. (1976) Ácaros despredadores de *Eriophyes guerreronis* (Keifer) en la zona Tecpán de Galeana. *Folia Entomologica Mexicana* **39–40**, 41–42.

FAO (2005) FAO Agricultural Statistics. Food and Agriculture Organization of the United Nations, http://www.fao.org.

Fernando, L.C.P., Wickramananda, I.R. & Aratchige, N.S. (2002) Status of coconut mite, *Aceria guerreronis* in Sri Lanka. pp. 1–8 *in* Fernando, L.C.P., Moraes, G.J. & Wickramananda, I.R. (*Eds*) *Proceedings of the International Workshop on Coconut Mite* (Aceria guerreronis). Coconut Research Institute, Sri Lanka. 6–8 January 2000, Coconut Research Institute, Sri Lanka.

Flechtmann, C.H.W. (1989) *Cocos weddelliana* H. Wendl. (Palmae: Arecaceae), a new host plant for *Eriophyes guerreronis* (Keifer, 1965) (Acari: Eriophyidae) in Brazil. *International Journal of Acarology* **15**, 241.

Foale, M. (2003) The coconut odyssey: the bounteous possibilities of the tree of life. *Australian Centre for International Agricultural Research* **101**, 132 pp.

Gondim Jr, M.G.C. & Moraes, G.J. (2001) Phytoseiid mites (Acari: Phytoseiidae) associated with palm trees (Arecaceae) in Brazil. *Systematic and Applied Acarology* **6**, 65–94.

Gondim Jr, M.G.C., Flechtmann, C.H.W. & Moraes, G.J. (2000) Mites (Arthropoda: Acari) associates of palms (Arecaceae) in Brazil V. Descriptions of four new species in the Eriophyoidea. *Systematic and Applied Acarology* **5**, 99–110.

Griffith, R. (1984) The problem of the coconut mite, *Eriophyes guerreronis*, in the coconut groves of Trinidad and Tobago. pp. 128–132 *in* Webb, R., Knausenberger, W. & Yntema, L. (*Eds*) *Proceedings of the 20th Annual Meeting of the Caribbean Food Crops Society*. East Caribbean Center, College of the Virgin Islands and Caribbean Food Crops Society, October 1984, St. Croix, Virgin Islands, USA.

Haq, M.A. (2001) Life cycle and behaviour of the coconut mite *Neocypholaelaps stridulans* (Evans) (Acari: Ameroseiidae) in India. pp. 361–365 *in* Halliday, R.B., Walter, D.E., Proctor, H.C., Norton R.A. & Colloff M.J. (*Eds*) *Proceedings of the 10th International Congress of Acarology*. Australia, 2001, CSIRO Publishing, Collingwood, 657 pp.

Howard, F.W., Abreu-Rodriguez, E. & Denmark, H.A. (1990) Geographical and seasonal distribution of the coconut mite, *Aceria guerreronis* (Acari: Eriophyidae), in Puerto Rico and Florida, USA. *Journal of Agriculture of the University of Puerto Rico* **74**, 237–251.

Jeffries, M.J. & Lawton, J.H. (1984) Enemy free space and the structure of ecological communities. *Biological Journal of the Linnean Society* **23**, 269–286.

Keifer, H.H. (1965) Eriophyid studies B-14. Sacramento, California Department of Agriculture, Bureau of Entomology, pp. 6–8.

Lebrun, P., Grivet, L. & Baudoin, L. (1998) Dissémination et domestication du cocotier à la lumière des marqueurs RFLP. *Plantations Recherche Développement* **5**, 233–245.

Mariau, D. (1969) *Aceria guerreronis* Keifer: récent ravageur de la cocoteraie Dahoméenne. *Oléagineux* **24**, 269–272.

Mariau, D. (1977) *Aceria* (*Eriophyes*) *guerreronis*: un important ravageur des cocoteraies africaines et américaines. *Oléagineux* **32**, 101–111.

Moore, D. (2000) Non-chemical control of *Aceria guerreronis* on coconuts. *Biocontrol News and Information* **21**, 83–87.

Moore, D. & Howard, F.W. (1996) Coconuts. pp 561–570 *in* Lindquist, E.E., Sabelis, M.W. & Bruin, J. (*Eds*) *Eriophyoid Mites: Their Biology, Natural Enemies and Control*. Amsterdam, Elsevier.

Moore, D., Alexander, L. & Hall, R.A. (1989) The coconut mite, *Eriophyes guerreronis* Keifer in St. Lucia: yield losses and attempts to control it with acaricide, polybutene and *Hirsutella* fungus. *Tropical Pest Management* **35**, 83–89.

Moraes, G.J. & Zacarias, M.S. (2002) Use of predatory mites for the control of eriophyid mites. pp. 78–88 *in* Fernando, L.C.P., Moraes, G.J. & Wickramananda, I.R. (*Eds*) *Proceedings of the International Workshop on Coconut Mite* (Aceria guerreronis). Coconut Research Institute, Sri Lanka. 6–8 January 2000. Coconut Research Institute, Sri Lanka.

Moraes, G.J., McMurtry, J.A, Denmark, H.A. & Campos, C.B. (2004) A revised catalogue of the family Phytoseiidae. *Zootaxa* **434**, 1–494.

Navia, D. & Flechtmann, C.H.W. (2002) Mites (Arthropoda: Acari) associates of palms (Arecaceae) in Brazil: VI. New genera and new species of Eriophyidae and Phytoptidae (Prostigmata: Eriophyoidea). *International Journal of Acarology* **28**, 121–146.

Navia, D., Moraes, G.J., Roderick, G. & Navavajas, M. (2005) The invasive coconut mite *Aceria guerreronis* (Acari: Eriophyidae): origin and invasion sources inferred from mitochondrial (16S) and nuclear (ITS) sequences. *Bulletin of Entomological Research* **95**, 505–516.

Perring, T.M. (2002) Eriophyiod mites: Special considerations in applied ecological research. pp. 71–77 *in* Fernando, L.C.P., Moraes, G.J. & Wickramananda, I.R. (*Eds*) *Proceedings of the International Workshop on Coconut Mite* (Aceria guerreronis). Coconut Research Institute, Sri Lanka. 6–8 January 2000. Coconut Research Institute, Sri Lanka.

Persley, G.J. (1992) *Replanting the Tree of Life: Towards an International Agenda for Coconut Palm Research*. 156 pp. Wallingford, CAB International.

Pielou, E.C. (1966) The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology* **13**, 131–144.

Ramaraju, K. & Rabindra, R.J. (2002) Palmyra, *Borassus flabellifer* L. (Palmae) a host of the coconut eriophyid mite *Aceria guerreronis* Keifer. *Pest Management in Horticulture Ecosystems* **7**, 149–151.

Ramaraju, K., Natarajan, K., Sundara Babu, P.C., Palanisamy, S. & Rabindra, R.J. (2002) Studies on coconut eriophyid mite, *Aceria guerreronis* Keifer in Tamil Nadu, India. pp. 13–31 *in* Fernando, L.C.P., Moraes, G.J. & Wickramananda, I.R. (*Eds*) *Proceedings of the International Workshop on Coconut Mite* (Aceria guerreronis). Coconut Research Institute, Sri Lanka. 6–8 January 2000. Coconut Research Institute, Sri Lanka.

Rodríguez, N. (1990) *Neoseiulus paspalivorus* (Acari: Phytoseiidae) presente en el cultivo del cocotero. *Ciencia y Técnica en la Agricultura* **13**, 35–39.

Santana, D.L.Q. & Flechtmann, C.H.W. (1998) Mite (Arthropoda, Acari) associates of palms (Arecaceae) in Brazil I. Present status and new records. *Revista Brasileira de Zoologia* **15**, 959–963.

Seaman, E.K., Goluboff, E., Barchama, N. & Fisch, H. (1996) Accuracy of semen counting chambers as determined by the use of latex beads. *American Society for Reproductive Medicine* **66**, 662–665.

Seguni, Z. (2002) Incidence, distribution and economic importance of the coconut eriophyid mite, *Aceria guerreronis* Keifer in Tanzanian coconut based cropping systems. pp. 54–57 *in* Fernando, L.C.P., Moraes, G.J. & Wickramananda, I.R (*Eds*) *Proceedings of the International Workshop on Coconut Mite* (Aceria guerreronis). Coconut Research Institute, Sri Lanka. 6–8 January 2000. Coconut Research Institute, Sri Lanka.

Shannon, C.E. & Weaver, W. (1949) *The Mathematical Theory of Communication*. Urbana, University of Illinois Press, 117 pp.

Siriwardena, P.H.A.P., Fernando, L.C.P. & Peiris, T.S.G. (2005) A new method to estimate a population size of coconut mite, *Aceria guerreronis*, on a coconut. *Experimental and Applied Acarology* **37**, 123–129.

Sreerama Kumar, P. & Singh, S.P (2000) *Hirsutella thompsonii*: the best biological control option for the management of the coconut mite in India. *Indian Coconut Journal Cochin* **31**, 11–17.

Sreerama Kumar, P., Singh, S.P. & Gopal, T.S. (2001) Natural incidence of *Hirsutella thompsonii* Fisher on the coconut eriophyid mite, *Aceria guerreronis* Keifer in certain districts of Karnataka and Tamil Nadu in India. *Journal of Biological Control* **15**, 151–156.

Tixier, M.-S., Kreiter, S., Cheval, B., Guichou, S., Auger, P. & Bonafos, R. (2006) Immigration of phytoseiid mites from surrounding uncultivated areas into a newly planted vineyard. *Experimental and Applied Acarology* **39**, 227–242.

Tuovinen, T. (1994) Influence of surrounding trees and bushes on the phytoseiid mite fauna on apple orchard trees in Finland. *Agriculture, Ecosystems & Environment* **50**, 39–47.

Van der Geest, L.P.S., Moraes, G.J., Navia, D. & Tanzini, M.R. (2002) New records of pathogenic fungi in mites (Arachnida: Acari) from Brazil. *Neotropical Entomology* **31**, 493–495.

Vietmeyer, N.D. (1986) Lesser-known plants of potential use in agriculture and forestry. *Science* **232**, 1379–1384.

Zuluaga, C.I. & Sánchez, P.A. (1971) La roña o escoriación de los frutos del cocotero (*Cocos nucifera* L.) en Colombia. *Oléagineux* **26**, 767–770.