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BIOLOGICAL CONTROL

Status of *Aceria guerreronis* Keifer (Acari: Eriophyidae) as a Pest of Coconut in the State of Sao Paulo, Southeastern Brazil

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Arecaceae, biological control, coconut mite, *Cocos nucifera*, predatory mites

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Abstract

The coconut mite, *Aceria guerreronis* Keifer, is one of the main pests of coconut palms (*Cocos nucifera*) in northeastern Brazil. The objective of this study was to evaluate the levels of the coconut mite and other mites on coconut palms in the state of São Paulo and to estimate the possible role of predatory mites in the control of this pest. The effect of cultivated genotypes and sampling dates on the mite populations was also estimated. We sampled attached fruits, leaflets, inflorescences, and fallen fruits. The coconut mite was the main phytophagous mite found on attached and fallen fruits, with average densities of 110.0 and 20.5 mites per fruit, respectively. The prevalent predatory mites on attached and fallen fruits were *Proctolaelaps bulbosus* Moraes, Reis & Gondim Jr. and *Proctolaelaps bickleyi* (Bram), both Melicharidae. On leaflets, the tenuipalpids *Brevipalpus phoenicis* (Geijsks) and *Tenuipalpus coyacus* De Leon and the tetranychid *Oligonychus modestus* (Banks) were the predominant phytophagous mites. On both leaflets and inflorescences, the predominant predatory mites belonged to the Phytoseiidae. *Neoseiulus baraki* (Athias-Henriot) and *Neoseiulus paspalivorus* (De Leon), predators widely associated with the coconut mite in northeastern Brazil and several other countries, were not found. The low densities of the coconut mite in São Paulo could be related to prevailing climatic conditions, scarcity of coconut plantations (hampering the dispersion of the coconut mite between fields), and to the fact that some of the genotypes cultivated in the region are unfavorable for its development.

Introduction

The coconut mite, *Aceria guerreronis* Keifer, is considered a major pest of coconut palm in the American, African, and Asian continents (Moore & Howard 1996, Haq *et al* 2002, Negloh *et al* 2010). It colonizes mainly the region between the bracts and the underlying surface of the fruit. Besides being protected from its predators in this micro-environment, the coconut mite has a high capacity for population increase on queen palm, *Syagrus romanzoffiana* (Arecaceae), allowing it to reach high population levels (Ansaloni & Perring 2004). The initial symptom of infestation is a triangular chlorosis on the surface of the fruit, which originates beneath the bracts. These spots increase in size progressing to a necrosis as the fruit develops. Often, attacked fruits may become deformed or fall off prematurely (de Moraes & Flechtmann 2008).

The control of this mite by chemicals is hampered by the protection provided by the bracts (Fernando *et al* 2002, Ramaraju *et al* 2002, de Moraes & Flechtmann 2008). Although some systemic chemicals have been shown effective in controlling the coconut mite (Mariau & Tchibozo 1973, Cabrera 1991), there is a major impediment to their use, as they can leave residues in the edible part of fruits.

Among the strategies for the control of the coconut mite, great attention has been given to biological control (de Moraes & Zacarias 2002). Several studies have been conducted in the Americas in search of promising biological control agents of this pest. Predatory mites of the families Ascidae s. lato, Bdellidae, Cheyletidae, Cunaxidae, and especially Phytoseiidae have been found in association with the coconut mite. In this publication, the term "ascoid" will be conveniently used to refer to species of two very similar families (Blattisociidae and Melicharidae), previously included in Ascidae (Lindquist & Evans 1965). The phytoseiids *Neoseiulus baraki* (Athias-Henriot) and *Neoseiulus paspalivorus* (De Leon) have been the predatory mites most commonly found associated with the coconut mite in several countries (Fernando *et al* 2003, Lawson-Balagbo *et al* 2008, Fernando *et al* 2010, Hountondji *et al* 2010, Negloh *et al* 2010). Laboratory studies have shown that this pest is a suitable food source for *N. baraki* and *N. paspalivorus* (Lawson-Balagbo *et al* 2007, Negloh *et al* 2010). The "ascoids" *Proctolaelaps bickleyi* (Bram) and *Proctolaelaps bulbosus* Moraes, Reis & Gondim Jr. have also been found associated with the coconut mite, especially on fallen fruits. Again, laboratory studies have shown the coconut mite to be an adequate food for those predators (Lawson-Balagbo *et al* 2007, Galvão *et al* 2011). However, even in areas where these phytoseiids and "ascoids" are found, the coconut mite causes significant damage to coconuts (de Moraes & Flechtmann 2008), suggesting that these predators are less effective than desirable.

Studies to evaluate the levels of occurrence of the coconut mite and its natural enemies in Brazil have been conducted almost exclusively in the north and northeast regions (Navia *et al* 2005, Lawson-Balagbo *et al* 2008, Reis *et al* 2008, de Souza 2010). Unpublished observations in São Paulo suggest its incidence to be low; growers from this state do not consider it as major problem on coconut. The objective of this study was to evaluate the levels of the coconut mite and other mites on coconut palms in the state of São Paulo and to estimate the possible role of predatory mites in the control of this pest. The effects of cultivated genotypes and sampling dates on the population of the mites sampled were also estimated.

Material and Methods

Sampling procedure

Three samplings were performed at periods with different weather conditions. The first was performed in the second half of July 2009 (middle of the dry season, when the temperature is lower), the second in the first half of December 2009 (middle of the rainy season, when the temperature is higher), and the third in the first half of April 2010 (early dry season, with intermediate temperature levels).

Eight sampling sites were taken in the northwest part of São Paulo (Table 1), where most of the commercial coconut fields of the state are located (Cati—Coordenadoria de Assistência Técnica Integral 2007/2008), and two near the coast (east), where coconut is also commonly cultivated. Sampling locations were determined to represent the types of natural vegetation that originally prevailed in the state (Programa Biota Fapesp 2009). At each sampling date, samples were taken from five randomly determined coconut palms in each coconut field, at least 30 m from each other and 20 m from the edges.

From each plant, 10 fruits (6–13 cm long and 4–9 cm in diameter, corresponding to approximately 3 to 4 months old), five spikelets with female and male flowers at different stages of development, and 30 leaflets (10 from each of basal, median, and apical regions of a leaf from the middle of the canopy, combined to form a single sample) were collected. Whenever available, up to 10 fallen coconuts were taken from each field, for a total of 105 fallen fruits evaluated throughout the study. The sample corresponding to each plant organ of each plant was packed in a paper bag, in turn put in a plastic bag that was kept in a cooler (about 20°C) for transport to the laboratory.

Laboratory procedure

Samples were examined under stereomicroscope. Initially, the exposed surface of each fruit was examined; then the bracts of each fruit were removed with the aid of a knife to examine their underside and the subjacent surface of the fruit. Both sides of each leaflet were examined. The inflorescences were beaten over a dark surface to facilitate mite visualization.

Mites were collected in 70% ethanol and later mounted in Hoyer's medium. However, in samples in which eriophids were most abundant, only 50 of these were mounted to confirm the identity of the species. In this case, their total numbers were estimated using a method similar to that described by Siriwardena *et al* (2005) and used by Lawson-Balagbo *et al* (2008); the eriophids were transferred to 10 ml of 70% ethanol, and mites were subsequently counted in an aliquot of 1.0 ml in a Peter's counting chamber (Southey 1986), estimating the total number by extrapolation. Identification was done using the original descriptions and redescriptions of each mite group. Representatives of each mite species were deposited in the reference collection of the Depto de Entomologia & Acarologia, Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo, Piracicaba.

Meteorological information

The characterization of fields was done using climatic normals (1961–1990) obtained from Instituto Nacional de

Table 1 Characterization of the coconut fields sampled in this study in the state of São Paulo, Brazil.

Municipalities	Original[a] vegetation	Average annual[b] temperature (°C)	Average[b] annual RH (%)	Average[c] annual rainfall (mm)	Field	Geographic coordinates	Area (ha)	Number of plants	Genotypes	Age (years)
Riolândia—northeast (Inland)	Cerrado	23	65	1,335	1	19°59′S/49°40′W	3.0	1,480	Green Dwarf	15
					2	20°05′S/49°38′W	0.5	70	Hybrid	13
Cedral—northeast (Inland)	Semideciduous Forest	21	65	1,455	1	20°56′S/49°15′W	1.5	235	Green Dwarf	10
					2	20°54′S/49°15′W	0.6	100	Hybrid	14
Mirandópolis—northeast (Inland)	Semideciduous Forest	23	65	1,179	1	21°08′S/51°07′W	4.5	2,000	Green Dwarf	12
					2	20°59′S/51°05′W	2.0	300	Hybrid	12
Tupã—northeast (Inland)	Semideciduous Forest	21	65	1,291	1	21°54′S/50°31′W	12.0	2,000	Green Dwarf	12
					2	21°54′S/50°27′W	10.0	5,000	Hybrid	11
Peruíbe—east (Coast)	Restinga Forest	19	78	1,630	1	24°14′S/47°01′W	0.5	60	Hybrid	8
					2	24°14′S/47°00′W	7.0	3,000	Hybrid	7

[a] Source: Programa Biota Fapesp, 2009.

[b] Normal for 1961–1990, provided by Inmet—Instituto Nacional de Meteorologia (2009).

[c] Normal for 1961–1990, provided by Cepagri—Centro de Pesquisas Meteorológicas e Climáticas Aplicadas à Agricultura (2009).

Meteorologia (Inmet—Instituto Nacional de Meteorologia 2009), for temperature and relative humidity, and from Centro de Pesquisas Meteorológicas e Climáticas Aplicadas à Agricultura (Cepagri—Centro de Pesquisas Meteorológicas e Climáticas Aplicadas à Agricultura 2009), for rainfall. Climatic data of survey period (temperature, relative humidity, and rainfall) were provided by Centro Integrado de Informações Agrometeorológicas (Ciiagro—Centro Integrado de Informações Agrometeorológicas 2012). These data correspond to averages of four meteorological stations, each closest to a sampling site; distance between each sampling site and the closest meteorological station was no more than 15 km.

Statistical analyses

For the analysis of mite densities, each plant constituted an experimental unit. Densities of coconut mites, "ascoids," and Phytoseiidae on attached fruits were compared between genotypes and between sampling dates. For comparisons between genotypes, only fields of the northwestern region of the state were considered, given that only hybrids were sampled on the coast. For comparisons between sampling dates, only fields of the Green Dwarf variety were considered, given the extremely low densities on hybrids. "Ascoids" and Phytoseiidae on leaflets and inflorescences were combined before their densities were compared between genotypes and between sampling dates. For comparisons between genotypes, only fields of the northwestern region of state were considered, for the same reason mentioned for attached fruits, whereas for comparisons between sampling dates, all fields were considered.

The original data were not normally distributed. Thus, each datum (mite density per replicate) was initially summed to 0.5 and then transformed according to Box & Cox (1964) before being submitted to analysis of variance, using the following transformation parameters (λ): between genotypes (mites on fruits), coconut mite (−0.1), "ascoids" (−3.7), and Phytoseiidae (−8.6); between genotypes (mites on leaflets and inflorescences), "ascoids" (−3.6), and Phytoseiidae (0.1); between sampling dates (mites on fruits), coconut mite (0.1), "ascoids" (−2.0), and Phytoseiidae (−10.4); and between sampling dates (mites on leaflets and inflorescences), "ascoids" (−3.1), and Phytoseiidae (0.1).

When means were shown to be significantly different, they were compared by Tukey test ($P<0.05$). All statistical analyses were performed using SAS® 9.2 (SAS Institute 2008).

Results

In total, 170,769 mites were found, of which 52,725 in Cedral, 43,703 in Tupã, 38,746 in Riolândia, 34,349 in Mirandópolis, and 1,246 in Peruíbe. These accounted for 51 species of 17 families; diversities were similar in Cedral and Tupã (27 species each), Riolândia (28 species), and Peruíbe (31 species), but distinctly lower in Mirandópolis (20 species).

Variability between and within functional groups

Phytophagous mites accounted for 98.4% of all collected mites. Mites belonging to groups of predominantly predatory feeding habit and groups of variable feeding habits accounted for 0.7 and 0.9% of the total, respectively.

Phytophagous mites. These accounted for approximately 99.8% of mites found on attached fruits and were represented almost exclusively by the coconut mite, except for sporadic specimens of *Tarsonemus* sp. (Tarsonemidae) (Table 2). On leaflets, phytophagous mites accounted for 29.2% of mites found, represented by two species of Tetranychidae [*Oligonychus modestus* (Banks) and *Tetranychus* sp.] and two of Tenuipalpidae [*Brevipalpus phoenicis* (Geijskes) and *Tenuipalpus coyacus* De Leon]. Phytophagous mites were not found on inflorescences. On fallen fruits, phytophagous mites accounted for 87.3% of mites found, represented only by the coconut mite.

The coconut mite was found in samples from all sampled fields, except for Peruíbe (however, it was found on fallen fruits of isolated plants in the urban area of that municipality). *Oligonychus modestus*, *B. phoenicis* and *T. coyacus* were found in all municipalities.

Mites of groups of predominantly predatory feeding habits. These corresponded to only 0.06% of mites on attached fruits but represented 15 species, *P. bickleyi* and *P. bulbosus* being the most numerous (Table 3). On leaflets, predatory mites accounted for 28.8% of mites found. Twenty-seven species were collected, the phytoseiids *Iphiseiodes zuluagai* Denmark & Muma and *Euseius citrifolius* Denmark & Muma being the most numerous. On inflorescences, 15 species were found, predominantly the phytoseiids *E. citrifolius* and *Typhlodromalus peregrinus* (Muma), in addition to *P. bickleyi*. On fallen fruits, these accounted for 6.9% of the mites found. Seven species were found, all "ascoids". *Proctolaelaps bickleyi* and *P. bulbosus* were also predominant on fallen fruits. *Proctolaelaps bickleyi* and *P. bulbosus* were found in all municipalities, while *I. zuluagai* was not present in Mirandópolis, *E. citrifolius* was not present in Peruíbe, and *T. peregrinus* was only found in Peruíbe.

Mites of groups of varied feeding habits. These corresponded to 0.1% of the mites found on attached fruits. Besides the Oribatida (not identified at lower taxonomic levels), six species were found on fruits (Table 4). *Lorryia formosa* Cooreman (Tydeidae) and *Tyrophagus putrescentiae* (Schranck) (Acaridae) were predominant. On leaflets, mites of varied feeding habits accounted for 42.6% of the mites found. Besides the oribatids, six other species were found, with *L. formosa* and oribatids being prevalent. Only three species were found on inflorescences (*L. formosa*, *Parapronematus* sp. and *Oulenzia* sp.) at extremely low levels. In fallen fruits, besides the oribatids, four species were found, *T. putrescentiae* being the predominant one.

Tyrophagus putrescentiae, *Parapronematus* sp. and oribatids were found in all municipalities. *Lorryia formosa* was not found only in Peruíbe.

Effect of environmental factors

Genotypes. On attached fruits, densities of the coconut mite and "ascoids" were significantly higher on Green Dwarf (2,465.3±614.75 and 0.6±0.15 mites per 10 fruits) than on hybrid (283.4±107.76 and 0.1±0.05 mites per 10 fruits) palms (F=36.88, df=119, P<0.0001 and F=7.32, df=119, P<0.0078). No significant differences in densities of phytoseiids (≤0.1±0.05 mites per 10 fruits) were found between genotypes (F=0.89, df=119, P<0.3468). Combining mites on leaflets and inflorescences, phytoseiids were found in significantly higher densities on hybrid (5.3±0.74

Table 2 Phytophagous mites on fruits attached to the coconut palm, leaflets, and fallen fruits in the state of São Paulo, Brazil.

Taxon	Total	Proportions[a] (%)	Density	Frequency[b] (%)
Attached fruits				
Aceria guerreronis Keifer—Eriophyidae	164,923	99.9	110/fruit	35.5
Tarsonemus sp.—Tarsonemidae	7	0.1	0.5/100 fruits	2.0
Leaflets				
Brevipalpus phoenicis (Geijskes)—Tenuipalpidae	410	46.4	9.1/100 leaflets	26.7
Oligonychus modestus (Banks)—Tetranychidae	271	30.6	6/100 leaflets	26.7
Tenuipalpus coyacus De Leon—Tenuipalpidae	187	21.1	4.2/100 leaflets	24.7
Tetranychus sp.—Tetranychidae	17	1.9	0.4/100 leaflets	4.7
Fallen fruits				
A. guerreronis	2,150	100	20.5/fruit	–

[a]In relation to the total number of phytophagous mites found on each plant organ.

[b]In relation to the total of plants sampled.

Table 3 Mites of groups of predominantly predatory feeding habits on fruits attached to the coconut palm, leaflets, and fallen fruits in the state of São Paulo, Brazil.

Taxon	Total	Proportions[b] (%)	Density	Frequency[c] (%)
Attached fruits				
Proctolaelaps bulbosus Moraes, Reis & Gondim Jr.—Melicharidae	29	30.9	2/100 fruits	10.6
Proctolaelaps bickleyi (Bram)—Melicharidae	26	27.7	2/100 fruits	10.6
Other[a]	37	≤7.4	≤5/1,000 fruits	≤4.0
Leaflets				
Iphiseiodes zuluagai Denmark & Muma—Phytoseiidae	234	26.8	5.2/100 leaflets	30.0
Euseius citrifolius Denmark & Muma—Phytoseiidae	169	19.4	3.8/100 leaflets	36.7
Agistemus sp.—Stigmaeidae	108	12.4	2.4/100 leaflets	27.3
Other[a]	362	≤8.7	≤1.7/100 leaflets	≤21.3
Fallen fruits				
P. bulbosus	58	33.9	5.5/10 fruits	–
P. bickleyi	52	30.4	5/10 fruits	–
Lasioseius sp.1—Blattisociidae	32	18.7	3/10 fruits	–
Lasioseius sp.2—Blattisociidae	22	12.9	2/10 fruits	–
Other[a]	7	≤2.9	≤4.8/100 fruits	–

[a]See full list in Appendix 1 in *Supplementary Online Material.*

[b]In relation to the total number of predatory mites found on each plant organ.

[c]In relation to the total number of plants sampled.

mites per sample) than on Green Dwarf (3.2±0.53 mites per sample) palms (F=6.44, df=119, P<0.0125). There were no significant differences in the densities of "ascoids" (≤0.3±0.08 mites per sample) between genotypes (F=0.21, df=119, P<0.6479).

Sampling dates. On attached fruits, significant differences between sampling dates were observed only for densities of coconut mite and "ascoids" (F=6.69, df=59, P<0.0025 and F=5.08, df=59, P<0.0093) (Fig 1a). The former was found in significantly lower density in the first sampling date (July 2009), which corresponded to the period when rainfall, relative humidity, and temperature were close to the minimum monthly averages (Fig 1b). Densities were not statistically different between the second (December 2009) and third sampling dates (April 2010). The "ascoids" were found in higher density in the first than in the second sampling date; however, density on the third sampling was not significantly different from densities at other sampling dates. Combining mites on leaflets and inflorescences, significant differences were observed only for "ascoids" (F=10.45, df=149, P<0.0001); similar to that found on fruits, densities of "ascoids"

Table 4 Mites of varied feeding habits on fruits attached to the coconut palm, leaflets, and fallen fruits in the state of São Paulo.

Taxon	Total	Proportions[b] (%)	Density	Frequency[c] (%)
Attached fruits				
Lorryia formosa Cooreman—Tydeidae	69	42.9	4.6/100 fruits	10.0
Tyrophagus putrescentiae (Schranck)—Acaridae	66	41.0	4.4/100 fruits	16.7
Other[a]	26	≤5.6	≤6/1,000 fruits	≤3.3
Leaflets				
L. formosa	552	43.4	12.3/100 leaflets	34.7
Oribatida	274	21.5	6.1/100 leaflets	22.0
Benoinyssus sp.—Eupodidae	189	14.9	4.2/100 leaflets	12.0
Oulenzia sp.—Winterschmidtiidae	187	14.7	4.1/100 leaflets	23.3
Other[a]	70	≤3.4	≤9.6/1,000 leaflets	≤14.0
Fallen fruits				
T. putrescentiae	62	43.7	6/10 fruits	–
Oribatida	50	35.2	4.8/10 fruits	–
Histiostoma sp.—Histiostomatidae	28	19.7	2.7/10 fruits	–
Other[a]	2	≤0.7	≤9.5/1,000 fruits	–

[a]See full list in Appendix 1 in *Supplementary Online Material.*

[b]In relation to the total number of mites of varied feeding habits found on each plant organ.

[c]In relation to the total numbers of plants sampled.

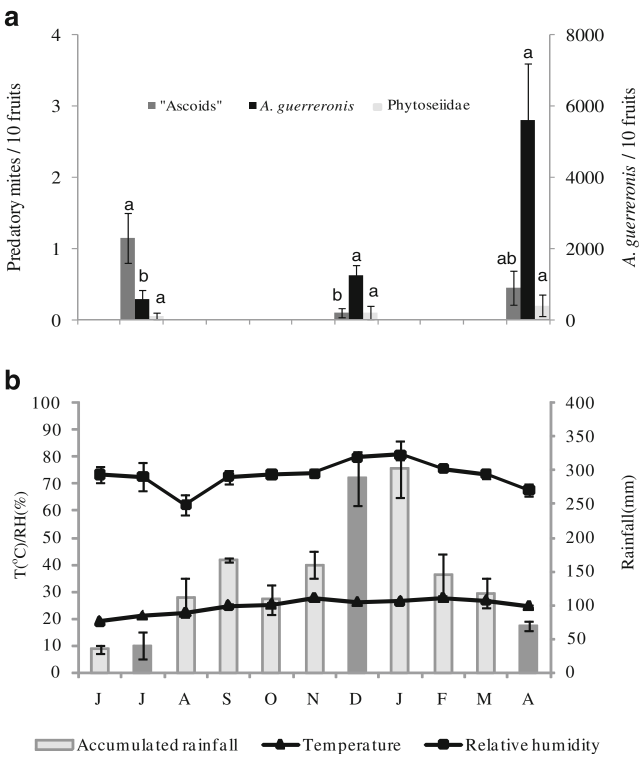

Fig 1 **a** Average number of *Aceria guerreronis* and predatory mites ("ascoids" and Phytoseiidae) per 10 fruits (±SE) in fields of northwest Sao Paulo State at different sampling dates. For each mite group, *different letters on top of bars* indicate significant differences between sampling dates, Tukey's test (P<0.05). **b** Climatic conditions during the period in which the work was conducted (averages of four meteorological stations, each closest to a sampling site, ±SE); data provided by Ciiagro—Centro Integrado de Informações Agrometeorológicas (2012).

were higher in the first sampling date and no significant difference was found between other sampling dates.

Discussion

The prevalence of phytophagous mites when all plant parts were considered together was due to their predominance on fruits. The much lower number of mites in Peruíbe than in other municipalities was due to the absence of phytophagous mites on fruits in that municipality. However, the diversity of species in Peruíbe was comparable to that observed in Cedral, Riolândia, and Tupã and greater than observed in Mirandópolis. The variables recorded in this study do not allow the determination of possible causes for the lower mite diversity in the latter municipality.

Variability between and within functional groups

Phytophagous mites. As expected, the population levels of the coconut mite determined on attached fruits were much lower than those determined in previous studies in Brazil and other countries in Africa and Asia (Lawson-Balagbo *et al* 2008, Fernando *et al* 2010, Negloh *et al* 2010). These levels corresponded to approximately 10% of those usually found in north and northeastern Brazil (Lawson-Balagbo *et al* 2008, Reis *et al* 2008). Also, other species commonly found on coconuts in previous studies in Brazil (Navia *et al* 2005, Lawson-Balagbo *et al* 2008, Reis *et al* 2008, de Souza 2010), namely *Amrineus cocofolius* Flechtmann (Eriophyidae), *Steneotarsonemus concavuscutum* Lofego & Gondim Jr., and *Steneotarsonemus furcatus* De Leon (Tarsonemidae), were not found.

Conversely, the densities of phytophagous mites prevalent on leaflets of coconut palms were higher than those found in north and northeastern Brazil (Lawson-Balagbo *et al* 2008). The populations of the tenuipalpids *B. phoenicis* and *T. coyacus* were probably favored by relatively lower temperatures and higher humidity levels, as these were more abundant in Peruíbe than in municipalities of northwest São Paulo, where the average annual temperature is about 2 to 4°C higher and annual relative humidity is about 10 to 15% lower than in Peruíbe. de Castro & de Moraes (2007) also observed the prevalence of tenuipalpids among phytophagous mites found on leaves of several plant species (not including coconut) collected about 100 km from Peruíbe.

As in the north and northeast Brazil (Lawson-Balagbo *et al* 2008) and elsewhere in Latin America (Silva *et al* 2010), the coconut mite was not detected on leaflets. *Notostrix nasutiformes* Gondim Jr., Flechtmann & Moraes (Eriophyidae) and *Retracrus johnstoni* Keifer (Phytoptidae), usually found on coconut leaves in previous studies conducted in Brazil (Navia 2004, Lawson-Balagbo *et al* 2008), were not found in this study, neither was *Raoiella indica* Hirst, recently introduced in the extreme north of Brazil (Navia *et al* 2011).

Mites of groups of predominantly predatory feeding habits. The absence of *N. baraki* and *N. paspalivorus* is intriguing. These mites are prevalent predators on coconuts in the north and northeast Brazil, Asia, and Africa (Fernando *et al* 2003, Lawson-Balagbo *et al* 2008, Reis *et al* 2008, Fernando *et al* 2010, Hountondji *et al* 2010, Negloh *et al* 2010). In those countries, *N. baraki* and *N. paspalivorus* have been found exclusively on coconut palms. A possible reason for their absence is that they still have not dispersed to the state of São Paulo, where the commercial cultivation of coconut palms is relatively recent. Another possible reason could correspond to the low levels of occurrence of the coconut mite, apparently a preferred prey of those predators (Lawson-Balagbo *et al* 2007, Domingos *et al* 2010). Perhaps, the levels at which the coconut mite occurs in São Paulo are lower than the minimum necessary for the survival of populations of *N. baraki* and *N. paspalivorus*. Another possible cause could refer to unfavorable levels of temperature and/or relative humidity. According to data obtained by Domingos *et al* (2010) under laboratory conditions, the minimum temperature for development of immature stages of *N. baraki* is 15.8°C, which occasionally occurs in the state of São Paulo in certain times of year (Inmet—Instituto Nacional de Meteorologia 2009). However, in a study involving monthly samplings conducted in the state of Bahia, Brazil (de Souza 2010), these predatory mites were also not found, despite the fact that the prevailing temperatures and coconut mite densities seemed to be within the ranges acceptable to those predators (Lawson-Balagbo *et al* 2008). The number of predatory mites found on attached fruits was low when compared to those in northern and northeastern Brazil (Lawson-Balagbo *et al* 2008, Reis *et al* 2008), even *P. bickleyi* and *P. bulbosus*, the most numerous predators in this study.

The most numerous predators on leaflets were different from those in northern and northeastern Brazil. The prevalence of *I. zuluagai* among the predators, as observed in this study, is consistent with the results of previous studies conducted on palm trees and other plants from Atlantic Forest in the state of São Paulo (Gondim & de Moraes 2001, de Castro & de Moraes 2010). The density of this predator on leaflets was approximately four-fold that reported on coconut leaflets in northern and northeast Brazil (Lawson-Balagbo *et al* 2008). *Euseius citrifolius* and *Amblyseius neochiapensis*, also prevalent on leaflets in this study, were not previously reported on coconut palms in Brazil (Gondim & de Moraes 2001, Navia *et al* 2005, Lawson-Balagbo *et al* 2008, Reis *et al* 2008, de Souza 2010). The fact that these have been found in all municipalities in northwestern São Paulo but not in Peruíbe and that they were not found in a study conducted with plants of the Atlantic Forest in the coast of São Paulo (de Castro & de Moraes 2010) suggests that they may be favored by conditions of low relative humidity, common in northwestern São Paulo. Perhaps this may explain the absence of *E. citrifolius* on coconut palms in northern and northeastern Brazil, where most surveys have been conducted along the coast, where the relative humidity is usually high (Lawson-Balagbo *et al* 2008).

Amblyseius largoensis, predominant on coconut leaflets in northern and northeastern Brazil (Lawson-Balagbo *et al* 2008), Florida (Roda *et al* 2008), the Caribbean, and other Latin American countries (Etienne & Flechtmann 2006, Silva *et al* 2010, Carrillo *et al* 2011), was not found in this study. This mite has been reported in the state of São Paulo, in other plant species of the Atlantic Forest (de Castro & de Moraes 2010), but never on coconut palms (Gondim & de Moraes 2001, Navia *et al* 2005). Although this work has for the first time reported the occurrence of predatory mites on coconut inflorescences in Brazil, their densities were low and may be spurious.

The greatest number of *P. bulbosus* and *P. bickleyi* on fallen fruits compared to attached fruits may be due to the easier access on them under the bracts than on attached coconuts, or availability of a range of potential foods on fallen fruits, particularly fungi (Lawson-Balagbo *et al* 2007). Nothing is known about the possible role of predatory mites on fallen fruits in reducing the number of mites that could disperse to other attached fruits.

Mites of groups of varied feeding habits. The presence of mites with varied feeding habits on coconuts was also reported in other studies, especially the prevalence of species such as *L. formosa* and *T. putrescentiae* (Lawson-Balagbo *et al* 2008). The prevalence of *L. formosa* and oribatids on coconut leaflets was also noticed in northern and northeastern Brazil (Lawson-Balagbo *et al* 2008). The absence of Ameroseiidae on inflorescence differs from what has been observed on coconut palms in Africa and Asia, where mites of this family are very common on coconut inflorescences (Haq 2001, G.J. Moraes, unpublished observations). Ameroseiids have also not been found in studies conducted in northern and northeastern Brazil (Lawson-Balagbo *et al* 2008). The effect of these mites to coconut palms is not well-known, but *Neocypholaelaps stridulans* (Evans) was cited by Haq (2001) to possibly cause the drop of female buttons in India.

Effect of environmental factors

Genotypes. It was not possible to determine the origins and the similarity between the genotypes referred as hybrids in different fields, but the virtual absence of the coconut mite in fields of the hybrid genotypes is noteworthy. One possible explanation could be the attachment of the bracts, very close to the surface of the fruit in these genotypes, as assumed in the studies conducted by Kannaiyan *et al* (2002) and Schiesske (1988) with other genotypes, which could be hampering the entry of the mites under the bracts. Not even the highest density of phytoseiid on leaflets and inflorescences of hybrids seems to explain the very low occurrence of the coconut mite on these genotypes, as phytoseiids were rarely found on fruits. The lowest densities of "ascoids" on hybrids could be a result of the lower densities of the coconut mite on these plants.

Sampling dates. The lower population level of the coconut mite in the first sampling date is compatible with the prevailing low temperature in this period. Although the low levels of rainfall and relative humidity corresponding to the first sampling can be considered favorable to the coconut mite, the low temperatures could have had a more important adverse effect on the pest (Lawson-Balagbo *et al* 2008). Conversely, the higher level of "ascoids" could be explained by a less important washing effect of the lower rainfall in this period. Lawson-Balagbo *et al* (2008) found no relation between the population levels of *P. bickleyi*, one of the two most abundant "ascoids" in the present study, and the environmental conditions.

The higher incidence of "ascoids" in the first sampling date might suggest that this group of mites could be one of the factors responsible for the lowest population of the coconut mite in this period. However, the "ascoids" population levels were always very low, weakening such an interpretation.

The population densities of the coconut mite in the state of São Paulo, confirming our initial hypothesis, were expected. A question to be asked is whether this low incidence could be a function of the actions of its natural enemies. That possibility could have been supported if we had found high populations of predatory mites or a significant number of predatory mites unknown from other regions where this mite is a pest. However, this was not the case. Although the predatory mites *A. neochiapensis*, *E. citrifolius*, *Proprioseiopsis neotropicus* (Ehara), and *Proprioseiopsis ovatus* (Garman) were found in this study, but not in studies conducted in northern and northeastern Brazil (Lawson-Balagbo *et al* 2008, Reis *et al* 2008, de Souza 2010), their densities were very low, corresponding to not more than three mites per 1,000 fruits. In addition, these mites were also infrequent, occurring in at most 3.3% of the analyzed plants, contrasting with the occurrence of the coconut mite on 35.3% of the plants. Therefore, it is unlikely that these predators are responsible for the low incidence of the coconut mite in São Paulo.

It cannot be ruled out that the predatory mites on fallen fruits could be exerting an important role in maintaining low levels of the coconut mite. The densities of those predators on those fruits were higher than found in northern and northeastern Brazil. The predators could be acting primarily in the dispersal process of the pest from fallen to attached fruits.

Climate could be an important factor responsible for the low levels of the coconut mite in the state of São Paulo. According to Lawson-Balagbo *et al* (2008), the largest populations of the coconut mite may occur in areas with relatively high average annual temperature (27–30°C), and low humidity (50–70%) and rainfall (300–600 mm). High populations of the coconut mite have been reported in areas where climate is relatively similar to that of the regions where the present work was conducted, as in southern Florida, USA (Howard *et al* 1990) and West Bengal, India (K. Karmakar, unpublished). However, Brazilian populations of this pest could behave differently from the populations of those other countries. Scarcity of coconut plantations could also be an important factor, hampering the dispersion of the coconut mite between fields, as concluded by Howard *et al* (1990) for parts of Florida, and as we have observed in different areas of South America.

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