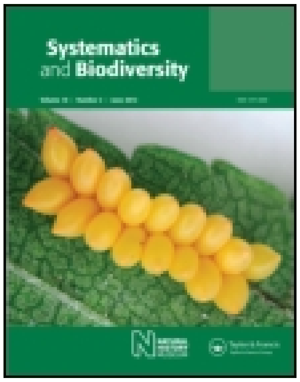

Systematics and Biodiversity
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tsab20

Can the red palm mite threaten the Amazon vegetation?

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To cite this article: Manoel G. C. Gondim Jr. , Tatiane M. M. G. Castro , Alberto L. Marsaro Jr. , Denise Navia , José W. S. Melo , Peterson R. Demite & Gilberto J. de Moraes (2012): Can the red palm mite threaten the Amazon vegetation?, Systematics and Biodiversity, 10:4, 527-535

To link to this article: http://dx.doi.org/10.1080/14772000.2012.752415

Systematics and Biodiversity (2012), **10(4)**: 527–535

Taylor & Francis
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Research Article

Can the red palm mite threaten the Amazon vegetation?

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(Received 1 August 2012; revised 20 November 2012; accepted 20 November 2012)

The red palm mite *Raoiella indica* Hirst (Tenuipalpidae) was first reported in the New World in 2004, dispersing quickly and widely while adopting new plant species as hosts. Since then, it has caused severe damage in this region, especially to coconut (*Cocos nucifera* L.). It was first found in Brazil in 2009, in the northern Amazonian state of Roraima. In the present study, native and introduced plants were sampled between March 2010 and February 2011 in sites of the 15 Roraima municipalities, to estimate its distribution and the associated mite fauna. In addition, monthly samples were taken from a coconut plantation in Mucajaí throughout the same period, for an initial appraisal of the levels *R. indica* could reach. It was found in 10 municipalities, on 19 plant species of four families. Six species are reported for the first time as hosts. Among the associated predators, 89.1% were Phytoseiidae, most commonly *Amblyseius largoensis* (Muma), *Iphiseiodes zuluagai* Denmark & Muma and *Euseius concordis* (Chant). The highest densities of *R. indica*, 1.5 and 0.35 mites/cm^2 of leaflet (approx total of 331 and 77 mites/leaflet), were reached respectively in March 2010 and February 2011. The highest density of phytoseiids on coconut (0.009 mites/cm^2 or about 2 mites/leaflet) was reached in November 2010. The average densities of *R. indica* recorded for Roraima were comparable to those reported for countries in which the mite is reportedly economically damaging. The dispersal of *R. indica* through the Amazon forest may result in damage to cultivated and native palms, and plants of other families, if the projected increase in both the frequency and the severity of drought events occurs. Parts of the Amazon have undergone periods of low rainfall, a condition that appears to favour the biology of this mite. Its eventual arrival to northeastern Brazil may result in heavy economic and ecological losses.

Key words: biological control, coconut, mites, Phytoseiidae, *Raoiella indica*

Introduction

The red palm mite, *Raoiella indica* Hirst (Tenuipalpidae), was originally described from specimens collected from coconut (*Cocos nucifera* L.) in India (Hirst, 1924) and found much later on other palm plants (Arecaceae) in several African, Asian and the Middle Eastern countries (Mesa *et al*., 2009). About 8 years ago, this mite was first reported in the New World, on the French Island of Martinique (Flechtmann & Etienne 2004). Soon after, it was found in other Caribbean Islands, Brazil, Colombia, Mexico, USA and Venezuela (Etienne & Flechtmann 2006; Rodrigues *et al*., 2007; Vásquez *et al*., 2008; Carrillo *et al*., 2011, 2012*a*; Navia *et al*., 2011; Kane *et al*., 2012). *Raoiella indica* considerably expanded its host range in the New World, attacking numerous palm species and a number of Cycadaceae, Heliconiaceae, Musaceae, Pandanaceae, Strelitziaceae and Zingiberaeae species (Cocco & Hoy, 2009; Lima *et al*., 2011; Carrillo *et al*., 2012*a*). Palms constitute an important component in the ecology of tropical vegetation around the world, including tropical America, and are considered to be sentinel plants for conservation in the Amazon (Goulding & Smith, 2007).

Leaves heavily infested by *R. indica* initially turn yellowish and later become necrotic (Flechtmann & Etienne, 2004), which in turn may lead to heavy yield losses, especially of coconuts. In Trinidad, coconut production has been reported to have dropped about 70% due to damage by

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ISSN 1477-2000 print / 1478-0933 online

http://dx.doi.org/10.1080/14772000.2012.752415

R. indica (unpublished information of Philippe Agostine, President of Trinidad and Tobago Growers Association, reported by Roda *et al*., 2012).

In a recent revision, Carrillo *et al*. (2012*b*) listed 28 predatory mite and insect species that have been reported in association with *R. indica* worldwide. Among these, *Amblyseius largoensis* (Muma) (Acari: Phytoseiidae) has been the most frequently found (Etienne & Flechtmann, 2006; Peña *et al*., 2009; Lima *et al*., 2011; Moraes *et al*., 2012; Taylor *et al*., 2012). Laboratory evaluations have suggested the significant role of this species as a control agent of *R. indica* (Peña *et al*., 2009; Carrillo *et al*., 2010; Carrillo & Peña, 2012). Field evaluations of the possible role of predators (Peña *et al*., 2009; Roda *et al*., 2012) and of abiotic factors (Taylor *et al.*, 2012) on the densities of *R. indica* have also been conducted. It has been reported that the effect of native natural enemies in some of the recently invaded areas has not been sufficient to prevent damage by the pest.

Within an organized programme designed to provide the early detection of *R. indica* in northern Brazil, this mite was first found in this country in July 2009, attacking coconut plants in Boa Vista, located near the centre of the northern half of Amazonian state of Roraima (Navia *et al*., 2011). This state borders Venezuela in the north and in the west, Guyana in the east, the Brazilian state of Amazonas in the south and the Brazilian state of Pará in the southeast. Most of the state is covered by extensive areas of cerrado (savannah-like vegetation) in the north and by tropical rain forests in the south. Despite its importance for local consumption, coconut is not a major crop in this state. Even so, since the arrival of *R. indica* coconut trees have often shown pronounced damage by this mite (our unpublished observation). In addition, the presence of the mite has caused great concern to local banana growers, due to restrictions imposed on the exportation of bananas to other parts of the country (Navia *et al.*, 2011), given that some banana varieties have been mentioned to be heavily attacked by the mite (Kane *et al*., 2012; Rodrigues & Irish, 2012). More recently, *R. indica* was found in Amazonas state (Rodrigues & Antony, 2011). Given the recent history of *R. indica* as a destructive pest in the Caribbean area, it is assumed that its potential to cause significant ecological and economic damage to native and cultivated palm plants in that region is high.

The objective of this work was to estimate the distribution of *R. indica* in Roraima at this early stage of the invasion, the mite fauna associated with it and the densities that it could reach in different seasons in that state.

Materials and methods

The field activities were conducted between March 2010 and February 2011.

Distribution of *R. indica* and determination of the associated mite fauna

Sampling was conducted at irregular intervals at sites in the 15 Roraima municipalities. As some areas are inaccessible, sampling could not be uniformly distributed across the state. The sites were concentrated in regions of human occupation, mainly along BR-174 federal road. The number of samples from each municipality was: Pacaraima 112, Bonfim 96, Mucajaí 96, Caracaraí 38, Normandia 27, Boa Vista 25, Cantá 16, Rorainópolis 15, Iracema 7, Amajari 4 and Alto Alegre 1. In the first three municipalities, sampling was conducted at least once every 2 months, while in others it was done sporadically.

Sampling was focused on plant species and families that had been previously reported as hosts. At each site, plants were visually inspected, and only leaves showing possible symptoms of mite attack were targeted. Non-coconut plants were not sampled from vegetation immediately surrounding coconut plants in an effort to avoid sampling plants onto which the mites have accidentally drifted. Each sample was put in a plastic bag and temporarily stored in a cool box for transportation to the laboratory, where they were stored in a refrigerator (about 10 °C) until inspected, within a period of 5 days. Inspection was done under a stereomicroscope, mounting all mites in Hoyer′s medium for later identification. A plant was only considered a host of *R. indica* if it harboured colonies containing all developmental stages of this mite, as this indicated that development and reproduction were possible.

Levels of occurrence of *R. indica* and associated mites on coconut

The study was conducted in a commercial coconut plantation of the ‘Green Dwarf’ variety, in the municipality of Mucajaí (02°26′N, 60°55′W). The plantation was about 0.2 hectare in size and the plants were about 5 years old, spaced at 7.0 × 7.0 m.

Samples were taken monthly from leaf 14 (when the leaf about to open is numbered ‘0’) of four plants randomly determined at each sampling date (total of about 40 plants in the plot). Each sample consisted of five leaflets, taken separately from each of the basal, median and apical thirds of the leaf of a plant. Each sample was placed in a plastic bag, transported, stored in the laboratory and processed as described in the previous section. Active stages of mites of each sample preliminarily identified as *R. indica* were counted and approximately 20 of these were taken at random (including adults and immatures) and mounted in Hoyer’s medium for later confirmation of the identification. All mites of other species were mounted in Hoyer’s medium for identification and counting. The area of each leaflet was measured with photoelectric equipment (LI-COR model

LI-3100 Area meter). Data about temperature and rainfall were obtained from the Brazilian Instituto Nacional de Meteorologia (INMET, 2012).

The average numbers of mites per leaflet of each third of the coconut leaf were statistically compared. For such, the data were initially subjected to normality (Kolmogorov's) and homogeneity (Bartlett's) tests, and subsequently subjected to ANOVA and Fisher's multiple range test, using SAS software (SAS Institute, 2002).

To estimate the main factors related to the fluctuation of *R. indica* throughout the evaluation period, simple correlations between densities of *R. indica*, phytoseiid predators, temperature, rainfall and relative humidity were initially performed, using PROC CORR (SAS Institute, 2002). A multifactorial stepwise regression analysis was subsequently performed taking those factors into account, using PROC STEPWISE (SAS Institute, 2002).

Results

Distribution of *R. indica* and determination of the associated mite fauna

Raoiella indica was found on 19 species of Arecaceae, Cannaceae, Heliconiaceae and Musaceae (Table 1), in 10 municipalities (Fig. 1).

In total, 39 951 mites were collected, about 94.4% of which were phytophagous and 4.9% were predators (Table 2). *Raoiella indica* corresponded to 94.3% of the phytophagous mites. Phytoseiids corresponded to about 89.1% of the predators collected, the most abundant being *A. largoensis* (19.8% of the specimens of the family) followed by *Iphiseiodes zuluagai* Denmark & Muma (12.2%) and *Euseius concordis* (Chant) (11.6%); each of the other 23 species corresponded to less than 7% of the phytoseiids.

Levels of occurrence of *R. indica* and associated mites on coconut

The densities of *R. indica* ranged from 0 to 2.0 mites/cm^2 on basal, from 0 to 1.5 on median and from 0 to 1.1 on apical leaflets (adults: *c*. 78% females). However, because of the considerable variability of the data, no significant difference was observed between the corresponding average densities in any of the sampling dates ($F < 0.82$, $P > 0.46$). For this reason, the subsequent analyses were done considering all leaflets combined, irrespective of their position on the leaf.

The highest density of *R. indica* was 1.5 mites/cm^2 of coconut leaflet (Fig. 2), observed in the first sampling date (March 2010), whereas the second highest density was 0.35 mites/cm^2, observed in the last sampling date (February 2011). As the average size of the leaflets was 220.4 ±

Table 1. Number of sites of each municipality in which colonies of *Raoiella indica* were found on each plant species between March 2010 and February 2011, in Roraima state, Brazil.

Family	Plant species	Cities and number of sites
Arecaceae	*Adonidia merrillii* (Becc.) Becc.	Boa Vista (1), Bonfim (3), Cantá (1), Pacaraima (1)
	Attalea maripa (Aubl.) Mart.*	Cantá (1), Mucajaí (1)
	Acanthophoenix sp.	Pacaraima (1)
	Bactris gasipaes Kunth*	Boa vista (1)
	Caryota urens L.	Cantá (1)
	Cocos nucifera L.	Alto Alegre (1), Amajari (1) Bonfim (13), Cantá (2), Caracaraí (1), Iracema (4) Mucajaí (12), Normandia (7), Pacaraima (7)
	Dypsis lutescens (H. Wendl.) Beentje & J. Dransf.	Boa vista (1)
	Elaeis guineensis Jacq.	Boa vista (1)
	Euterpe oleracea Mart.*	Bonfim (2), Mucajaí (5), Normandia (1), Pacaraima (4)
	E. precatoria Mart.*	Bonfim (1)
	Mauritia flexuosa L.*	Boa Vista (1), Bonfim (1), Cantá (1), Mucajaí (2), Normandia (2), Pacaraima (2)
	Phoenix roebelenii O'Brien	Amaraji (1)
	Pritchardia pacifica Seem. & H. Wendl.	Boa vista (1)
	Raphis excelsa (Thunb.) A. Henry ex Rehder	Boa vista (1)
Cannaceae	*Canna indica* L.*	Bonfim (1)
Heliconiaceae	*Heliconia bihai* (L.) cv. Napi	Boa vista (1)
	H. psittacorum Sassy cv. Golden Torch	Boa vista (1)
	Heliconia sp.	Boa Vista (1), Bonfim (1), Mucajaí (1), Normandia (2)
Musacea	*Musa* sp.	Boa Vista (1), Bonfim (5), Cantá (1), Mucajaí (6), Normandia (4), Pacaraima (7)

*First reported as host of *R. indica*.

Fig. 1. Sites where *Raoiella indica* was found on different hosts between March 2010 and February 2011 in Roraima state, Brazil.

8.1 cm^2, the two highest densities corresponded respectively to about 331 and 77 mites per leaflet. Densities reduced quickly after the first sampling date to levels below 0.04 mites/cm^2, with the concurrent increased levels of rainfall and decreased levels of temperature (May–September). Upward trends in *Raoiella* population levels were observed between October–November and January–February, coinciding with and/or preceded by periods of low rainfall. Other phytophagous mites (57% of which represented by Tetranychidae) were almost always found at low levels, reaching a combined peak of 0.007 mites/cm^2 in September.

The phytoseiid species found in this study and their respective proportions (%) were: *A. largoensis*, 58; *Amblyseius tamatavensis* Blommers, 29; *Euseius concordis* (Chant), 11; *Amblyseius aerialis* (Muma), 2; and *Amblyseius chiapensis* De Leon, 2. The pattern of phytoseiid population fluctuation was similar to that of *R. indica* for most of the year, except during February–March, when *R.*

Table 2. Prevalence of mite species found together with *Raoiella indica* on different hosts, between March 2010 and February 2011, in Roraima state, Brazil.

Family/Species	Total	Prevalence (%)	
PHYTOPHAGOUS SPECIES	37732	94.4[1]	
Tenuipalpidae	36430	96.5[1]	
Raoiella indica	35578		97.6[2]
Brevipalpus phoenicis	852		2,4
Tetranychidae	1260	3.3	
Eriophyidae	42	0.1	
PREDACEOUS SPECIES	1953	4.9	
Bdellidae	56	2.9	
Cunaxidae	15	0.8	
Cheyletidae	44	2.2	
Iolinidae	22	1.1	
Phytoseiidae	1740	89.1	
Amblydromalus aff. *rapax* (De Leon)*	1		0.1
Amblydromalus sp.	3		0.2
Amblyseius aerialis (Muma)*	48		2.9
Amblyseius chiapensis De Leon*	66		3.9
Amblyseius fernandezi Chant & Baker*	2		0.1
Amblyseius herbicolus (Chant)*	39		2.3
Amblyseius largoensis (Muma)	334		19.8
Amblyseius tamatavensis Blommers*	109		6.5
Arrenoseius cf. *urquharti* (Yoshida-Shaul & Chant)*	1		0.1
Cocoseius elsalvador Denmark & Andrews*	6		0.4
Cocoseius palmarum Gondim Jr, Moraes & McMurtry*	1		0.1
Euseius alatus De Leon*	11		0.7
Euseius citrifolius Denmark & Muma*	2		0.1
Euseius concordis (Chant)*	196		11.6
Iphiseiodes zuluagai Denmark & Muma*	206		12.2
Kuzinellus sp.	1		0.1
Metaseiulus (*M.*) aff. *cornus**	1		0.1
Neoseiulus idaeus Denmark & Muma	1		0.1
Neoseiulus sp.	1		0.1
New genus	6		0.4
Proprioseiopsis cannaensis (Muma)*	1		0.1
Proprioseiopsis cf. *tenax**	3		0.2
Proprioseiopsis dominigos (El-Banhawy)*	1		0.1
Proprioseiopsis neotropicus (Ehara)*	30		1.8
Ricoseius loxocheles (De Leon)*	41		2.4
Typhlodromina subtropica Muma & Denmark*	6		0.4
Immatures (unidentified)	571		33.8
Stigmaeidae	76	3.9	
SPECIES OF VARIABLE FEEDING HABIT	266	0.7	
Acaridae	19	7.1	
Eupodidae	13	4.9	
Tarsonemidae	14	5.3	
Tydeidae	219	82.3	
Winterschmidtiidae	1	0.4	
Total	39951	100	

[1]For each feeding habit (phytophagous, predator, variable), each value refers to the proportion of specimens in relation to the total number of specimens collected; for each family, each value refers to proportion in relation to the total number of specimens of the same feeding habit collected. [2]For species, each value refers to proportion in relation to the total number of mite of the same family. *Reported for the first time in association with *R. indica*.

indica populations were at their highest and phytoseiid densities were at their lowest (Fig. 2). The maximum density was approximately 0.009 phytoseiids/cm^2 of coconut leaflet, which occurred in November, coinciding with an increase in both the population of *R. indica* and rainfall. Considering the average size of the leaflets, the highest density corresponds to about 2 predators per leaflet. Other predatory mites (56% of which were Bdellidae) were always found at very low levels, reaching a peak (0.002 mites/cm^2) in November, which also coincided with an increase in the population of both *R. indica* and phytoseiids.

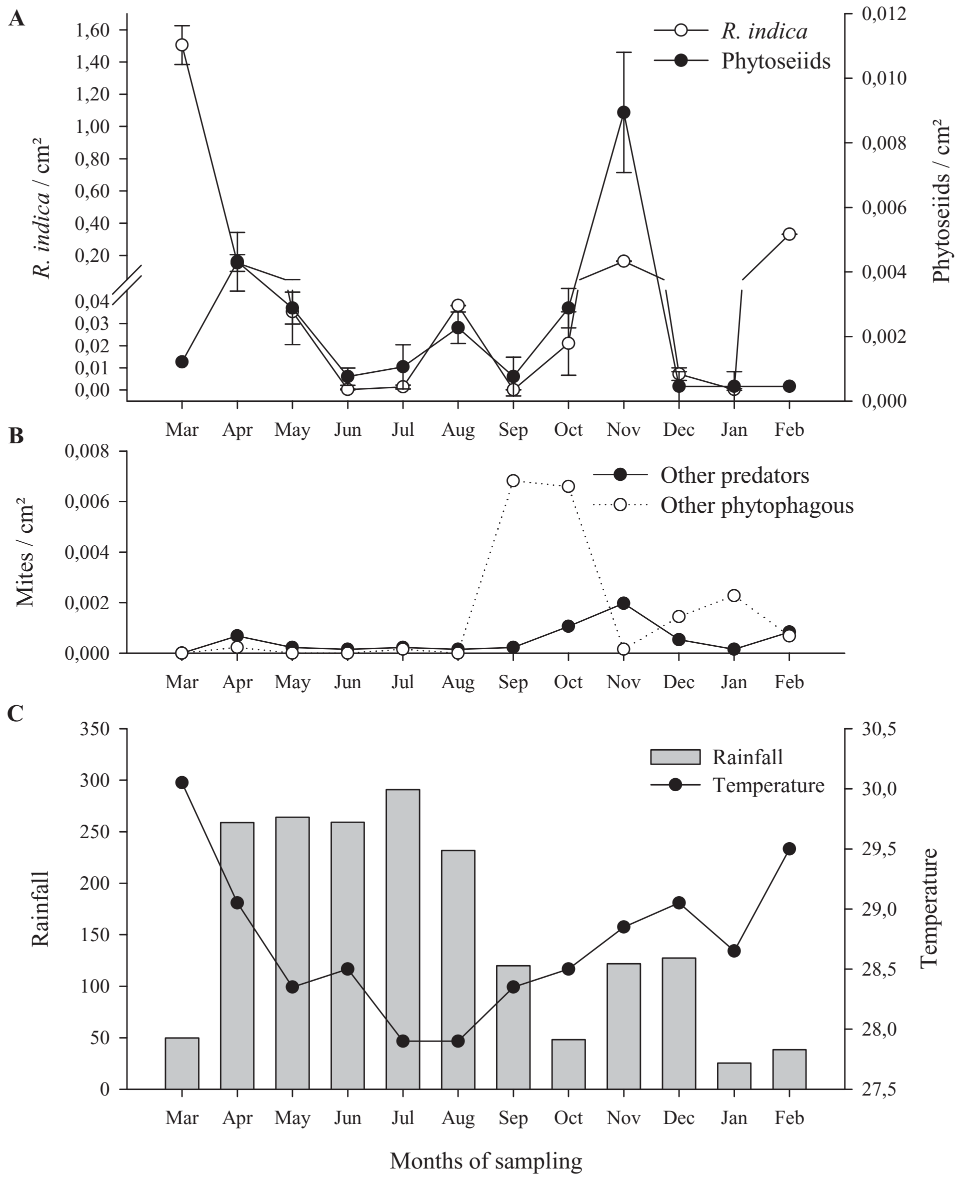

Fig. 2. Mean numbers (and corresponding standard errors) of *Raoiella indica* and predaceous Phytoseiidae mites per cm^2 of coconut leaflet, as well as monthly precipitation (mm) and average temperature (°C) in Mucajaí, Roraima state, Brazil between March 2010 and February 2011.

Significant correlations were observed between densities of *R. indica* and temperature ($R = 0.77$, $P = 0.003$), between densities of *R. indica* and phytoseiids ($R = 0.91$, $P < 0.001$) and between levels of rainfall and relative humidity ($R = 0.94$, $P < 0.01$). Given the significant correlation between rainfall and relative humidity, the latter parameter was not included in the multifactorial analysis. In that analysis, when the remaining factors were considered in the equation to estimate the level of *R. indica*, the coefficient of determination (R^2) was 0.61, but the contributions corresponding to 'phytoseiid densities' and by rainfall were very low ($R^2 = 0.008$ and 0.002, respectively). When the multifactorial analysis was performed without taking into account the first and the last sampling dates, the coefficient of determination reached 0.90, and the highest partial contribution (0.81) corresponded to 'phytoseiid densities'.

Discussion

Since its first detection in Boa Vista, *R. indica* has spread over a wide area in Roraima state. Its distribution in that state now ranges from Pacaraima to Caracaraí, corresponding to a distance of about 295 km in a straight line between the extreme northern and southern sites where the mite was found in this study.

In the Amazon region, where Roraima is located, the annual average temperature is high, *c*. 25.6 (INMET, 2012). The results of the present study suggested that the peak temperature of the region where the study was conducted (close to 30°C) favoured the build up of *R. indica* populations. The results obtained in relation to the effect of rainfall needs some further consideration. Although the analyses conducted for rainfall show no direct relationship with the fluctuating densities of this mite, an examination of Fig. 2 shows clear increases in mite population during periods of relatively low rainfall and high temperatures (March 2010, October–November and January–February 2011) and clear decreases during periods of high rainfall and low temperatures (April–September and November–December 2011). Thus, it seems that the effect of rainfall is not proportional to its varying intensity, but is determined by a threshold level, below which the biology of *R. indica* would be favoured. A visual examination of Fig. 2 suggest that threshold to be somewhere between 50 and 100 mm of rainfall a month. Yet, the changing temperature in the field certainly interferes with an attempt to precisely relate rainfall with mite population change.

Thus, the long rainy season and the high rainfall prevailing in the luxurious Amazon forest seem unfavourable for the biology of this pest. Average annual rainfall throughout the Brazilian Amazon is nearly 2450 mm (INMET, 2012). However, the Amazon forest undergoes cyclical periods of low rainfall (Lewis *et al*., 2011), and these events can be severe, as observed in 2005 and 2010 (Marengo *et al*., 2008; Lewis *et al*., 2011). An increase in the frequency and severity of drought events in the Amazon region has been predicted, as a consequence of greenhouse gas emissions (Lewis *et al.*, 2011). In this event, the spread of *R. indica* would be facilitated.

A large number of studies have been recently published on different aspects of the biology of *R. indica*. Some of these have investigated the relationships between biotic and abiotic factors and the population levels of this mite. Roda *et al*. (2012) studied the distribution of *R. indica* on coconut in the Caribbean region. They determined that the densities varied between 0 and 1.0 mites/cm^2 of coconut leaflet in Puerto Rico and 0.5 and 2.0 mites/cm^2 in Trinidad and Tobago; these densities are comparable to those determined in the present study. Taylor *et al*. (2012) studied the population dynamics of *R. indica* in the dry season of southwest India, observing that it reached 0.15 and 0.4 mites/cm^2 of coconut leaflet in Palakkad and Nilambur, respectively. In that study, no significant correlations were observed between *R. indica* densities and temperature, humidity or rainfall, probably because of the prevailing low population densities, compared with the levels determined in the present study. In any case, the present study lasted only one season, and additional similar studies should be conducted to confirm the relation between climatic data and *R. indica* population trend. In a year-long study about the dynamics of *R. indica* population on banana leaves in Cuba, Lima *et al*. (2011) reported population increases in periods of low rainfall and vice versa.

The recent finding of *R. indica* in the urban area of Manaus (Rodrigues & Antony, 2011) may facilitate its continued spread to other parts of the country and even to other South American countries. Manaus is the capital of the Brazilian state of Amazonas, and it is located about 570 km in a straight line south of Caracaraí. The origin of the population of *R. indica* found in Manaus is not known, but it is possible that it came from Roraima, despite the ongoing efforts to prevent its dispersal from Roraima to other states.

Manaus can only be reached from the southern part of Brazil by fluvial or aerial transportation, but the traffic between this city and others in the same state is intense and occurs mainly via the Amazon River. Even though it is advisable to restrict the transportation of plant parts by the local population to prevent the spread of pest organisms, in this region it is logistically almost impossible.

A major proportion of the interstate traffic leaving Manaus is bound for Belém, the capital of Pará state. Coconut and oil palm (*Elaeis guineensis* NJ Jacquin) are extensively cultivated in that state. Although available information indicates that oil palm is an unfavourable host for this pest, research for the production of new interspecific hybrids has been conducted, using germplasms native to different regions of the Amazon, and some of these could be susceptible to *R. indica*. Transportation of goods from Pará to other parts of Brazil occurs mainly by roads, with relatively easy access to the main coconut-growing areas in the northeast. Thus, if and when the mite reaches Belém, there is a high risk that it will rapidly spread to new areas of production of native and introduced palm species within a relatively short time. In northeastern Brazil, where about 84% of the Brazilian coconut production is concentrated, the average temperature is high (annual average *c*. 25 °C; INMET, 2012), and rainfall is high (annual average *c*. 1900 mm; INMET, 2012) along most of the coastal area, but low inland (annual average *c*. 900 mm; INMET, 2012). Thus, it appears that northeastern Brazil, especially the inland area, is a suitable habitat for *R. indica* to thrive.

Independent of human-assisted spread of *R. indica*, its natural spread over the Amazon seems quite possible, especially since several native palm plants seem to be favourable hosts. Six of the plants on which *R. indica* was found in this work are reported as hosts for the first time, including the palms *Attalea maripa* (Aubl.), *Bactris gasipaes* Kunth, *Euterpe oleracea* Mart, *Euterpe precatoria* Mart., *Mauritia flexuosa* L. and an introduced Cannaceae (*Canna indica* L.). Three of these, *B. gasipaes*, *E. precatoria* and *M. flexuosa*, are of particular importance as they cover extensive areas in the Amazon, and even extend into neighbouring biomes (Goulding & Smith, 2007). The latter species is particularly important as it naturally occurs as extensive monocultures, often covering areas similar in size to Costa Rica.

Fruits and/or growing tips (palm heart) of *B. gasipaes*, *E. oleracea*, *E. precatoria* and *M. flexuosa* are widely used for human consumption (Lorenzi *et al*., 2010), while *C. indica* is extensively cultivated as an ornamental. Over 140 other palm species are known from the Amazon (Goulding & Smith, 2007), and these also represent potential hosts for the pest. Many other palm plants grow naturally or are cultivated all over Brazil for different uses (Lorenzi *et al*., 2010; Shanley *et al*., 2010), and could represent suitable hosts for *R. indica*. In an extensive study, Beard *et al*. (2012) reported that the morphology of the stomata and adjacent leaf surface plays a major role in determining which plant species can be explored by *R. indica* as hosts, given that this mite feeds on its hosts via the stomata. A detailed study of the characteristics of the stomata of those species could indicate the potential of each of the Amazonian species to allow colonization by this pest.

Knowledge about the ecology of *R. indica* in Brazil and the native fauna associated with it could prove helpful in developing strategies to reduce major damage and loss caused by this mite. The great diversity of phytoseiids found in association with *R. indica* on different host plants suggests their potential role in the control of the pest. However, 20 of the phytoseiid species found in this survey are reported in association with *R. indica* for the first time, and hence nothing is known about their relationship with this pest. For example, they could be feeding on other mite species or on other food sources present on the sampled leaflets.

As reported in the present study, *A. largoensis* was one of the predators most commonly associated with *R. indica* in Florida (Peña *et al*., 2009), Puerto Rico and Trinidad and Tobago (Peña *et al.*, 2009; Roda *et al*., 2012) and Cuba (Lima *et al*., 2011). However, despite the presence of this predator, the densities of *R. indica* were still sufficiently high to cause considerable damage to coconut.

The main reason for the seemingly ineffectiveness of *A. largoensis* and other phytoseiid species during certain periods of the present study may be that they are not favoured by low humidity levels (Fig. 2). There is a close relationship between the fluctuation of *R. indica* and of the phytoseiid predators during most of the observation period, which is compatible with the statistically significant (simple) correlation between the population levels of these species. However, this type of relationship did not occur on the first and the last sampling dates, when the *R. indica* population level was at its highest, and the phytoseiid levels and relative humidity and rainfall were at or near their lowest levels. As a consequence, the contribution to the calculated total coefficient of determination in the multifactorial analysis relating the population density of *R. indica* with other environmental factors made by 'phytoseiid densities' was minor. Disregarding those two dates in the analysis increased the total coefficient of determination of the equation, with the major contribution now corresponding to 'phytoseiid densities'. The unsuitability of low humidity levels to the biology of *A. largoensis* is indicated by the fact that this species has not been reported from tropical regions of the world with low rainfall and relative humidity (see references in Moraes *et al*., 2004). In synthesis, the results of this work suggest that the phytoseiids naturally occurring in Roraima could be an important factor in maintaining *R. indica* at low levels during most of the year, but not in the peak of the dry season, when the phytoseiid populations drop to low levels.

It is also worthy to point out that *A. largoensis* is not dependent on *R. indica* as prey. This predator is often a dominant phytoseiid on many plant species, independently of the occurrence of *R. indica*. It was by far the most numerous phytoseiid on a wide range of plant species in the French Antilles (Moraes *et al*., 2000) as well as on coconut leaves in northern and northeastern Brazil (Lawson-Balagbo *et al*., 2008), before the introduction of *R. indica*. Despite its abundance, this phytoseiid has not been frequently reported from Central America (Moraes *et al*., 2004), and was not even mentioned in the extensive study published by Denmark *et al*. (1999) about the phytoseiids from that part of the world.

When *R. indica* reaches the semi-arid region of northeastern Brazil, it is possible that emergency measures to control it on coconut will be adopted, given the high economic importance of that crop in the region. Care should be taken to avoid a negative impact of these measures on the predatory mites. In addition, it seems that attempts to determine possible sources of effective natural enemies in countries where the pest is found at low densities should be conducted, for the development and implementation of a classical biological control programme. An ongoing attempt in this regard was recently reported by Moraes *et al*. (2012), who searched for effective natural enemies on La Réunion Island, where *R. indica* is reported to occur in relatively low densities. Low levels of *R. indica* have also been reported, in Thailand (A. Chandrapatya, Kasetsart University, and M. Kongshuensin, Thailand Department of Agriculture, personal communication), and this could also be the case in neighbouring countries. Although at this point the reason for the low levels of *R. indica* in those countries remains unknown, it could be due to the action of natural enemies, which could be considered for use in the New World.

Acknowledgements

We thank R. J. da Silva Jr and L. Oliveira e Oliveira for the help in the field and laboratory works, respectively, and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for the financial support.

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Associate Editor: Elliot Shubert