What is the southern limit of the distribution of red palm mite, *Raoiella indica* (Acari: Tenuipalpidae), in agricultural lands in Brazil?

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Abstract

The red palm mite, *Raoiella indica* Hirst (Acari: Tenuipalpidae), has been considered one of the most threatening pests of coconut, banana, and other monocotyledonous plants. It now has been reported from several Brazilian states, but little is known about its current distribution in the southern half of Brazil. The objective of this study was to evaluate the distribution of *R. indica* and the associated predatory mites in mid-southern Brazil, and to determine the possible southern limit to its distribution in the country. It was found in the Federal District and in 49 municipalities of 9 states, of which the southernmost was Iporã, Paraná State (24.007222°S, 53.698333°W). The majority of the surveyed sites south of Iporã had higher altitude than this municipality and surveyed sites immediately north of it. Thus, sites south of Iporã seem ecologically unsuitable to *R. indica*, most probably because of the low temperature in the winter. Eighteen species of predatory mites were found in association with *R. indica*, all of which belong to the order Mesostigmata, and 14 of which belong in the family Phytoseiidae. However, they are not *R. indica*-specific, as most have been reported from coconut (and other plants) in Brazil and elsewhere, regardless of the occurrence of *R. indica*.

Key Words: phytoseiid mites; natural enemies; coconut

Resumo

Raoiella indica tem sido considerada uma das pragas mais importantes de coqueiro, bananeira e plantas de importância florística. Atualmente foi relatado em vários estados brasileiros, mas pouco se sabe sobre sua distribuição atual no sul do Brasil. O objetivo deste estudo foi avaliar a distribuição de *R. indica* e os ácaros predadores associados no centro-sul do Brasil, discutindo o possível limite sul de sua distribuição. *Raoiella indica* foi encontrado no Distrito Federal e em 49 municípios de 9 estados, dos quais o mais meridional foi Iporã, estado do Paraná (24.007222°S, 53.698333°W). A maioria dos pontos pesquisados ao sul de Iporã tem altitude maior do que este município e dos pontos pesquisados imediatamente ao norte. Assim, pontos ao sul Iporã parecem ecologicamente inadequadas para *R. indica*, muito provavelmente por causa da baixa temperatura no inverno. Dezoito espécies de ácaros predadores foram encontradas em associação com a *R. indica*, todos dos quais pertencentes à ordem Mesostigmata e 14 pertencem a família Phytoseiidae. No entanto, eles não são inimigos naturais específicos de *R. indica*, pois, a maioria foi relatada em coqueiro (e outras plantas) no Brasil e em outros lugares, independentemente da ocorrência de *R. indica.*

Palavras Chave: Ácaros fitoseídeos; inimigos naturais; coqueiro

The red palm mite, *Raoiella indica* Hirst (Acari: Tenuipalpidae), is considered one of the most threatening pests of coconut, banana, and other monocotyledonous plants on the American continent and in the Caribbean region (Etienne & Flechtmann 2006; Carrillo et al. 2011a; Navia et al. 2015). Infested leaves usually become yellowish, with the attacked area drying as the population grows (Flechtmann & Etienne 2004; Peña et al. 2006). Plants are more seriously affected when infestations are associated with water stress and malnutrition (Navia et al. 2015).

Raoiella indica was first reported from the Western Hemisphere in the mid 2000s (Flechtmann & Etienne 2004), spreading since then to extensive areas in the tropical and subtropical regions of the American continent and the Caribbean (Welbourn 2006; Rodrigues et al. 2007; Vásquez et al. 2008; Carrillo et al. 2011b; Kane et al. 2012). Since its first report in Brazil in 2009, in the state of Roraima (Navia et al. 2011), new records were published from the states of Amazonas (Rodrigues & Antony 2011), São Paulo (Oliveira et al. 2016), Paraná (Hata et al. 2017), Alagoas, Bahia, Ceará, Distrito Federal, Goiás, Maranhão, Minas

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Gerais, Paraíba, Pernambuco, Piauí, Rio Grande do Norte and Sergipe (Melo et al. 2018). The risk of establishment of this mite in different parts of Brazil has been evaluated by Amaro & Morais (2013), although knowledge about the distribution of this mite in the southern half of the extensive Brazilian territory is still limited (Oliveira et al. 2016; Hata et al. 2017).

Coconut, *Cocos nucifera* L. (Arecaceae), is the principal host of *R. indica* (Carrillo et al. 2011a; Navia et al. 2015; Otero-Colina et al. 2016; Gómez-Moya et al. 2017; Polanco-Arjona et al. 2017). Although mid-southern Brazil is not very important in the production of coconut, this plant is commonly found in southern Brazil and other parts of the country as backyard plantations, or as ornamentals in this and other Brazilian regions (IBGE 2017). Conversely, banana (*Musa* spp.; Musaceae), also a host of *R. indica* (Carrillo et al. 2011a), is an important crop in mid-southern Brazil, especially in the states of Espírito Santo, Minas Gerais, Rio de Janeiro, and Sao Paulo. In fact, severe damage to banana varieties 'Prata' (AAB group) and 'Cavendish' (AAA group) was observed in 2016 in Missão Velha, Ceará State, northeastern Brazil (Rita de Cassia Rodrigues, personal communication). High levels of *R. indica* also were report-

Table 1. Sampling sites where *Raoiella indica* was present or absent[1] on each plant species in surveys conducted in mid-southern Brazil between Nov 2015 and Oct 2018.

Host plant	Family	State	Municipality
		PRESENT	
Adonidia merrillii (Becc.)	Arecaceae	Espírito Santo	Colatina and Marilândia
Archontophoenix sp.	Arecaceae	Paraná	Umuarama
		São Paulo	Cerquilho
Cocos nucifera L.	Arecaceae	Espírito Santo	Colatina, Domingos Martins and Venda Nova do Imigrante
		Goiás	Pirenópolis
		Mato Grosso	Sinop
		Mato Grosso do Sul	Bataguassu, Brasilândia, Santa Rita do Pardo and Três Lagoas
		Paraná	Cafezal do Sul, Cianorte, Ibiporã, Iguaraçú, Iporã, Jussara, Londrina, Maringá, Tamboara and Umuarama
		Rio de janeiro	Rio de Janeiro
		São Paulo	Avaí, Castilho, Dracena, Itapura, Jaboticabal, Jafa, Lençóis Paulistas, Marabá Paulista, Marília, Monte Aprazível, Nova Independência, Osvaldo Cruz, Pacaembu, Paulicéia, Piracicaba, Piratininga, Santópolis do Aguapeí, Vera Cruz and Ubatuba
Euterpe edulis Martius	Arecaceae	Paraná	Cruzeiro do Oeste
Musa sp.	Musaceae	São Paulo	Jafa and Piracicaba
Phoenix roebelenii O'Brien	Arecaceae	Distrito Federal	Brasília
		Espírito Santo	Linhares
		Mato Grosso	Sinop
		Rio de Janeiro	Petrópolis and Volta Redonda
		São Paulo	Jaguariúna
Pritchardia hillebrandii (Kuntze) Becc.	Arecaceae	São Paulo	Campinas
Rhapis excelsa (Thunb.) A.Henry	Arecaceae	Espírito Santo	Colatina
Wodyetia bifurcata AK Irvine	Arecaceae	Espírito Santo	Fundão and Nova Venécia
		ABSENT[1]	
A. merrillii	Arecaceae	Paraná	Palmeira and Ponta Grossa
Archontophoenix sp.	Arecaceae	Rio Grande do Sul	Boa Vista das Missões
Butia eriospatha (Mart. ex Drude)	Arecaceae	Rio Grande do Sul	Carazinho
C. nucifera	Arecaceae	Paraná	Campo Largo, Corbélia, Laranjeiras do Sul, Morretes, Palotina, Paranaguá, Ponta Grossa, Pontal do Paraná, Terra Roxa and Toledo
E edulis	Arecaceae	Paraná	Cascavel and Irati
Heliconia sp.	Heliconiaceae	Paraná	Campo Largo
		Paraná	Laranjeiras do Sul and Paranaguá
P. roebelenii	Arecaceae	Rio Grande do Sul	Frederico Westphalen
		Santa Catarina	Campo Erê
R. excelsa	Arecaceae	Paraná	Cascavel, Laranjeiras do Sul, Morretes, Paranaguá and Ponta Grossa
Roystonea oleracea (Jacq.)	Arecaceae	Paraná	Cascavel and Guaraniaçu
Syagrus romanzoffiana (Cham.)	Arecaceae	Paraná	Coronel Vivida, Curitiba, Guarapuava and Ivaiporã

[1]South of the southernmost site in which *R. indica* was found.

ed on banana cultivation in the Caribbean (Cocco & Hoy 2009; Kane et al. 2012; Rodrigues & Irish 2012).

The objective of this study was to evaluate the distribution of *R. indica* and associated predatory mites in mid-southern Brazil on coconut, banana, and a few other plant species on which this mite has been found, discussing the possible southern limit to its distribution in the country.

Materials and Methods

The study was conducted between 2015 and 2018, soon after the first detection of the mite in Brazil south of the Amazonas River (Oliveira et al. 2016). Symptomatic coconut plants (especially), as well as ornamental date and banana plants found along highways, urban parks, and nurseries were examined in the Federal District, and in the states of Espírito Santo (ES), Goiás (GO), Mato Grosso (MT), Mato Grosso do Sul (MS), Minas Gerais (MG), Paraná (PR), Rio de Janeiro (RJ), Rio Grande do Sul (RS), Santa Catarina (SC), and São Paulo (SP). When mites resembling *R. indica* were detected with the use of hand lenses, leaflets or leaf pieces were transferred to vials partially filled with 70% ethanol and transported to the laboratory, where the mites were collected and mounted in Hoyer's medium. They were subsequently identified to species by comparing their morphology with the information provided in the original descriptions and redescriptions in the literature. Representative specimens of the species collected were deposited in the mite reference collection of Departamento de Entomologia e Acarologia, Escola Superior de Agricultura "Luiz de Queiróz," Universidade de São Paulo (ESALQ/USP), Piracicaba, São Paulo, Brazil.

Results

Raoiella indica was found in the Federal District and 49 municipalities of the 9 states visited in the study (Table 1), of which the southernmost was Iporã, Paraná State (24.007222°S, 53.698333°W). It was not found in 26 other municipalities south of Iporã (Table 1, Fig. 1), namely: Paraná State: Campo Largo, Candoi, Cascavel, Corbélia, Coronel Vivida, Cruzeiro do Oeste, Curitiba, Guaraniaçú, Guarapuava, Imbaú, Irati, Ivaiporã, Laranjeiras do Sul, Mandaguari, Morretes, Palmeira, Palotina, Paranagá, Ponta Grossa, Pontal do Paraná, Terra Roxa, and Toledo; Rio Grande do Sul State: Boa Vista das Missões, Carazinho, and Frederico Westphalen; Santa Catarina State: Campo Erê.

All 18 species of predatory mites found in association with *R. indica* are found in the order Mesostigmata (Table 2). Fourteen of them were in family Phytoseiidae, 1 in Blattisociidae, and 3 in Melicharidae. By far, the phytoseiid *Euseius citrifolius* Denmark & Muma was the most numerous and widespread (45 specimens found in 5 states), followed by *Iphiseiodes zuluagai* Denmark & Muma, and *Amblyseius largoensis* (Muma), also phytoseiids and both found in similar numbers (17 and 14 specimens in 3 and 1 states, respectively).

Discussion

The results of this study expand the known distribution of *R. indica* in Brazil to include areas where its most important host plant, coconut, is not an important crop. Although the absence of *R. indica* in some sampling sites could have been due to the unsuitability of some of the plants examined, this does not seem to have been the case, because in

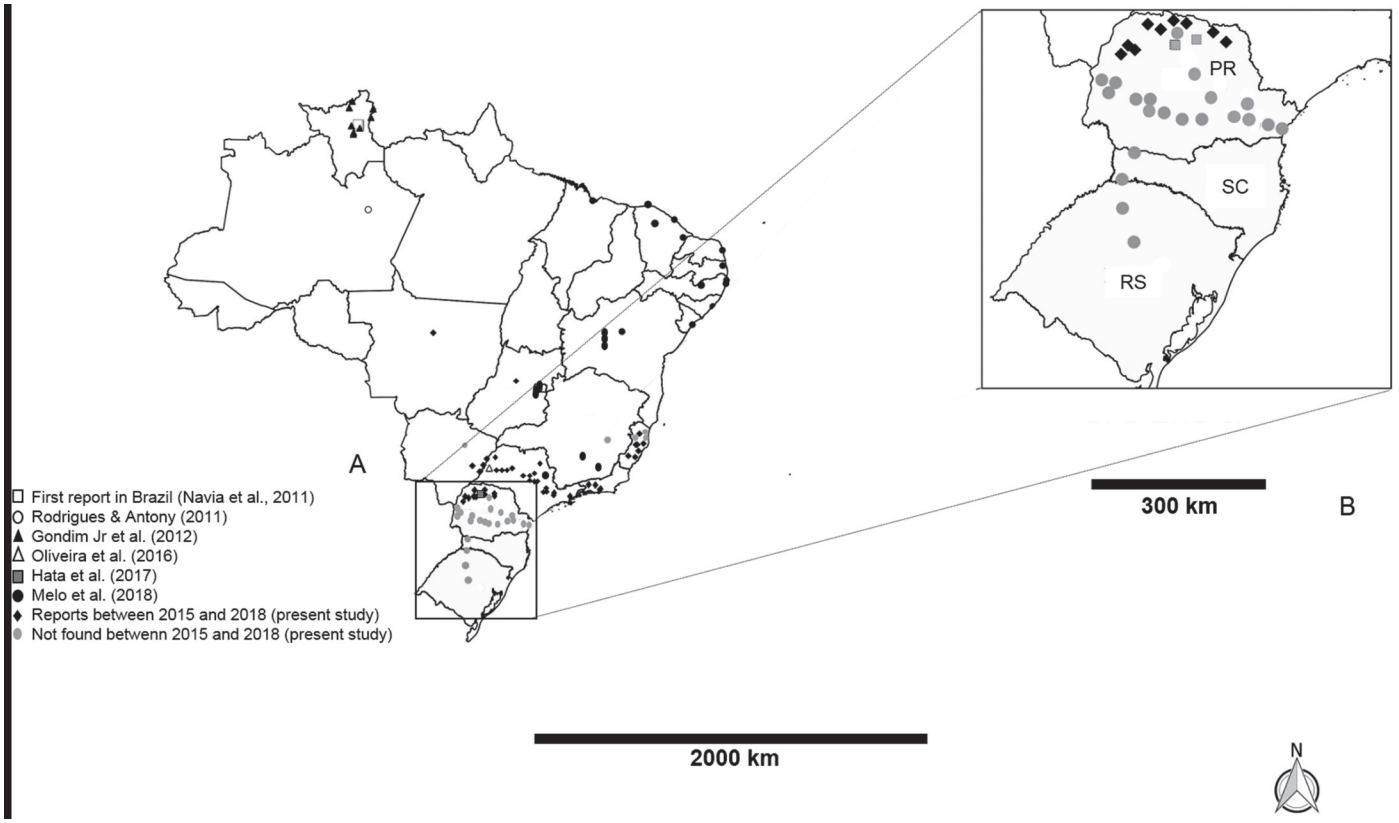

Fig. 1. New findings of *Raoiella indica* in mid-southern Brazil between 2015 and 2018, and previous records throughout the country. (A) Brazilian map showing sites where the presence of the mite has been evaluated in this and previous surveys; (B) Enlarged view of the position of sites in Paraná (PR), Rio Grande do Sul (RS), and Santa Catarina (SC) states.

most places the plants examined were known hosts of *R. indica*, except for *Syagrus romanzoffiana* (Cham.) Glassman (Aracaceae) (in Coronel Vivida, Curitiba, and Ivaiporã), where coconut was not found.

Although failure to find *R. indica* in some sampling areas could be by chance, its absence in areas of southern Brazil (Rio Grande do Sul, Santa Catarina, and part of Paraná States) could reflect the ecological unsuitability of those places. These results fit well with what was predicted by the model developed by Amaro & Morais (2013), based on 20 environmental variables. The authors concluded that the variables that most influenced their prediction were related to temperature. The altitude of the sites where *R. indica* was not found across the central region of Paraná State is at least about 500 masl, except Morretes, Palotina, Pontal do Paraná, and Terra Roxa (333, 374, 11, and 285 masl, respectively). Conversely, the altitude of the sites where it was found in the northern part of the state is at most 500 masl, except Londrina (543 masl). Hence, being higher and further south make central Paraná State colder than northern Paraná. An examination of the historical records (Continente 2018) showed that average minimum monthly temperatures in places where *R. indica* was found in northern Paraná are at least 9 °C, except Maringá (7.2 °C), whereas in places where it was not found, temperatures are at most 9 °C, except Morretes, Palotina, Pontal do Paraná, and Terra Roxa (12.3, 9.6, 13.7, and 9.8 °C, respectively). However, according to that the study of Amaro & Morais (2013), it is still possible that the mite could be found further south, along the coast of Rio Grande to Sul and Santa Catarina, areas not surveyed in this work. Also, according to that study, *R. indica* is expected to be able to extend south of the maximum latitude where it was detected during the current study (Iporã), in neighboring Paraguay and Argentina, along the low lands of the Paraguay River basin.

The highest frequency of *R. indica* on coconut in this study is certainly due to the concentrated effort to search for it on symptomatic coconut, given its known preference for this host plant. The spread of *R. indica* is facilitated by the fact that new coconut plantations are usually established with plantlets acquired commercially, which may harbor the mite at low population levels, allowing its unnoticeable transportation over long distances. Dispersal can be facilitated further by the transportation of other infested plants that are used principally as ornamentals. The permanent availability of the host plant, and the seemingly limited capacity of natural enemies to maintain the pest at low levels, may account also for its ability to disperse (Navia et al. 2013). Hence, occurrence of *R. indica* south of Iporã in Brazil seems possible, in protected or restricted microhabitats, especially on protected ornamentals or in banana-producing areas, usually microhabitats with mild climate.

Although the diversity of predatory mites associated with *R. indica* in this study could not be considered low, not much can be said about the type of relationship they have to that prey, because basically most of those species found in this work have been reported from coconut in Brazil and elsewhere, regardless of the presence of *R. indica* (Lawson-Balagbo et al. 2008; Oliveira et al. 2012). *Amblyseius largoensis*, the third most numerous phytoseiid predator in association with *R. indica* in the present study, often has been reported in association with *R. indica* in the Neotropics, usually in coastal areas (Etienne & Flechtmann 2006; Rodrigues et al. 2007; Roda et al. 2008; Carrillo et al. 2010; Hastie et al. 2010; Carrillo et al. 2011c; Gondim Jr. et al. 2012; Moraes et al. 2012; Flores-Gallano et al. 2017). This

Table 2. Mesostigmatid mites associated with *Raoiella indica* on host plants in mid-southern Brazil in surveys conducted between 2015 and 2018.

Taxa	Number of specimens	State	Host plant
Phytoseiidae			
Amblyseius acalyphus Denmark & Muma	5	São Paulo	*Cocos nucifera* L.
Amblyseius aerialis (Muma, 1955)	1	Rio de Janeiro	*C. nucifera*
Amblyseius chiapensis De Leon	6	Espírito Santo and Paraná	*Archontophoenix* sp.
Amblyseius compositus Denmark & Muma	2	Paraná	*C. nucifera*
Amblyseius herbicolus (Chant)	2	Paraná	*C. nucifera*
Amblyseius largoensis (Muma)	14	Espírito Santo	*Adonidia merrillii* (Becc.)
Amblyseius tamatavensis Blommers	8	Espírito Santo and São Paulo	*C. nucifera*
Amblyseius sp.	1	Espírito Santo	*C. nucifera*
Euseius alatus De Leon	2	Paraná	*Archontophoenix* sp.
Euseius citrifolius Denmark & Muma	45	Goiás, Mato Grosso do Sul, Paraná, Rio de Janeiro and São Paulo	*Archontophoenix* sp., *C. nucifera*, *Euterpe edulis* Martius, *Musa* sp. and *Phoenix roebelenii* O'Brien
Euseius concordis (Chant)	5	Espírito Santo, Paraná and São Paulo	*A. merrillii*, *C. nucifera* and *E. edulis*
Iphiseiodes zuluagai Denmark & Muma	17	Mato Grosso do Sul, Rio de Janeiro and São Paulo	*C. nucifera*
Neoseiulus anonymus (Chant & Baker)	1	São Paulo	*C. nucifera*
Proprioseiopsis ovatus (Garman)	2	São Paulo	*C. nucifera*
Typhlodromus (*Anthoseius*) *transvaalensis* (Nesbitt)	2	São Paulo	*C. nucifera*
Immatures	23		
Males	3		
Blattisociidae			
Blattisocius dentriticus (Berlese, 1918)	5	São Paulo	*C. nucifera*
Melicharidae			
Proctolaelaps bickleyi (Bram)	2	Mato Grosso do Sul and São Paulo	*C. nucifera*
Proctolaelaps pygmaeus (J. Müller)	1	São Paulo	*C. nucifera*
Proctolaelaps bulbosus Moraes, Reis & Gondim Jr	4	São Paulo	*C. nucifera*
Immatures	5		
Males	5		

predator has received the most attention as a possible candidate for practical use as biological control agent of the pest (Carrillo et al. 2010; Carrillo et al. 2011c; Carrillo et al. 2012; Domingos et al. 2012; Carrillo et al. 2014; Morais et al. 2016; Mendes et al. 2018).

In conclusion, since its first report in Brazil, *R. indica* now has been found in 18 states in the country, in sites ranging from 2°N to 23°S latitude. Complementary studies, especially in western Brazil, might demonstrate that it is also present there.

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