Feeding, Reproduction, and Development of the Red Palm Mite (Acari: Tenuipalpidae) on Selected Palms and Banana Cultivars in Quarantine

Authors: Cocco, Aeturo, and Hoy, Marjorie A.

Source: Florida Entomologist, 92(2) : 276-291

Published By: Florida Entomological Society

URL: https://doi.org/10.1653/024.092.0212

FEEDING, REPRODUCTION, AND DEVELOPMENT OF THE RED PALM MITE (ACARI: TENUIPALPIDAE) ON SELECTED PALMS AND BANANA CULTIVARS IN QUARANTINE

ARTURO COCCO[1] AND MARJORIE A. HOY
Department of Entomology and Nematology, University of Florida, Bldg. 970, Natural Area Drive, Gainesville, FL, 32611-0629, USA

[1]Presently at Dipartimento di Protezione delle Piante, Sezione Entomologia Agraria, Università di Sassari, Via De Nicola 1, 07100 Sassari, Italy
E-mail: acocco@uniss.it

ABSTRACT

The red palm mite, *Raoiella indica* Hirst, an important pest of coconut, banana, and date palms is a new invasive pest in the Western Hemisphere. The red palm mite (RPM) has been observed attacking bananas and plantains in Dominica and in Florida (M. A. Hoy, A. Cocco, personal observation). In order to develop an efficient method to rear the RPM in quarantine for a classical biological control project, several banana and plantain varieties were tested as hosts for the RPM. Bananas are more desirable than coconut (a favored host plant) because bananas are easier to rear in small cages and will produce new shoots quickly after pruning. Red palm mite females did not establish on the banana and plantain varieties (Dwarf Cavendish, Dwarf Nino, Gran Nain, Dwarf Zan Moreno, Dwarf Green, Truly Tiny, *Musa sumatrana* × Gran Nain, Dwarf Puerto Rican, Rose, Nang Phaya, Misi Luki, Manzano, Lady Finger, Glui Kai, and Ebun Musak) of leaf discs tested, but they established on coconut leaf discs. The mites could not be reared on potted banana trees (Glui Kai, Dwarf Green, and Nang Phaya varieties), but a multigenerational colony has been maintained on coconut trees and leaf discs. No RPM females survived on native palms tested (saw palmetto, cabbage palm, and dwarf palmetto), but RPM completed a generation on needle palm, with longer development time, higher mortality, and lower fecundity than when reared on coconut discs. Our results indicate that coconut leaf discs and trees are better hosts for rearing RPM in quarantine than banana, plantain varieties, or native palms tested. Quarantine tests and field observations suggest that the host range of RPM may not be as broad as some reports indicate because plants from which RPM adults and/or eggs have been collected might not be suitable for establishment of a multigenerational colony. More studies under natural conditions need to be conducted to evaluate the ability of *R. indica* to establish and spread on native and ornamental palms in natural landscapes in Florida.

Key Words: *Raoiella indica*, laboratory rearing, host plants, saw palmetto, dwarf palmetto, cabbage palm, needle palm, coconut

RESUMEN

El acaro rojo de la palmera, *Raoiella indica* Hirst, una plaga importante del coco, banano, y de la palmera datilera es una plaga nueva invasora del Hemisferio Occidental. El acaro rojo de la palmera (ARP) ha sido observado atacando bananos y plátanos en Dominica y en la Florida (M. A. Hoy, A. Cocco, observación personal). Para desarrollar un método eficiente para criar el ARP en cuarentena para un proyecto de control biológico clásico, varias variedades de banano y plátano fueron probadas como hospederos para el ARP. Los bananos son mas deseables que los cocos (una planta hospedera preferida) por que los banano son mas fáciles para criar en jaulas pequeñas y producen nuevos brotes rápidamente después de la poda. Las hembras del acaro rojo de las palmeras no se establecieron sobre las variedades de banano y plátano (Dwarf Cavendish, Dwarf Nino, Gran Nain, Dwarf Zan Moreno, Dwarf Green, Truly Tiny, *Musa sumatrana* × Gran Nain, Dwarf Puerto Rican, Rose, Nang Phaya, Misi Luki, Manzano, Lady Finger, Glui Kai y Ebun Musak) en los discos de hojas probados, pero se establecieron en los discos de hojas del coco. Estos ácaros no pudieron ser criados en árboles de bananos en macetas (variedades Glui Kai, Dwarf Green y Nang Phaya), pero ha mantenido una colonia multigeneracional sobre árboles de coco y discos de hojas. Ningún hembra de ARP sobrevivió las palmas nativas probadas (saw palmetto, cabbage palm, and dwarf palmetto), pero ARP completo una generación sobre la "needle palm" (palmera de aguja), con un periodo de desarrollo mas largo, mortalidad mas alta y fecundidad mas baja que cuando fue criado sobre discos de coco. Nuestros resultados indican que los discos de la hoja de coco y los árboles de coco son mejores hospederos para criar ARP en cuarentena que las variedades de plátano, banano o las palmeras nativas probadas. Las pruebas en cuarentena y las observaciones indican que el rango de los hospederos de ARP posiblemente no sea tan amplio como indican algunos informes porque las plantas sobre que han recolectado adultos y/o huevos de ARP pueden ser no apropiadas para el establecimiento de una colonia multigeneracional. Se necesitan realizar mas estudios bajo condiciones naturales para evaluar la habilidad de *R. indica* para establecerse y esparcirse sobre palmeras nativas y ornamentales en áreas naturales de la Florida.

The red palm mite, *Raoiella indica* Hirst (Acari: Tenuipalpidae) (RPM), is a serious pest of economically important fruit-producing trees such as coconut *Cocos nucifera* L. and banana *Musa* spp. (Nagesha-Chandra & Channabasavanna 1984; Welbourn 2006). In addition, significant infestations have been reported on the date palm *Phoenix dactylifera* L., plantains *Musa* spp., and ornamental palms, including the Christmas palm *Adonidia* (= *Veitchia*) *merrillii* (Becc.) H. E. Moore, and the Mexican fan palm *Washingtonia robusta* H. Wendl (Zaher et al. 1969; Etienne & Fletchmann 2006). The RPM was found in the Caribbean for the first time in Martinique and Saint Lucia in 2004 (Fletchmann & Etienne 2004), and has now spread throughout the Caribbean islands and invaded Florida and Venezuela (Kane et al. 2005; Etienne & Fletchmann 2006; Gutiérrez et al. 2007; Rodrigues et al. 2007). *Raoiella indica* was detected in southeastern Florida in 2007 and is now established in 3 counties (Florida Department of Agriculture and Consumer Services 2008). Plants reported by USDA-APHIS to be hosts of *R. indica* in Florida include ornamental palms such as the Fiji fan palm *Pritchardia pacifica* Seem. & H. Wendl., the Miraguama palm *Coccothrinax miraguama* (Kunth) Leon, and the endangered native Florida thatch palm *Thrinax radiata* Lodd. ex J. A. & J. H. (K. M. Griffiths, personal communication; Coile & Garland 2003).

The establishment of *R. indica* in North America has caused concerns about the economic impact of this new pest in palm nurseries, subtropical agriculture, and natural and urban landscapes. The biology of *R. indica* was studied on coconut in India by Nagesha-Chandra & Channabasavanna (1984) and on date palm in Egypt by Zaher et al. (1969), while studies on ornamental and landscape palms, bananas, or plantains have not been reported. The potential susceptibility of native Florida palms to the RPM is of interest in the spread of the pest, as well as for its effects in parks and natural areas.

A classical biological control program for Florida was initiated by identifying potentially effective predatory mites from areas where the RPM is endemic (Hoy et al. 2006). Predatory mites (Acari: Phytoseiidae) were imported from Mauritius and colonies were established in the quarantine laboratory at the Department of Entomology and Nematology, University of Florida, in Oct 2007. Colonies of the RPM and predatory mites are being reared in quarantine on coconut leaf discs (H. Bowman & M.A. Hoy, unpublished). Bananas and plantains were observed to be a suitable host for the RPM in Dominica and in Florida (M.A. Hoy, N. Commodore, and A. Cocco, personal observation) and were considered more appropriate for rearing in small spaces than the coconut palm because they can be grown in small pots, fit into small cages, and produce new shoots quickly after pruning so they can be reused several times in quarantine.

Thus, we conducted rearing tests to determine whether *R. indica* could be reared on banana and plantain leaf discs or trees under quarantine conditions outside the infestation zone. In addition, the suitability of selected Florida native palms as hosts for the RPM was investigated. Native palms commonly occur in natural landscapes and the fan-shaped palm leaves could provide wider leaf discs than the split-leafed coconut palms for bioassays with the phytoseiids being evaluated in quarantine. In addition, these trials could provide new biological information about the host range and the behavior of the RPM.

Materials and Methods

Source of *Raoiella indica*, Coconut, and Native Palms

Foliage containing the RPM was collected from heavily infested banana and coconut trees of unknown cultivars in Lake Worth, FL during 2008, placed into ice chests with ice packs, and brought into the quarantine facility at the Department of Entomology and Nematology, University of Florida, Gainesville. The foliage samples were kept at 21.5-23.8°C inside ice chests until RPM were used in tests. Potted coconut trees were purchased from nurseries in southern Florida, tested for pesticide residues, and reared at the Department of Entomology and Nematology. Leaf discs used in the experiments were obtained from mature leaves. The native palms tested as suitable hosts were dwarf palmetto *Sabal minor* (Jacq.) Pers., saw palmetto *Serenoa repens* (Bartr.) Small, cabbage palm *Sabal palmetto* (Walter) Lodd. ex Schult., and needle palm *Rhapidophyllum hystrix* (Pursh). These native palm samples were collected in Gainesville, FL on the campus of the University of Florida and at Kanahapa Botanical Gardens from mature leaves that had not been treated with pesticides.

Raoiella indica Rearing on Banana Discs and Trees

To verify that the RPM can be reared on banana leaf discs (leaves cut into pieces of specific size), 4 banana varieties (Dwarf Puerto Rican [plantain], Dwarf Cavendish, Dwarf Nino, and Gran Nain) obtained from Agri-Starts, Inc. (Apopka, FL) were potted into 3.8-L pots and allowed to produce 6-10 leaves before being evaluated, with coconut leaf discs used as a positive control. Discs 18 × 45 mm wide cut with a single-edge razor blade from mature leaves were cleaned with a brush and inspected for undesirable predatory mites or insects under a dissecting microscope. Banana and coconut discs were placed on water-soaked cotton in a plastic tray (13 × 13 × 2.5 cm), with the abaxial surface of the leaves facing up. The cotton was kept wet for the duration of the bioassay by adding water periodically, and narrow paper strips (Kimwipe, Kimberly-Clark Corporation, Roswell, GA) were placed along the edge of each leaf arena to reduce the likelihood of mites running off or under the discs. Five young RPM females, field collected from coconut trees (unknown cultivar), were placed on each disc; the survivorship and the number of eggs laid were recorded under a dissecting microscope every 24 h for 7 d. Body length and dimensions of dark patches on the dorsum of the body were considered to estimate the age of the females (Hoy et al. 2006). Twelve replicates were conducted by placing 6 leaf discs for each treatment in 2 trays at 26.9-31.4°C, 56-100% RH, under a 16L:8D photoperiod.

Because the establishment of *R. indica* on banana leaf discs might be affected by the original host of the mite, additional banana and plantain varieties were screened with young females collected from infested banana leaves (unknown variety) in Lake Worth, FL. Additional small banana and plantain trees (ca. 20 cm tall) were obtained from Agri-Starts, Inc. (Apopka, FL) and Dwarf Zan Moreno, Dwarf Green, Truly Tiny, *Musa sumatrana* × Gran Nain (hybrid), Dwarf Puerto Rican (plantain), Rose, Nang Phaya, Misi Luki, Manzano, Lady Finger, Glui Kai, and Ebun Musak varieties were tested, with coconut as a positive control. Discs from leaves about 2-3 weeks old were set up as described above, except that each disc (ca. 70 × 70 mm wide) was placed in a tray containing cotton saturated with water. Ten young RPM females were placed on each disc and left undisturbed for 11 d. Each female was considered a replicate. The survivorship, the behavior (feeding, not feeding, drowned, or dead), and the number of eggs laid in each disc were recorded under a dissecting microscope every 24 h, at 27.8-33.6°C, 44-100% RH, under a 16L:8D photoperiod.

To investigate whether the female's behavior was determined by some chemical or physical modification of the newly prepared banana discs, another bioassay was conducted with banana discs from leaves about 2-3 weeks old and held on the bioassay trays for 3 d before RPM were placed on them. The experimental design was the same as the above experiment, except that only the cultivars Nang Phaya, Dwarf Green, and Glui Kai were tested, with coconut used as a control and 25 females were added. Development of the progeny was monitored until adulthood was reached. Leaf discs were replaced after 3 weeks, when they became yellow. Mites were moved from degraded to new leaf discs with a sable-hair brush (size 0000). These bioassays were carried out at 27.8-33.1°C, 43-100% RH during the oviposition period and at 25.6-31.6°C, 51-100% RH during the developmental period of progeny, with both under a 16L:8D photoperiod.

To determine whether live banana trees could be used to rear the RPM under quarantine conditions, potted banana trees (varieties Glui Kai, Nang Phaya, and Dwarf Green) ca. 20-30 cm tall were tested. Because of space limitations inside the quarantine room, a single potted coconut tree was used as a control. Banana trees were pruned so that only a single leaf about 2-3 weeks old was used as the test arena. The leaves were cleaned with a brush for undesirable insects and predatory mites, and 20 young RPM females from field-collected coconut leaves were placed on the abaxial surface of the leaves and left undisturbed for 7 d. Trees were placed into PVC-frame cages covered with organdy cloth at 22.6-31.9°C, 42-73% RH, under a 16L:8D photoperiod. Live and dead adults and the number of eggs and larvae on each leaf were recorded under a dissecting microscope. Each treatment was replicated 5 times on 2 dates. If leaves were found that contained eggs or larvae, they were cut and placed on water-soaked cotton for further observations of developmental success.

Survival analysis was estimated with the PROC LIFEREG procedure (SAS Institute 2002). Pairwise comparisons were performed to evaluate significant differences between survivorship patterns. The proportion of mites feeding, not feeding, or drowned/dead on each disc was compared by logistic regression (PROC LOGISTIC, SAS Institute 2002).

To evaluate the RPM oviposition rate, the mean number of eggs laid on each of the banana or plantain discs was compared to the oviposition rate on coconut discs with the Mann-Whitney U test (Proc NPAR1WAY, SAS Institute 2002). The treatment means were not compared with each other because we were interested in comparing each to coconut only. Mortality rates of RPM eggs and immatures were compared with the Fisher's exact test (PROC FREQ, SAS Institute 2002). In the first bioassay, replicate discs of each treatment were combined and analyzed as 1 data set.

Two-Choice Test for Host Preference on Selected Palms

A two-choice test was conducted to determine the host preference of RPM with coconut vs. coconut, coconut vs. needle palm, coconut vs. saw palmetto, coconut vs. cabbage palm, and coconut vs. dwarf palmetto. Discs 18 × 45 mm wide were cut with a single-edge razor blade from mature leaves and hand washed with tap water and allowed to dry, which usually took 10-15 min. The 2 different disc halves were sealed together by painting a 4-5 mm wide stripe of melted paraffin wax with a camel-hair brush on the abaxial (lower) surface (Hoy & Smilanick 1981). The joined leaf discs were placed on water-soaked cotton in plastic trays as for the previous tests. A single young RPM female was placed on the midline paraffin stripe of each arena with a sable-hair brush (size 0000) and allowed to move freely. The location (disc half type or paraffin wax stripe), the behavior (feeding, not feeding, drowned, or dead), and the number of eggs laid were recorded under a dissecting microscope after 48 h. Mites were checked under a dissecting microscope after 24 h to confirm the survival of each female and to determine whether females had moved from the paraffin midline. RPM females were touched gently with a sable-hair brush and considered alive if they moved or walked away, while dead females were removed and replaced with live adults. The experiment was replicated 35 times by placing 5 arenas for each type of two-choice leaf disc in 7 trays. Two bioassays were conducted with RPM females collected either from coconut or banana trees in the field in order to investigate whether the original host plant affected host choice. The experiments were conducted at 28.1-34.6°C, 52-100% RH when mites from coconut were used, and at 28.5-33.4°C, 42-100% RH when mites from bananas were tested, both under a 16L:8D photoperiod. Temperature and RH were recorded with a Traceable® Digital Thermometer (Fisher Electronics, Pittsburgh, PA).

Exact logistic regression (PROC LOGISTIC, SAS Institute 2002) was used to analyze *R. indica* behavioral response (host choice) to host plants because some observations had zero values or separation of the data set occurred (Heinze & Ploner 2003). The number of eggs laid by RPM females on discs of the same arena was compared with the Mann-Whitney *U* test (Proc NPAR1WAY, SAS Institute 2002).

Survival and Reproduction of Females in No-choice Tests on Selected Ornamental and Native Palms

To determine whether RPM females were able to establish and oviposit on selected native palms of Florida, the behavior of single young females in single leaf discs was observed on coconut, needle palm, saw palmetto, cabbage palm, and dwarf palmetto. The leaf discs were set up as for the two-choice test, except that the discs were of a single leaf type. The survivorship, behavior (feeding, not feeding, drowned, or dead), and the number of eggs laid by single young *R. indica* females on each disc were recorded under a dissecting microscope every 24 h for 8 d.

To determine whether immature stages were able to establish on these native palm species from the eggs deposited by the females above, egg eclosion and survival of immatures were recorded. The entire experiment was conducted with young RPM females collected from both infested coconut and banana trees and was replicated 50 times on 2 dates. The bioassays with RPM from coconut were carried out at 28.1-32.6°C, 50-100% RH; those with RPM from banana at 28.8-33.4°C, 52-100% RH, both under a 16L:8D photoperiod.

Survivorship patterns were compared by the PROC LIFEREG procedure (SAS Institute 2002). Pairwise comparisons were performed to evaluate significant differences between treatments. The proportion of mites feeding, not feeding, or drowned/dead on each disc was compared by logistic regression (PROC LOGISTIC, SAS Institute 2002). The mean number of eggs laid during 8 d on each palm species was compared to that on coconut discs Mann-Whitney *U* test (Proc NPAR1WAY, SAS Institute 2002). The percentages of egg, larval, and protonymphal mortality were analyzed with exact logistic regression (PROC LOGISTIC, SAS Institute 2002).

Survival of *R. indica* on Needle Palm Leaf Discs

To determine whether *R. indica* could establish on needle palm discs, the survival of RPM immatures on that host plant was investigated and compared to survival on coconut discs. The leaf discs were set up as described above, except that they were 25 × 90 mm wide and were not washed but cleaned with a brush to preserve the cuticle characteristics. Fifteen young RPM females were sampled from field-collected coconut leaves and placed on the leaf discs for 6 d and then removed. Dead or drowned females were replaced every 24 h to maximize the number of eggs laid on coconut and needle palm leaf discs. The number of eggs laid, the percentage of egg eclosion, and the survival rate of RPM immatures were recorded every 24 h until adulthood was reached. The mean egg incubation time was estimated per each disc as

$$\text{MIT} = \bar{\chi}\ \text{egg eclosion date} - \bar{\chi}\ \text{egg oviposition date} \quad (1)$$

where MIT is the Mean Incubation Time, the mean egg eclosion date is the mean between the first and last day of egg eclosion, and the mean egg oviposition date is the mean between the first and the last day of egg oviposition. The mean development time from larva to adult was estimated per each disc as

MDT = $\bar{\chi}$ adult emergence date – $\bar{\chi}$ egg eclosion date (2)

where MDT is the Mean Development Time, the mean adult emergence date is the mean between the first and last adult emergence, and the mean egg eclosion date is the mean between the first and last day of egg eclosion. The emerging F_1 females were examined every 24 h to verify whether they laid eggs or not. Leaf discs were replaced every 3-4 weeks, when discs appeared degraded. Mites were transferred from aged to new leaf discs with a sable-hair brush. The bioassay was replicated 8 times, at 27.8-32.9°C, 48-72% RH during the oviposition period and at 25.6-29.9°C, 56-100% RH during the developmental period, both under a 16L:8D photoperiod.

The mean egg incubation time, and the mean development time from larva to adult were analyzed with the Mann-Whitney *U* test (Proc NPAR1WAY, SAS Institute 2002) (Lee 1992). Mortalities of eggs and immatures were evaluated with one-way ANOVA in Proc GLIMMIX (SAS Institute 2002).

Results and Discussion

Raoiella indica Rearing on Banana Discs and Trees

During the first experiment, RPM females did not establish on the 4 varieties of banana or plantain leaf discs, but they settled down on coconut discs (Fig. 1). There were significant differences in survival of RPM females on different leaf discs (χ^2 = 166.28; *df* = 4; *P* < 0.0001). Survivorship of RPM females on coconut leaf discs after 7 d was 52%, significantly different than the survival on Dwarf Puerto Rican, Dwarf Cavendish, Dwarf Nino, or Gran Nain discs (all pairwise comparisons: *P* < 0.0001). The survivorship pattern of RPM females on Dwarf Nino and Gran Nain leaf discs was not statistically different (χ^2 = 0.30; *df* = 1; *P* = 0.5831). Dwarf Cavendish (banana variety) and Puerto Rican (plantain variety) leaf discs were significantly less suitable than the other hosts tested.

During the 7-day bioassay, 60 RPM females laid a total of 261 eggs on coconut leaf discs, while surviving females laid a total of 6, 3, 32, and 42 eggs on Dwarf Puerto Rican, Dwarf Cavendish, Gran Nain, and Dwarf Nino discs, respectively (data not shown). The pairwise comparisons between the mean oviposition rate of the RPM on coconut discs (0.76 eggs/female/d) showed significant differences from these on Dwarf Puerto Rican (0.17 eggs/female/d) (*P* = 0.0054), Dwarf Cavendish (0.05 eggs/female/d) (*P* = 0.0033), Gran Nain (0.25 eggs/female/d) (*P* = 0.0037), and Dwarf Nino (0.27 eggs/female/d) (*P* = 0.0068) leaf discs.

When RPM females that were field collected from banana trees were tested on 12 different banana and plantain leaf discs, significant differences in survivorship were observed among the treatments (χ^2 = 108.85; *df* = 4; *P* < 0.0001) (Table 1). The banana variety Misi Luki appeared to be the least suitable host, with all RPM females dying or running off the discs by the second day of the bioassay. After 4 d, 100% mortality was observed on Truly Tiny, Dwarf Puerto Rican, Rose,

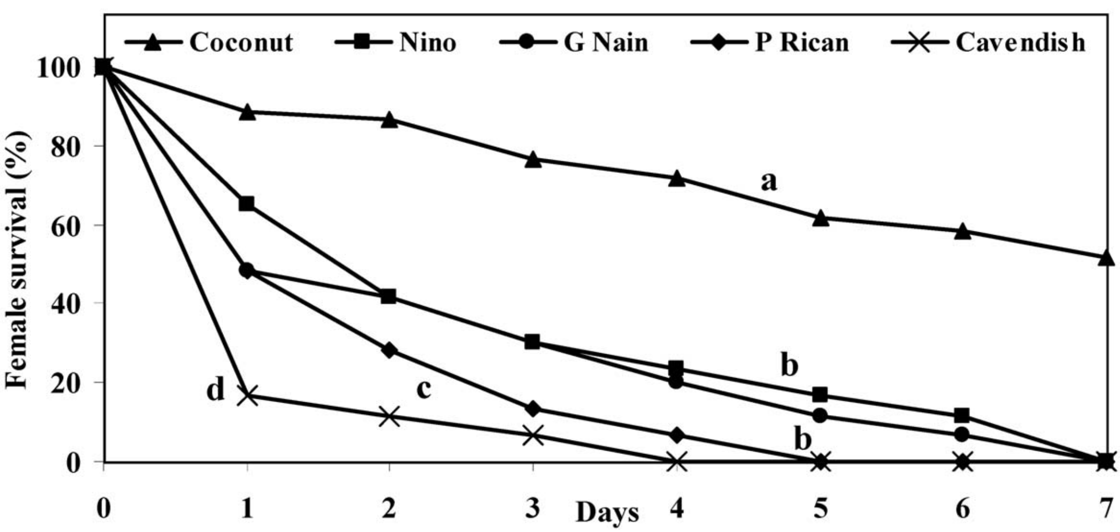

Fig. 1. Survivorship of *R. indica* females collected from coconut on different banana and plantain leaf discs under quarantine conditions (*n* = 60 for each plant type). Treatments followed by the same letter are not significantly different (*P* < 0.05).

TABLE 1. SURVIVORSHIP, BEHAVIOR AND MEAN OVIPOSITION RATE OVER 11 D OF *R. INDICA* FEMALES COLLECTED FROM BANANA ON SELECTED HOST PLANT DISCS UNDER NO-CHOICE QUARANTINE CONDITIONS.

Host plant[a]	Comparisons of survivorship over 11 d[b]	No. of observations[c]	Female behavior (%)[d]			Mean no. of eggs/♀/d (±SE)[e]
			Feeding	Not feeding	Drowned or dead	
Coconut	a	95	94 a	2 b	4 c	0.97 ± 0.18
Glui Kai	b	61	61 b	23 a	16 b	0.15 ± 0.05 *
Dwarf Green	c	34	38 cd	32 a	30 ab	0.23 ± 0.10 *
Nang Phaya	c	31	49 bc	19 a	32 ab	0.26 ± 0.22 *
M. sumatrana × Gran Nain	cd	25	32 cd	28 a	40 ab	0.07 ± 0.05 *
Manzano	cd	25	20 d	40 a	40 ab	0.03 ± 0.03 *
Rose	cde	21	38 cd	14 a	48 a	0.08 ± 0.08 *
Zan Moreno	cde	17	29 cd	12 ab	59 a	0.22 ± 0.16 *
Ebun Musak	cde	21	28 cd	24 a	48 a	0.23 ± 0.19 *
Truly Tiny	de	17	23 cd	18 a	59 a	0.13 ± 0.13 *
Puerto Rican	e	13	15 d	8 ab	77 a	0 *
Lady Finger	e	15	26 cd	7 ab	67 a	0.75 ± 0.25 ns
Misi Luki	e	15	26 cd	7 ab	67 a	0.30 ± 0.30 ns

[a]Laboratory conditions: 27.8-33.6°C, 44-100% RH, under a 16L:8D photoperiod. Number of females tested for each plant type = 10.

[b]Significant differences among survivorship patterns compared with PROC LIFEREG, treatments followed by the same letter within a column are not significantly different ($P < 0.05$).

[c]Discrepancies in number of observations (potentially 10♀ × 11 d = 110) are due to the different female survival rates.

[d]Significant differences compared with PROC LOGISTIC, treatments followed by the same letter within a column are not significantly different ($P < 0.05$).

[e]Significant differences between coconut and each host plant compared with Mann-Whitney *U* test (PROC NPAR1WAY), treatment means with * are significantly different compared to coconut ($P < 0.05$).

and Lady Finger leaf discs, while on Dwarf Green and Ebun Musak the same mortality rate was observed after 5 d. On Dwarf Zan Moreno, Nang Phaya, and Manzano leaf discs, no live female was observed after 6 d, while the longest survival among banana varieties was observed on Glui Kai leaf discs (11 d). By contrast, RPM females on coconut discs exhibited 40% mortality after 11 d. During the leaf disc bioassay, the Glui Kai variety appeared to be the most suitable banana host for the RPM (Table 1). Survivorship patterns of RPM females on Dwarf Green and Nang Phaya discs were not different than on *Musa sumatrana* × Gran Nain, Manzano, Rose, Dwarf Zan Moreno, and Ebun Musak, while they were statistically different from the survival rate on Truly Tiny, Dwarf Puerto Rican, Misi Luki, and Lady Finger leaf discs (Table 1).

Observations on feeding behavior showed that RPM females fed significantly more frequently on coconut than on banana or plantain leaf discs ($P < 0.0001$) (Table 1). Females of *R. indica* were observed feeding on Glui Kai discs in 61% of the observations, significantly more than on Dwarf Green, *Musa sumatrana* × Gran Nain, Manzano, Dwarf Zan Moreno, Ebun Musak, Truly Tiny, Dwarf Puerto Rican, Misi Luki, and Lady Finger leaf discs ($P < 0.05$). The proportion of RPM females feeding on the host ranged from 15 to 38% on Dwarf Green, Rose, *Musa sumatrana* × Gran Nain, Manzano, Rose, Dwarf Zan Moreno, Ebun Musak, Truly Tiny, Dwarf Puerto Rican, Misi Luki, and Lady Finger, but the differences were not significant (Table 1).

The oviposition rate of RPM females on coconut was 0.97 eggs/female/d, which was significantly higher than on Glui Kai, Dwarf Green, Nang Phaya, *M. sumatrana* × Gran Nain, Puerto Rican, Manzano, Rose, Zan Moreno, Ebun Musak, Truly Tiny, and Puerto Rican leaf discs (all pairwise comparisons were between the oviposition rate on each banana or plantain leaf disc and that on coconut discs: $P < 0.05$) (Table 1). *Raoiella indica* females laid 0.75 and 0.30 eggs/female/d on Lady Finger and Misi Luki leaf discs, respectively, which were not significantly different from that on coconut discs. Only 15 behavior observations were made on those discs because RPM females survived only 4 and 2 d, respectively, suggesting that females laid eggs immediately after being placed on the discs and then ran off the discs.

When RPM females were tested on 3-d-old Dwarf Green, Glui Kai, Nang Phaya, and coconut leaf discs, the 4 treatments exhibited significantly different survivorship patterns from one another ($F = 70.79$; $df = 3$; $P < 0.0001$) (Table 2). No live RPM females were observed on Nang Phaya and Dwarf Green after 5 and 7 d, respectively, while 100% mortality was observed on Glui Kai discs after 11 d. Consistent with the previous bioassay, female sur-

TABLE 2. SURVIVORSHIP AND OVIPOSITION RATE OF *R. INDICA* OVER 11 D, MORTALITY OF EGGS AND IMMATURES AND SUCCESSFUL DEVELOPMENT TO ADULT ON DIFFERENT 3-D-OLD BANANA LEAF DISCS UNDER NO-CHOICE QUARANTINE CONDITIONS.

Host plant[a]	Comparisons of survivorship over 11d[b]	Mean no. of eggs/♀/d (±SE)[c]	Mortality of *R. indica* (%)[d]		Successful development to adult (%)
			Eggs[ns]	Immatures*	
Coconut	a	0.93 ± 0.12	9	57	40
Glui Kai	b	0.26 ± 0.06 *	5	69	30
Dwarf Green	c	0.29 ± 0.11 *	4	77	22
Nang Phaya	d	0.13 ± 0.06 *	0	100	0

[a]Laboratory conditions: 27.8-33.1°C, 43-100% RH (oviposition period); 25.6-31.6°C, 51-100% RH (developmental period), both under a 16L:8D photoperiod. Number of females tested for each plant type = 25.
[b]Significant differences among survivorship patterns compared with PROC LIFEREG, treatments followed by the same letter within a column are not significantly different ($P < 0.05$).
[c]Significant differences between coconut and each host plant compared with Mann-Whitney *U* test (PROC NPAR1WAY), treatment means with * are significantly different compared to coconut ($P < 0.005$).
[d]Treatments were compared with the Fisher's exact test, ns = no differences among treatments; * = significant differences among treatments ($P < 0.05$).

vival on Glui Kai discs was significantly higher than these on Dwarf Green or Nang Phaya. At the end of the experiment, RPM females on coconut discs experienced 36% mortality. The mean fecundity of RPM females on coconut leaf discs (0.93 eggs/female/d) differed significantly from these of females on Glui Kai, Dwarf Green, or Nang Phaya discs (0.26, 0.29, and 0.13 eggs/female/d, respectively) (Table 2). All the pairwise comparisons between the oviposition rate on coconut discs and on banana discs indicated a significant difference with $P < 0.05$. The *R. indica* eggs experienced 0-9% mortality during the bioassay, but differences were not significant ($P = 0.8576$) (Table 2). Mortality of RPM immatures was significantly different among treatments (Fisher's exact test: $P = 0.0381$), ranging from 57% on coconut to 100% on Nang Phaya leaf discs. The rate of successful development from egg to adult on coconut, Glui Kai, Dwarf Green, and Nang Phaya discs was 40, 30, 22, and 0%, respectively (Table 2). The emerged RPM females did not deposit eggs on Glui Kai, Dwarf Green, or Nang Phaya discs and died within 7 d, while on coconut discs 88 RPM females established and laid 97 eggs over 7 d (data not shown).

RPM females also failed to establish on potted Glui Kai, Nang Phaya, and Dwarf Green banana trees. After 7 d, no females survived and a total of only 17, 10, and 1 eggs were observed on Glui Kai, Dwarf Green, and Nang Phaya leaves, respectively, corresponding to mean oviposition rates of 0.17, 0.10, and 0.01 eggs/female/7 d, respectively (Table 3). In the same climatic conditions, RPM females established and laid eggs on coconut leaves. A coconut leaf disc of ca. 25 cm^2 sampled randomly revealed 36 *R. indica* females alive and 154 eggs, with a mean fecundity of 4.3 eggs/female/7 d, and only 1 dead (3% mortality) (data not shown). Mortality rates of RPM eggs on banana leaves ranged from 0 (Nang Phaya) to 50% (Glui Kai), while larvae experienced 75, 0, and 100% mortality after 7 d on Glui Kai, Dwarf Green, and Nang Phaya leaves, respectively (Table 3). Leaves with eggs or larvae were cut and placed on water-soaked cotton, and subsequent observations indicated that all larvae died within 4 d and failed to molt to the protonymphal stage (Table 3).

Two-Choice Test for Host Preference on Selected Palms

Raoiella indica females did not exhibit a preference between needle palm or coconut leaf discs (Table 4, test A1: exact $P = 1.0000$; test B1: exact $p = 0.8506$). The proportion of females feeding on

TABLE 3. OVIPOSITION RATE AND MORTALITY OF ADULTS, EGGS AND LARVAE OF *R. INDICA* OVER 7 D ON DIFFERENT BANANA TREES UNDER QUARANTINE CONDITIONS.

Host plant[a]	Total no. eggs/20♀♀/7 d	Mean no. of eggs/♀/7 d (±SE)	Mortality of *R. indica* (%)			% molting from larvae to protonymphs
			Adults	Eggs	Larvae	
Glui Kai	17	0.17 ± 0.09	100	6	75	0
Dwarf Green	10	0.10 ± 0.05	100	50	0	0
Nang Phaya	1	0.01 ± 0.01	100	0	100	0

[a]Laboratory conditions: 22.6-31.9°C, 42-73% RH, under a 16L:8D photoperiod. Number of females in each treatment = 20. In the same climatic conditions, RPM females on coconut leaves exhibited 3% mortality and a mean fecundity of 4.3 eggs/female/7 d.

TABLE 4. BEHAVIOR AND OVIPOSITION RATE OF *R. INDICA* FEMALES OVER 2 D COLLECTED FROM COCONUT (A) AND BANANA (B) IN 2-CHOICE LEAF DISC BIOASSAYS UNDER QUARANTINE CONDITIONS.

		Female behavior (%)[c]			
Treatment[a]	Females observed on each half (%)[bc]	Feeding	Not feeding	Drowned or dead	mean no. of egg/♀/48 h (±SE)[d]
A Mites collected from coconut					
1) Coconut vs	49 a	88 a	6 a	6 a	1.4 ± 0.3 a
Needle palm	46 a	100 a	0 a	0 a	0.9 ± 0.3 a
2) Coconut vs	66 a	91 a	0 b	9 a	1.8 ± 0.3 a
Saw palmetto	9 b	0 b	67 a	33 a	0 b
3) Coconut vs	40 a	93 a	0 b	7 b	1.6 ± 0.3 a
Cabbage palm	34 a	0 b	42 a	58 a	0 b
4) Coconut vs	60 a	95 a	0 b	5 b	0.9 ± 0.2 a
Dwarf palmetto	26 b	0 b	33 a	67 a	0 b
5) Coconut vs	46 a	94 a	0 a	6 a	1.5 ± 0.3 a
Coconut	49 a	94 a	0 a	6 a	2.1 ± 0.3 a
B Mites collected from banana					
1) Coconut vs	37 a	100 a	0 a	0 a	1.0 ± 0.2 a
Needle palm	43 a	87 a	0 a	13 a	0.9 ± 0.3 a
2) Coconut vs	66 a	91 a	4 a	4 b	1.2 ± 0.3 a
Saw palmetto	29 b	0 b	10 a	90 a	0 b
3) Coconut vs	66 a	100 a	0 a	0 b	1.0 ± 0.2 a
Cabbage palm	14 b	0 b	0 a	100 a	0 b
4) Coconut vs	60 a	100 a	0 a	0 b	1.2 ± 0.2 a
Dwarf palmetto	14 b	0 b	0 a	100 a	0 b
5) Coconut vs	46 a	88 a	0 a	12 a	1.4 ± 0.3 a
Coconut	40 a	93 a	0 a	7 a	1.2 ± 0.3 a

[a]Laboratory conditions: (A) 28.1-34.6°C, RH 52-100%; (B) 28.5-33.4°C, RH 42-100%, both under 16L:8D photoperiod. Number of females observed after 48 h for each bioassay = 35.
[b]Discrepancies in the percentage of females on tested halves are because some females were found on the midline.
[c]Significant differences compared with PROC LOGISTIC, treatments followed by the same letter within a column for each bioassay are not significantly different (exact $P < 0.05$).
[d]Significant differences compared by the Mann-Whitney *U* test (PROC NPAR1WAY), means followed by the same letter within a column for each bioassay are not significantly different ($P < 0.05$).

coconut or needle palm discs after 48 h during tests A1 and B1 ranged from 87 to 100%, but the differences were not significant. RPM females appeared to prefer coconut over saw palmetto (test A2: exact $P < 0.0001$; test B2: exact $p = 0.0351$) or dwarf palmetto (test A4: exact $P = 0.0428$; test B4: exact $p = 0.0025$). No mites were observed feeding on saw palmetto or dwarf palmetto leaf discs during the 48-h experiments. Unexpectedly, RPM females did not show a preference between coconut and cabbage palm leaf discs in test A3 (exact $p = 0.8450$), while there was a significant difference between these host plants in test B3 (exact $p = 0.009$). However, no mites were detected feeding on cabbage palm discs during experiments A3 and B3, while all live females on the coconut halves of the test arenas appeared established. During the two-choice tests, no RPM female was observed feeding on saw palmetto, cabbage palm, or dwarf palmetto leaf discs. Observations after 24 and 48 h revealed that mites did not change their position after their original choice, perhaps due to the width of the paraffin seal (4-5 mm).

RPM oviposition rates on coconut and needle palm during the 48-h test were not significantly different, whether females were collected from coconut or banana (Table 4, tests A1: $\chi^2 = 1.6770$; $df = 1$; $p = 0.1953$; B1: $\chi^2 = 0.4678$; $df = 1$; $p = 0.4940$). However, no eggs were laid by females on saw palmetto, cabbage palm, or dwarf palmetto disc halves (Tests A2, A3, A4, B2, B3, B4), while RPM females on coconut halves of the same test arenas produced 0.9 to 1.8 eggs/female /48 h.

Survival and Reproduction of Females in No-choice Tests on Selected Ornamental and Native Palms

The native saw palmetto, cabbage palm, and dwarf palmetto do not seem to be palatable hosts for the RPM under quarantine conditions (Table 5). Despite the fact that adult females from the field-collected banana or coconut foliage were assigned randomly to the test leaf discs, there were significant differences in survivorship over 8 d (Table 5A: $\chi^2 = 218.2219$; $df = 4$; $P < 0.0001$; Table 5B: $\chi^2 = 241.0365$; $df = 4$; $P < 0.0001$). Coconut and needle palm discs appeared to be the most suitable hosts for RPM females, while they did not establish on saw palmetto, cabbage palm, or dwarf palmetto discs. Survivorship of *R. indica* females collected from coconut trees on needle palm and coconut leaf discs after 8 d were 76 and 90%, respectively, but the pairwise comparison was not significantly different ($\chi^2 = 3.68$; $df = 1$; $P = 0.0550$) (Table 5A). On saw palmetto discs, RPM females survived significantly longer than on cabbage palm ($\chi^2 = 17.83$; $df = 1$; $P < 0.0001$) or dwarf palmetto discs ($\chi^2 = 15.19$; $df = 1$; $P < 0.0001$) (Table 5A). When RPM females collected from banana were used, the survivorship on coconut and needle palm discs were 52 and 34%, respectively, showing a marginally significant difference ($\chi^2 = 3.96$; $df = 1$; $P = 0.0467$) (Table 5B). The survivorship pattern of *R. indica* females collected from infested banana trees on saw palmetto was significantly different than that on cabbage palm ($\chi^2 = 6.93$; $df = 1$; $P = 0.0085$), while there was no difference in female survival on saw palmetto and dwarf palmetto discs ($\chi^2 = 2.08$; $df = 1$; $P = 0.1491$). Survivorship patterns of *R. indica* on cabbage palm and dwarf palmetto discs were not significantly different in both experiments. Experiments A and B (Table 5) were performed using mites collected from infested coconut and banana trees on two dates, so no statistical analysis were performed to compare the two survivorship curves. However, RPM females collected from coconut appeared to survive longer than females collected from banana trees on coconut (90 and 55%, respectively) and needle palm (76 and 34%, respectively) leaf discs (data not shown).

Behavior observations during the no-choice test indicated that coconut was the better host for the RPM females (Table 5). Significantly more *R. indica* females were observed feeding on coconut discs than on needle palm, saw palmetto, cabbage palm, or dwarf palmetto discs in both experiments ($P < 0.0001$ for both) (Table 5A, B). However, needle palm discs appeared to be palatable to RPM females, which were observed feeding on that host 72 and 59% of the observations ($P < 0.0001$, Table 5A, B). Red palm mite females were observed feeding significantly less frequently on needle palm than on coconut leaf discs after 8 d (Table 5), while those differences in feeding behavior were not significant after 2 d (Table 4), suggesting that longer observations are more reliable to determine the palatability of the host plant.

Only 1 to 2% of the observations revealed *R. indica* feeding on saw palmetto, cabbage palm, or dwarf palmetto discs, whether using RPM females collected from coconut or banana trees, and

TABLE 5. SURVIVORSHIP AND BEHAVIOR OF *R. INDICA* FEMALES COLLECTED FROM COCONUT (A) AND BANANA (B) ON SELECTED HOST PLANT DISCS UNDER NO-CHOICE QUARANTINE CONDITIONS OVER 8 D.

Host plant [a]	Comparisons of survivorship over 8 d[b]	No. observations[c]	Female behavior (%)[d]		
			Feeding	Not feeding	Drowned or dead
A Mites collected from coconut					
Coconut	a	387	95 a	4 c	1 b
Needle palm	a	343	72 b	25 b	3 b
Saw palmetto	b	138	2 c	62 a	36 a
Cabbage palm	c	90	1 c	43 a	56 a
Dwarf palmetto	c	92	1 c	45 a	54 a
B Mites collected from banana					
Coconut	a	301	85 a	7 c	8 b
Needle palm	b	259	59 b	28 b	13 b
Saw palmetto	c	100	2 c	48 a	50 a
Cabbage palm	d	77	1 c	34 ab	65 a
Dwarf palmetto	cd	86	1 c	41 ab	58 a

[a]Laboratory conditions: (A) 28.1-32.6°C, 50-100% RH; (B) 28.8-33.4°C, 52-100% RH, both under a 16L:8D photoperiod. Number of females observed on each host plant = 50 for 8 d.

[b]Significant differences among survivorship patterns compared with PROC LIFEREG, treatments followed by the same letter within a column in each experiment are not significantly different ($P < 0.05$).

[c]Discrepancies in number of observations (potentially 50♀ × 8 d = 400) are due to the different female survival rates.

[d]Significant differences compared with PROC LOGISTIC, treatments followed by the same letter within a column are not significantly different ($P < 0.05$).

there were no significant differences in RPM feeding behavior on these discs ($P > 0.05$).

During the 8 d of the experiments, 50 *R. indica* females collected from coconut trees laid a total of 360 eggs on coconut leaf discs, with an oviposition rate of 0.92 eggs/female/d (Table 6A). RPM females from the same source laid a total 104 eggs on needle palm leaf discs, corresponding to an oviposition rate of 0.28 eggs/female/d, while females laid a total of only 1, 2, and 2 eggs (0.01 eggs/female/d) on dwarf palmetto, saw palmetto, and cabbage palm, respectively, over 8 d. The fecundity on coconut discs was significantly higher than on needle palm (Mann-Whitney U test, $P < 0.0001$), saw palmetto (Mann-Whitney U test, $P < 0.0001$), cabbage palm (Mann-Whitney U test, $P < 0.0001$), or dwarf palmetto discs (all pairwise comparisons between coconut vs. each native palm with Mann-Whitney U test: $P < 0.0001$). Likewise, when RPM females collected from banana trees were used, their oviposition rate on coconut discs (0.49 eggs/female/d) was significantly higher than on other hosts (all pairwise comparisons: $P < 0.0001$). On needle palm discs females laid a total of 36 eggs, at a rate of 0.11 egg/female/d, while on saw palmetto discs only 2 eggs were observed (0.01 egg/female/d) (Table 6B). No eggs were deposited on cabbage palm and dwarf palmetto discs. RPM females field collected from coconut trees exhibited a higher fecundity than females sampled from banana trees (0.92 and 0.49 eggs/female/d, respectively) (Table 6A, B), suggesting that coconut could be a more favorable host than banana in the field. The fecundity of RPM females on needle palm discs was significantly lower than coconut discs after 8 d (Tables 6A, B) while the oviposition rate was not different on coconut and needle palm discs after 2 d (Table 4), suggesting that RPM females laid most eggs on needle palm discs immediately after transfer, while the oviposition rate on coconut discs was more constant.

Mortality of eggs on coconut discs (11%) differed significantly from the egg mortality observed on needle palm discs (24%) (Table 6A, exact $P = 0.0014$). Mortality data of eggs from saw palmetto, cabbage palm, and dwarf palmetto was excluded from the statistical analysis because of the low number of eggs laid. Larvae that hatched on coconut discs experienced 11% mortality, which was significantly lower than the larval mortality on needle palm discs (81%) (exact $P < 0.0001$). Mortality of protonymphs on coconut discs was 21%, while all protonymphs on needle palm discs died before molting to the deutonymphal stage (exact $P < 0.0001$). Mortality rates of eggs laid by RPM females from banana trees on coconut and needle palm discs were significantly different (8 and 36%, respectively) (Table 6B, exact $P < 0.0001$). RPM larvae developed on coconut discs experienced 63% mortality, while no larvae molted successfully to the protonymphal stage on needle palm discs (exact $P = 0.0007$). RPM females

TABLE 6. MEAN FECUNDITY OVER 8 D OF *R. INDICA* FEMALES COLLECTED FROM COCONUT (A) AND BANANA (B) AND MORTALITY OF EGGS AND IMMATURES ON SELECTED HOST PLANT DISCS UNDER NO-CHOICE QUARANTINE CONDITIONS OVER 24 D.

Host plant[a]	Mean no. of eggs/♀/d (±SE)[b]	Mortality of *R. indica* (%)[c]		
		Eggs	Larvae	Protonymphs
A Mites collected from coconut				
Coconut	0.92 ± 0.04	11 b	33 b	21 b
Needle palm	0.28 ± 0.03 *	24 a	81 a	100 a
Saw palmetto	0.01 ± 0.01 *	—	—	—
Cabbage palm	0.01 ± 0.01 *	—	—	—
Dwarf palmetto	0.01 ± 0.01 *	—	—	—
B Mites collected from banana				
Coconut	0.49 ± 0.06	8 b	37 b	29
Needle palm	0.11 ± 0.02 *	36 a	100 a	—
Saw palmetto	0.01 ± 0.01 *	—	—	—
Cabbage palm	0	—	—	—
Dwarf palmetto	0	—	—	—

[a]Laboratory conditions: (A) 28.1-32.6°C, 50-100% RH; (B) 28.8-33.4°C, 52-100% RH, both under a 16L:8D photoperiod. Number of females observed on each host plant = 50 for 8 d.

[b]Significant differences between coconut and each host plant compared with Mann-Whitney U test (PROC NPAR1WAY), treatment means with * are significantly different compared to coconut ($P < 0.0001$).

[c]Significant differences compared with PROC LOGISTIC, treatments followed by the same letter within a column are not significantly different (exact $P < 0.05$). Mortality of eggs and larvae from saw palmetto, cabbage palm, and dwarf palmetto were excluded from the analysis because of the low number of eggs laid.

collected from coconut trees survived longer, exhibited an higher oviposition rate, and were observed feeding more often on coconut and needle palm discs than females collected from banana trees (Tables 5 and 6), perhaps due to the different age of leaves tested or to the lower suitability of banana for the RPM.

Survival of *R. indica* on Needle Palm Leaf Discs

During the 6-d assay, a total of 135 and 155 females were tested on coconut and needle palm discs, respectively. Thirty five females were replaced on needle palm because they died or ran off the discs, while 15 females were replaced on coconut discs for the same reason. Despite the lower number of females tested on coconut, a total of 648 eggs were laid on coconut discs and 365 on needle palm. Mortality of eggs laid on coconut discs was 3%, which was significantly lower than egg mortality (7%) on needle palm discs (F = 30.67; df = 1, 14; P < 0.0001). During development to adulthood, RPM immatures feeding on coconut discs exhibited significantly lower mortality (67%) than immatures growing on needle palm (84%) (F = 33.87; df = 1, 14; P < 0.0001) (Table 7). Although the determination of the exact development time of *R. indica* was beyond goal of the experiment, the Mean Incubation Time and the Mean Development Time were assessed. The mean Incubation Time ranged from 5.9 to 6.2 d on needle palm and coconut, respectively, but the difference was not significant (χ^2 = 1.7340; df = 1; P = 0.1879) (Table 7). The development time from larva to adult on coconut discs averaged 12.1 d, which was significantly lower than the Mean Development Time (25.9 d) on needle palm discs (χ^2 = 10.7299; df = 1; P = 0.0011). A total of 153 and 35 female progeny developed successfully on coconut and needle palm discs, respectively. Discs were examined every 24 h to verify the presence of F_2 eggs. On coconut discs, 21 d after the beginning of the experiment, a total 961 eggs were scored, with a 30% daily rate of increase which made mite counts difficult and observations on coconut discs were stopped. However, on needle palm discs, observations were stopped 64 d after the beginning of the bioassay, and a total of only 49 eggs were scored.

CONCLUSIONS

The RPM established on coconut leaf discs and potted trees, and small colonies have been maintained for many generations, while no stable colony has been obtained on banana or plantain discs or potted banana trees. Likewise, no RPM females survived on the ornamental and native palm discs tested, except on needle palm discs, where the RPM completed a generation but experienced high mortality and a long development time.

It is unclear whether *R. indica* can actually feed, reproduce, and develop within a normal time period on all plants listed in Table 8 because information about which RPM life stage was observed on these plants was not always provided (Fletchmann & Etienne 2004; Kane & Ochoa 2006; Mendonça et al. 2006; Welbourn 2006). Pedigo (1996, p. 425) defines a host plant as "Sufficiency of the plant as a host is finally determined during feeding. If nutrients are adequate and no toxicity occurs, the insect completes development within a normal time period and becomes an adult. Also sufficiency is indicated in normal adult longevity and fecundity". It is possible that the RPM was dispersed by wind currents to some of these plants located beneath palm canopies, and it is possible that gravid females could deposit a few eggs on these temporary hosts, but the establishment of a multigenerational colony has not always been documented.

Unknown varieties of bananas have been reported to be suitable hosts for the RPM in Florida (A. Cocco, personal observation), while in the Eastern Caribbean significant multigenerational infestations have been observed on the most widely grown banana (Dwarf Cavendish, Giant

TABLE 7. OVIPOSITION RATE OVER 6 D, MORTALITY OF EGGS AND IMMATURES, AND DEVELOPMENT TIME OF *R. INDICA* ON COCONUT AND NEEDLE PALM DISCS UNDER NO-CHOICE QUARANTINE CONDITIONS.

Treatment[a]	Total no. of ♀ tested on 6 d	Total no. of eggs/6 d	Mortality of *R. indica* (%)[b]		Mean Incubation Time (d ± SE)[c]	Mean Development Time larva to adult (d ± SE)[c]
			Eggs	Immatures		
Coconut	135	648	3 ± 1 b	67 ± 6 b	6.2 ± 0.1 a	12.1 ± 0.2 b
Needle palm	155	365	7 ± 3 a	84 ± 4 a	5.9 ± 0.1 a	25.9 ± 0.8 a

[a]Laboratory conditions: 27.8-32.9°C, 48-72% RH (oviposition period); 25.6-29.9°C, 56-100% RH (developmental period), both under a 16L:8D photoperiod. Initial number of females for each of 8 replications = 15.

[b]Treatment means were compared with PROC GLIMMIX, means with the same letter within a column are not significantly different.

[c]Significant differences compared by the Mann-Whitney *U* test (PROC NPAR1WAY); means followed by the same letter within a column for each bioassay are not significantly different (P < 0.05).

TABLE 8. REPORTED HOST PLANT SPECIES OF *RAOIELLA INDICA*[a].

Family	Plant species	Reference [b]
Aceracee	*Acer* sp.	Mitrofanov & Strunkova (1979)
Arecaceae	*Acoelorraphe wrightii* (Grises. & H. Wendl.)	Welbourn (2006)*
Arecaceae	*Adonidia merrilli* (Becc.) Becc. (= *Veitchia*)	Fletchmann & Etienne (2004)
Arecaceae	*Aiphanes caryotifolia* (Kunth) H. A. Wendl.	K. Griffiths, personal communication
Arecaceae	*Aiphanes* sp.	Kane et al. (2005)
Arecaceae	*Archontophoenix alexandrae* (F. Muell.) H. Wendl. & Drude	K. Griffiths, personal communication
Arecaceae	*Areca* sp.	Pritchard & Baker (1958)
Arecaceae	*Areca catechu* L.	Nagesha-Chandra & Channabasavanna (1984)
Arecaceae	*Bactris plumeriana* Mart.	Welbourn (2006)*
Arecaceae	*Beccariophoenix madagascariensis* Jum. & H. Perrier	K. Griffiths, personal communication
Arecaceae	*Bismarckia nobilis* Hildebr. & Wendl.	Welbourn (2006)
Arecaceae	*Butia capitata* (Mart.) Becc.	K. Griffiths, personal communication
Arecaceae	*Caryota mitis* Lour.	Etienne & Fletchmann (2006)
Arecaceae	*Chamaedorea* spp.	Welbourn (2006)
Arecaceae	*Coccothrinax argentata* (Jacq.) L. H. Bailey	A. Cocco, personal observation
Arecaceae	*Coccothrinax miraguama* (Kunth) Becc.	K. Griffiths, personal communication
Arecaceae	*Cocos nucifera* L.	Hirst (1924)
Arecaceae	*Corypha umbraculifera* L.	K. Griffiths, personal communication
Arecaceae	*Dictyosperma album* (Bory) H. Wendl. & Drude ex Scheff.	Moutia (1958)
Arecaceae	*Dypsis decaryi* (Jum.) Beentje & J. Dransf.	Welbourn (2006)
Arecaceae	*Dypsis lutescens* (H. Wendl.) Beentje & J. Dransf. (= *Chrysalidocarpus*)	Kane et al. (2005)
Arecaceae	*Elaeis guineensis* Jacq.	Welbourn (2006)
Arecaceae	*Licuala grandis* H. Wendl.	Etienne & Fletchmann (2006)
Arecaceae	*Livistona chinensis* (Jacq.) R. Br.	K. Griffiths, personal communication
Arecaceae	*Phoenix canariensis* hort. ex Chabaud	Etienne & Fletchmann (2006)
Arecaceae	*Phoenix dactylifera* L.	Sayed (1942)
Arecaceae	*Phoenix reclinata* Jacq.	Welbourn (2006)*
Arecaceae	*Phoenix roebelenii* O'Brien	Welbourn (2006)
Arecaceae	*Pritchardia pacifica* B.C. Seem. & H. Wendl.	Etienne & Fletchmann (2006)
Arecaceae	*Pritchardia vuylstekeana* H. Wendl. ?	A. Cocco, personal observation
Arecaceae	*Pseudophoenix sargentii* H. Wendl. ex Sarg.	Welbourn (2006)
Arecaceae	*Pseudophoenix vinifera* (Mart.) Becc.	Welbourn (2006)*
Arecaceae	*Ptychosperma elegans* (R.Br.) Blume	K. Griffiths, personal communication
Arecaceae	*Ptychosperma macarthurii* (H. Wendl. ex H .J.Veitch) H. Wendl. ex Hook. F.	Etienne & Fletchmann (2006)
Arecaceae	*Ptychosperma* sp.	A. Cocco, personal observation

[a]Most host plants are reported with no information about which RPM stage was found. The establishment of a multigenerational colony has not always been documented.
[b]Host plants with * are cited by Welbourn (2006) as by Pellegrano *in press*.

TABLE 8. (CONTINUED) REPORTED HOST PLANT SPECIES OF *RAOIELLA INDICA*[a].

Family	Plant species	Reference [b]
Arecaceae	*Rhapis excelsa* (Thunb.) A. Henry ex Rehder	Welbourn (2006)*
Arecaceae	*Roystonea borinquena* O.F. Cook.	Welbourn (2006)*
Arecaceae	*Schippia concolor* Burret	K. Griffiths, personal communication
Arecaceae	*Syagrus romanzoffianum* (Cham.) Glassman	Kane et al. (2005)
Arecaceae	*Syagrus schizophylla* (Mart) Glassman	Welbourn (2006)*
Arecaceae	*Thrinax radiata* Lodd. ex J. A. & J. H. Schult.	K. Griffiths, personal communication
Arecaceae	*Veitchia arecina* Becc.	A. Cocco, personal observation
Arecaceae	*Veitchia* sp.	K. Griffiths, personal communication
Arecaceae	*Washingtonia filifera* (L. Lind.) H. Wendl.	Welbourn (2006)
Arecaceae	*Washingtonia robusta* H. Wendl.	Etienne & Fletchmann (2006)
Arecaceae	*Washingtonia* sp.	K. Griffiths, personal communication
Arecaceae	*Wodyetia bifurcata* Irvine	Welbourn (2006)
Celastraceae	*Cassine transvaalensis* Burtt-Davy	Kane & Ochoa (2006)
Fabaceae	*Phaseolus* sp.	Gupta (1984)
Heliconiaceae	Heliconia sp.	Peña et al. (2006)
Heliconiaceae	*Heliconia bihai* (L.) L.	Welbourn (2006)*
Heliconiaceae	*Heliconia caribaea* Lam.	Welbourn (2006)*
Heliconiaceae	*Heliconia psittacorum* L.F.	Welbourn (2006)
Heliconiaceae	*Heliconia rostrata* Ruiz & Pavon	Etienne & Fletchmann (2006)
Lamiaceae	*Ocimum basilicum* L.	Chaudri et al. (1974)
Musaceae	*Musa acuminata* Colla	Kane et al. (2005)
Musaceae	*Musa balbisiana* Colla	Kane et al. (2005)
Musaceae	*Musa uranoscopus* Lour.	Kane et al. (2005)
Musaceae	*Musa x paradisiaca* L. (= *Musa sapientum* L.)	Kane et al. (2005)
Musaceae	*Musa corniculata* Rumph.	Welbourn, (2006)
Musaceae	*Musa* spp.	Etienne & Fletchmann (2006)
Myrtaceae	*Eucalyptus* spp.	Kane & Ochoa (2006)
Myrtaceae	*Eugenia* sp.	Kane & Ochoa (2006)
Oleaceae	*Olea* sp.	Kane & Ochoa (2006)
Pandanaceae	*Pandanus utilis* Bory	Welbourn (2006)
Pandanaceae	*Pandanus* sp.	Kane & Ochoa (2006)
Strelitziaceae	*Strelitzia reginae* Banks ex Dryard	Etienne & Fletchmann (2006)
Strelitziaceae	*Ravenala madagascariensis* Sonn.	Welbourn (2006)
Zingiberaceae	*Alpinia purpurata* (*Vieill.*) K. Schum	Etienne & Fletchmann (2006)

[a]Most host plants are reported with no information about which RPM stage was found. The establishment of a multigenerational colony has not always been documented.
[b]Host plants with * are cited by Welbourn (2006) as by Pellegrano *in press*.

TABLE 8. (CONTINUED) REPORTED HOST PLANT SPECIES OF *RAOIELLA INDICA*[a].

Family	Plant species	Reference [b]
Zingiberaceae	*Alpinia zerumbet* (Pers.) B. L. Burtt & R. M.Sm.	K. Griffiths, personal communication
Zingiberaceae	*Zingiber* sp.	Peña et al. (2006)
Zingiberaceae	*Etlingera elatior* (Jack.) M. Sm. (= *Nicolaia*)	Etienne & Fletchmann (2006)

[a]Most host plants are reported with no information about which RPM stage was found. The establishment of a multigenerational colony has not always been documented.
[b]Host plants with * are cited by Welbourn (2006) as by Pellegrano *in press*.

Cavendish, Robusta, and Williams) and plantain (Apem, Cents Livre, Ordinary, Dwarf French, and Horn) varieties (N. Commodore, personal communication). The banana and plantain varieties we tested in our leaf disc and potted tree bioassays were different from those reported from the Eastern Caribbean, except for the Dwarf Cavendish banana variety. Despite these reports, RPM females did not establish and were often observed not feeding on the banana and plantain varieties tested in our leaf disc and whole potted tree quarantine bioassays. However, in the same experiments, RPM females established and fed continuously on coconut leaf discs. Among the banana and plantain varieties tested, RPM females survived longer and were observed feeding more often on Glui Kai discs than on other varieties, suggesting that Glui Kai is the most palatable banana variety tested.

The behavior of RPM females may be a better index of host suitability than the oviposition rate because frequent observations of females not feeding, drowned or dead suggest that females are searching for a suitable host on which to establish and feed. The RPM progeny (F_1 females) reared on banana discs that reached adulthood did not deposit eggs and no established colony of the RPM was obtained on banana leaf discs or potted banana trees.

The reason(s) for the failure to establish RPM females and immatures on banana trees and leaf discs in quarantine are unclear. In our quarantine bioassays, the establishment of RPM females collected from coconut or banana trees was evaluated on newly prepared and 3-d-old banana leaf discs, but neither the original host of the RPM (coconut or banana) nor the age of the leaf discs appear to promote the establishment of RPM colonies on banana leaf discs. Physical and/or chemical modifications of banana and plantain leaf discs could have repelled RPM females, but the experiment with potted banana trees did not result in the establishment of a stable colony of the RPM. Characteristics of the cuticle or quantity of wax on the abaxial surface might make some banana or plantain varieties more suitable for the RPM than others. Consistent with this hypothesis, while sampling the RPM from 2 heavily infested banana trees of unknown variety(ies) in Lake Worth (Jun 2008), an uninfested banana tree of unknown variety was observed less than 1 m away. A sprout from the base of the infested tree was collected, potted, and a new banana/plantain tree was grown in the quarantine laboratory in Gainesville. RPM females were released on leaf discs and on young leaves of the growing shoot under quarantine conditions, but RPM did not establish, perhaps because the shoot contained only young leaves while the "mother" tree had RPM on mature leaves.

Field observations on both coconut and banana trees revealed that mature leaves were more often infested by the RPM than young leaves (A. Cocco and M. A. Hoy, personal observations). Young leaves might be unsuitable for the RPM because of higher concentration of secondary plant compounds than old leaves. For some trees, young leaves are reported to have higher levels of secondary metabolites such as alkaloids, phenols, flavonoids, and terpenoids than older leaves (Bernays & Chapman 1994). The desert clicker *Ligurotettix coquilletti* McNeill (Orthoptera: Acrididae) habitually feeds on older leaves of *Larrea tridentata* because they contain a lower concentration of the deterrent nordihydroguaiaretic acid than young leaves (Chapman et al. 1988). Woodhead (1983) observed that young leaves of some varieties of *Sorghum* sp. are unsuitable for the migratory locust *Locusta migratoria* L. (Orthoptera: Acrididae) because they contain a specific wax compound, while older leaves are accepted. To clarify whether the leaf age affects the establishment of the RPM on banana or plantain trees, young and old leaves of the same tree could be infested under field conditions with known numbers of RPM females. In our experiments, because RPM females established on coconut leaf discs and trees under the same climatic conditions as these of the banana discs and potted trees, we believe that abiotic factors such as temperature, RH, and photoperiod did not affect the establishment of the RPM.

Native and ornamental palms such as saw palmetto, cabbage palm, needle palm, dwarf palmetto, European and Chinese fan palms are common woody plants on the natural landscape of Florida and are used for landscaping homes, parks, and streets (Black 2003a, 2003b). In addition, saw palmetto and needle palm are economically important palms (Tanner et al. 2002; Coile & Garland 2003). Extracts of saw palmetto fruits are used to treat symptoms of benign prostatic hyperplasia (Gordon & Shaughnessy 2002). Our results indicate that saw palmetto, dwarf palmetto, and cabbage palm leaf discs are not suitable hosts for the RPM in quarantine. Preliminary laboratory tests indicated that the Chinese fan palm *Livistona chinensis* (Jacq.) R. Br. and the European fan palm *Chamaerops humilis* L. also failed to support establishment of RPM colonies (H. Bowman & M. A. Hoy, unpublished).

Although the RPM completed a generation on needle palm discs, it exhibited a doubled development time and higher mortality of eggs and immatures, and it is unclear if a multigenerational colony on needle palm leaf discs can be established. Anecdotal observations suggest that the RPM host range needs additional studies. For example, observations in Broward County during Oct 2008 revealed an uninfested needle palm in a botanical garden ca. 50 m away from other infested palm species (A. Cocco, personal observation), yet needle palm might be a host based on our laboratory observations. At the same site, the cabbage palm and the scrub palmetto *Sabal etonia* Swingle ex Nash (closely related to the dwarf palmetto) were inspected, but no RPM was found, possibly confirming our finding that they are not hosts. Observations conducted in 13 counties in Florida until Aug 2008 report only the Florida thatch palm and the Florida silver palm *Coccothrinax argentata* (Jacq.) L. H. Bailey among native palms are a host of the RPM; both palms are included on the Florida endangered and threatened plant list (Coile & Garland 2003) (A. Cocco, personal observation; K. M. Griffiths, personal communication). The ability of *R. indica* to establish and spread on native and ornamental palms raises important questions about the potential impact of the RPM on natural landscapes. Our quarantine experiments and field observations suggest that RPM adults can deposit eggs and survive some days on unsuitable hosts, so host range studies should report plants as suitable hosts only when all stages of RPM are observed, indicating that multigenerational colonies were established.

A multigenerational RPM colony has established on coconut potted trees and stable colonies can be maintained on coconut leaf discs by cutting the discs into pieces every 3 weeks and placing small portions of the infested old disc on new discs, allowing the RPM to move from the old to the new discs. Our results suggest that coconut leaf discs and trees are the most suitable hosts for RPM females and a better host on which to rear the RPM in quarantine than the other hosts tested.

ACKNOWLEDGMENTS

The authors thank Hector Perez of the University of Florida, Department of Environmental Horticulture, for palm identifications and James Colee of the University of Florida, Department of Statistics, for statistical consultation. Don Goodman of the Kanapaha Botanical Gardens, Gainesville, FL, and Jerry Behan of the Deerfield Beach Arboretum, Deerfield Beach, FL, kindly allowed sampling of palms, Karolynne Griffiths of the United States Department of Agriculture—APHIS—PPQ suggested sites for sampling the RPM from coconuts and bananas and provided information of hosts from which RPM were collected. This research was supported in part by the Davies, Fischer and Eckes Endowment in Biological Control to M.A. Hoy and a contract (07-8312-0541-CA) from USDA—APHIS—PPQ.

REFERENCES CITED

BERNAYS, A., AND CHAPMAN, R. F. 1994. Host-plant Selection by Phytophagous Insects. Chapman & Hall, New York, NY, 312 pp.

BLACK, R. J. 2003a. Ornamental palms for central Florida. Available from http://edis.ifas.ufl.edu/pdffiles/EP/EP02000.pdf. (Accessed November 1, 2008).

BLACK, R. J. 2003b. Ornamental palms for North Florida. Available from http://edis.ifas.ufl.edu/pdffiles/EP/EP01900.pdf. (Accessed November 1, 2008).

CHAPMAN, R. F., BERNAYS, E. A., AND WYATT, T. 1988. Chemical aspects of host-plant specificity in three *Larrea*-feeding grasshoppers. J. Chem. Ecol. 14: 561-579.

CHAUDHRI, W. M., AKBAR, S., AND RASOL, A. 1974. Taxonomic Studies of the Mites Belonging to the Families Tenuipalpidae, Tetranychidae, Tuckerellidae, Caligonellidae, Stigmaeidae and Phytoseiidae. University of Agriculture, Lyallpur, Pakistan, PL-480 Project on Mites, 250 pp.

COILE, N. C., AND GARLAND, M. A. 2003. Notes on Florida's Endangered and Threatened Plants. Botany Contribution No. 38, 4th ed. Florida Dept. Agric. and Consumer Serv., Div. Plant Industry, Gainesville, FL, 122 pp.

ETIENNE, J., AND FLETCHMANN, C. H. W. 2006. First record of *Raoiella indica* (Hirst, 1924) (Acari:Tenuipalpidae) in Guadeloupe and Saint Martin, West Indies. Intl. J. Acarol. 32: 331-332.

FLETCHMANN, C. H. W., AND ETIENNE, J. 2004. The red palm mite *Raoiella indica* Hirst, a threat to palms in the Americas (Acari: Prostigmata: Tenuipalpidae). Syst. Appl. Acarol. 9: 109-110.

FLORIDA DEPARTMENT OF AGRICULTURE AND CONSUMER SERVICES. 2008. Current Red Palm Mite Survey in Southern Florida. Available from http://www.doacs.state.fl.us/pi/caps/rpm_maps/RPM_Base_Map_34x44.pdf. (Accessed October 16, 2008).

GORDON, A. E., AND SHAUGHNESSY, A. F. 2003. Saw palmetto for prostate disorders. American Fam. Physician 67: 1281-1283.

GUPTA, Y. N. 1984. On a collection of tetranychoid mites from Tamil Nadu with description of a new species of *Aponychus* (Acari: Tetranychidae). Bull. Zool. Survey India. 6: 237-245.

GUTIÉRREZ, B., NOHELIA, N., AND GARCIA, A. 2007. Situación actual del cocotero en el Municipio Valdez del Estado Sucre. Available from http://www.produccionynegocio.com/edicion_20/cocotero.htm. (Accessed October 14, 2008).

HEINZE, G., AND PLONER, M. 2003. Fixing the nonconvergence bug in logistic regression with SPLUS and SAS. Comput. Methods Programs Biomed. 71: 181-187.

HIRST, S. 1924. On some new species of red spider. Ann. Mag. Nat. Hist. 14: 522-527.

HOY, M. A., AND SMILANICK, J. M. 1981. Non-random prey location by the phytoseiid predator *Metaseiulus occidentalis*: differential responses to several mite species. Ent. Exp. & Appl. 29: 241-253.

HOY, M. A., PEÑA, J., AND NGUYEN, R. 2006. Red Palm Mite, *Raoiella indica* Hirst (Arachnida: Acari: Tenuipalpidae). Available from http://edis.ifas.ufl.edu/IN711. (Accessed October 14, 2008).

KANE, E. C., OCHOA, R., MATHURIN, G., AND ERBE, E. F. 2005. *Raoiella indica* Hist (Acari: Tenuipalpidae): An island-hopping mite pest in the Caribbean. ESA Meeting, Fort Lauderdale, December 2005. Poster. Available from http://www.sel.barc.usda.gov/acari/PDF/Raoiella indica-Kane et al.pdf. (Accessed October 17, 2008).

KANE, E. C., AND OCHOA, R. 2006. Detection and identification of the red palm mite *Raoiella indica* Hirst (Acari:Tenuipalpidae). Available from http://www.sel.barc.usda.gov/acari/PDF/indicaGuide.pdf (Accessed October 30, 2008).

LEE, E. T. 1992. Statistical Methods for Survival Data Analysis. John Wiley, New York, NY, 482 pp.

MENDONÇA, R. S., NAVIA, D., AND FLETCHMANN, C. H. W. 2006. *Raoiella indica* Hirst (Prostigmata: Tenuipalpidae) o acaro vermelho das palmeiras—una ameaca para as Americas. Available from http://www.cenargen.embrapa.br/publica/trabalhos/doc146.pdf%20. (Accessed November 4, 2008) (in Portuguese).

MITROFANOV, V. I., AND STRUNKOVA, Z. I. 1979. Ofredelitel Kleshcheiploskotelok (a key to false spider mites). Donish, 148 pp. (in Russian).

MOUTIA, L. A. 1958. Contribution to study of some phytophagous acarina and their predators in Mauritius. Bull. Entomol. Res. 49: 59-75.

NAGESHA-CHANDRA, B. K. N., AND CHANNABASAVANNA, G. P. 1984. Development and ecology of *Raoiella indica* Hirst (Acari:Tenuipalpidae) on coconut, pp. 785-798 *In* D. A. Griffiths and C. E. Bowman [eds.], Acarology VI, 2.

PEDIGO, L. P. 1996. Entomology and Pest Management, 2nd ed. Prentice-Hall Inc., Upper Saddle River, NJ, 679 pp.

PEÑA, J. E., MANNION, C. M., HOWARD, F. W., AND HOY, M. A. 2006. *Raoiella indica* (Prostigmata: Tenuipalpidae): the red palm mite: a potential invasive pest of palms and bananas and other tropical crops in Florida. Available from http://edis.ifas.ufl.edu/pdffiles/IN/IN68100.pdf. (Accessed October 30, 2008).

PRITCHARD, A. E., AND BAKER, E. W. 1958. The False Spider Mites. Univ. Calif. Pub. Entomol. 14, 274 pp.

RODRIGUES, J. C. V., OCHOA, R., AND KANE, E. C. 2007. First report of *Raoiella indica* Hirst (Acari: Tenuipalpidae) and its damage to coconut palms in Puerto Rico and Culebra Island. Intl. J. Acarol. 33: 3-5.

SAYED, T. 1942. Contribution to the knowledge of Acarina in Egypt: 1. The genus *Raoiella* Hirst (Pseudotetranychinae—Tetranychidae). Bull. Soc. Fouad 1er Entomologie. 26: 81-91.

SAS INSTITUTE. 2002. SAS Procedure's Guide, version 9. SAS Institute, Cary, NY.

TANNER, G. W., MULLAHEY, J. J., AND MAEHR, D. 2002. Saw-palmetto: an ecologically and economically important native palm. Available from http://edis.ifas.ufl.edu/pdffiles/UW/UW11000.pdf. (Accessed November 1, 2008).

WELBOURN, C. 2006. Red palm mite *Raoiella indica* (Acari: Tenuipalpidae). Pest Alert. DPI-FDACS. Available from http://www.doacs.state.fl.us/pi/enpp/ento/r.indica.html. (Accessed October 10, 2008).

WOODHEAD, S. 1983. Surface chemistry of *Sorghum bicolor* and its importance in feeding by *Locusta migratoria*. Physiol. Entomol. 8: 345-352.

ZAHER, M. A., WAFA, A. K., AND YOUSEF, A. A. 1969. Biological studies on *Raoiella indica* Hirst and *Phyllotetranychus aegyptiacus* Sayed infesting date palm trees in U.A.R. (Acarina: Tenuipalpidae). Zeitschrift für angewandte Entomologie. 63: 406-411.