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Rhizoglyphus echinopus and *Rhizoglyphus robini* (Acari: Acaridae) from Australia and New Zealand: identification, host plants and geographical distribution

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Abstract

Rhizoglyphus echinopus (Fumouze & Robin, 1868) and *R. robini* Claparède, 1869 are important pests attacking bulbs, corms and tubers of a variety of crops (e.g. onions, garlic and other vegetables) and ornamentals (lily and other flowers) in greenhouses and in the field worldwide. Their taxonomy, however, is in a state of confusion. Based on a study of several hundreds of specimens from Australia and New Zealand, as well as other countries around the world, this paper provides diagnoses and illustrations of key characters to facilitate the rapid and accurate identification of these two species. Data on host plants, distribution and quarantine implications are also provided.

Key words: Acaridae, *Rhizoglyphus*, identification, biosecurity, plant hosts, distribution

Introduction

Mites of the genus *Rhizoglyphus* (Claparède) are commonly associated with plants with bulbs, corms and tubers. *Rhizoglyphus echinopus* (Fumouze & Robin, 1868) and *R. robini* Claparède, 1869 are the two most important members of this genus, and are known to cause damage to a variety of crops (e.g. onions, garlic and other vegetables) and ornamentals (lily and other flower bulbs) in greenhouses and in the field around the world (Diaz *et al*. 2000). Despite the economic importance of these two species, their taxonomy is in a state of confusion, as a result of (1) the inadequate original descriptions of the species, (2) the presumed loss of the type specimens, and (3) the different opinions of subsequent revisers in the species concepts (for details, see review in Diaz *et al*. 2000). Of these two species, the one with very short internal scapular setae (*sci*) is *R. robini* according to Eyndhoven (1960, 1963, 1968), Manson (1972) and many other authors, but is *R. echinopus* according to Zakhvatkin (1941) and Hughes (1948, 1961), whereas the species with longer *sci* is *R. echinopus* according to Eyndhoven, Manson and many other authors, but is *R. callae* according to Hughes.

The taxonomy of *Rhizoglyphus* in New Zealand is relatively well resolved due to the revision by Manson (1972), who recorded three species, *R. robini*, *R. echinopus* and *R. ranunculi* Manson, 1972.

The taxonomy of *Rhizoglyphus* in Australia, however, is confused due to a lack of detailed taxonomic study. Halliday (1998) included three species (*R. robini*, *R. echinopus* and *R. termitus* Womersley, 1941) in his checklist of Australian mites, but noted that the Australian specimens identified as *R. echinopus* (Fumouze & Robin) by Womersley (1941) and Champ (1965, 1966) had not been described/illustrated, and their identities could not be resolved. OConnor in Diaz *et al*. (2000) noted that Womersleyís *termitus* is actually not a member of *Rhizoglyphus*.

This project on Australasian *Rhizoglyphus* was initiated due to the quarantine importance of these mites. *Rhizoglyphus* in horticultural products exported from New Zealand are the mites most frequently intercepted by Australian biosecurity officers. Australia is concerned about *Rhizoglyphus* mites on vegetable crops (e.g. carrots) and ornamental bulbs, and a clarification of their status in Australia and New Zealand will assist with the trade in these commodities. Unfortunately, the unresolved taxonomy of *Rhizoglyphus* in Australia has limited Australiaís ability to correctly identify these mites, which often causes a delay in the processing of products at the port of entry and often unnecessary fumigation of the shipment. This can have serious negative economic consequences, as well as environmental and human health concerns. During this revision of Australasian *Rhizoglyphus*, we examined hundreds of specimens of *R. robini* and *R. echinopus* from Australia, New Zealand and many other countries. The objective of this paper is to facilitate the rapid and accurate identification of these two species by providing diagnoses and illustrations of key characters. Other data of biosecurity significance (host plants and distribution) are also provided. A full revision of Australasian *Rhizoglyphus* will be published later in a monograph.

Material and methods

Over 80 specimens of *Rhizoglyphus echinopus* mounted on 36 slides and 784 specimens of *R. robini* mounted on 246 slides were examined. They are from the following collections: New Zealand Arthropod Collection in Landcare Research, Auckland, New Zealand (NZAC); the National Plant Pest Reference Laboratory, Ministry of Agriculture and Forestry in Lincoln and Auckland, New Zealand (NPPRL); Agricultural Scientific Collections Unit, Orange Agricultural Institute, NSW Agriculture, Orange NSW, Australia (ASCU); Australian Quarantine and Inspection Service (AQIS); South Australian Museum, Adelaide, Australia (SAM); Australian National Insect Collection, Canberra, Australia (ANIC).

All specimens were studied using an interference-phase contrast microscope. Measurements were made in micrometres from slide-mounted specimens using stage-calibrated ocular micrometers. Legs were measured from the base of the trochanters to the tips of claws. Terminology and notation of setae follow Griffiths *et al*. (1990). All data analyses were performed using Systat 7.0 for Windows.

Rhizoglyphus echinopus (Fumouze & Robin)

(Figs. 1A, 2A, 3A, 4A, 5A, 6A, 7A)

Tyroglyphus echinopus Fumouze & Robin, 1868: 287.
Rhizoglyphus callae Oudemans, 1924: 258; Hughes, 1961: 78.
Rhizoglyphus lucasii Hughes, 1948: 39.
Rhizoglyphus echinopus: Eyndhoven, 1963: 48; Eyndhoven, 1968: 96; Manson, 1972: 626.

Diagnostic characters

The adult homeomorphic male is 590-756 µm long. Dorsal idiosomal setae are relatively long (Fig. 1A); setae *sci* are long, from 45-95 µm; the first two pairs of dorsomedian setae (c_1 and d_1) are longer than half of the distance between their bases. The supracoxal seta is thick, 45-50 µm long (Fig. 3A). The Grandjeanís organ has a distinctly forked tip (Fig. 3A). The aedeagus is broadly rounded with a short tube-like anterior opening (Fig. 4A). The dorsal spine on tibia IV is slender, 15-18 μm long (Fig. 5A).

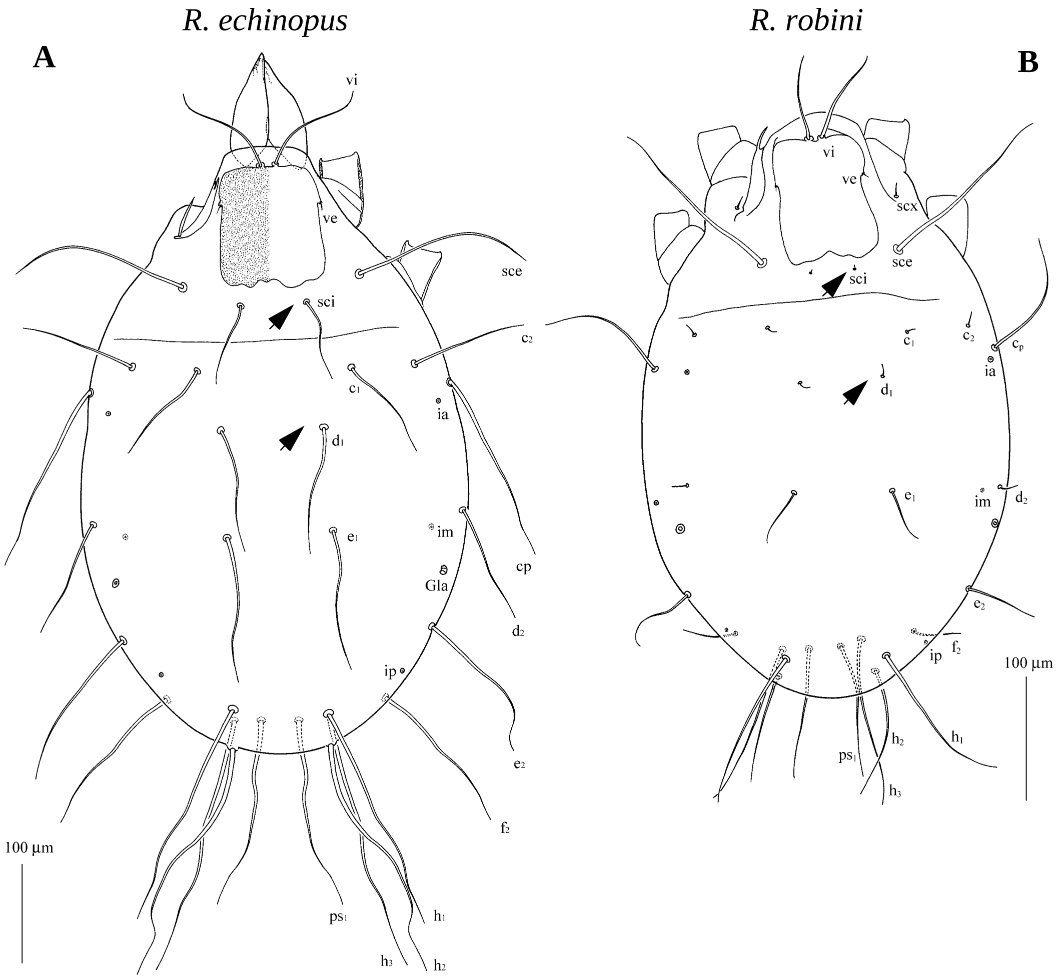

FIGURE 1. Dorsal view of homeomorphic adult male, showing the differences in lengths of some dorsal setae. A, *Rhizoglyphus echinopus*; B, *Rhizoglyphus robini*.

The adult female is 791-860 μm long. The bursa copulatrix has a large opening just posterior to the anal slit and opens internally into a large transverse sac with a V-shaped projection at each end (Fig. 6A). The supracoxal spine of the palp is long (27-42 μm). Setae ps_{1-3} are as long as or longer than double the length of ad_{1-3} (Fig. 7A).

Distribution and Host plants/habitats (Table 1)

This is a probably a cosmopolitan species (Diaz *et al*. 2000). In Australia, it is known from Adelaide, New South Wales and Victoria. In New Zealand, it is known from Blenheim, Palmerston North, and Raumati Beach.

In Australia, this species has been found on *Amaryllis* sp. (amaryllis, on bulbs), *Ipomoea batatas* (sweet potato), and seed in a budgerigar cage. In New Zealand, it is found on *Allium cepa* var. *bulbiferum* (tree onion, on bulbs), *Allium sativum* (garlic, on bulbs), *Gladiolus* sp. (gladioli, on bulbs), *Hyacinthus* sp. (hyacinth, on bulbs), *Iris* sp. (iris, on bulbs), *Lachenalia pendula* (on roots), *Narcissus* sp. (on bulbs), *Sinningia speciosa (*gloxinia), *Paeonia* sp. (paeony, on root), *Oryza sativa* (rice, on straw) and *Tulipa* sp. (tulip, on bulbs).

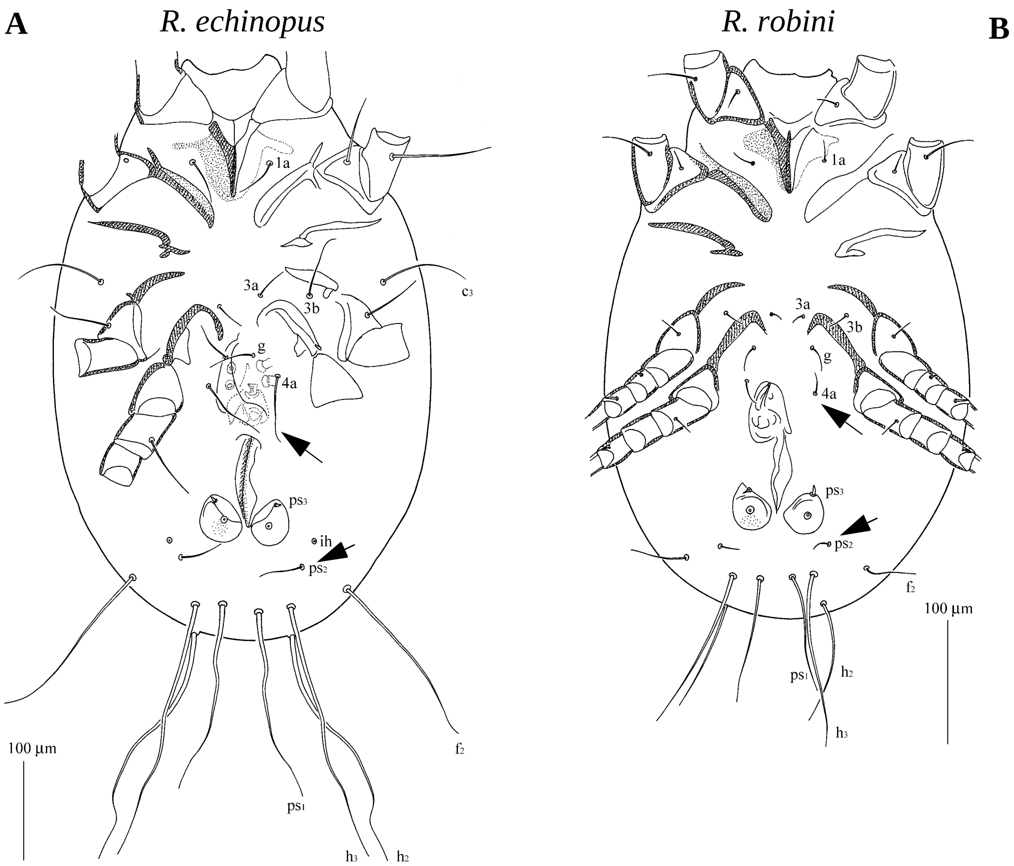

FIGURE 2. Ventral view of homeomorphic adult male, showing the differences in the length of some ventral setae. A, *Rhizoglyphus echinopus*; B, *Rhizoglyphus robini*.

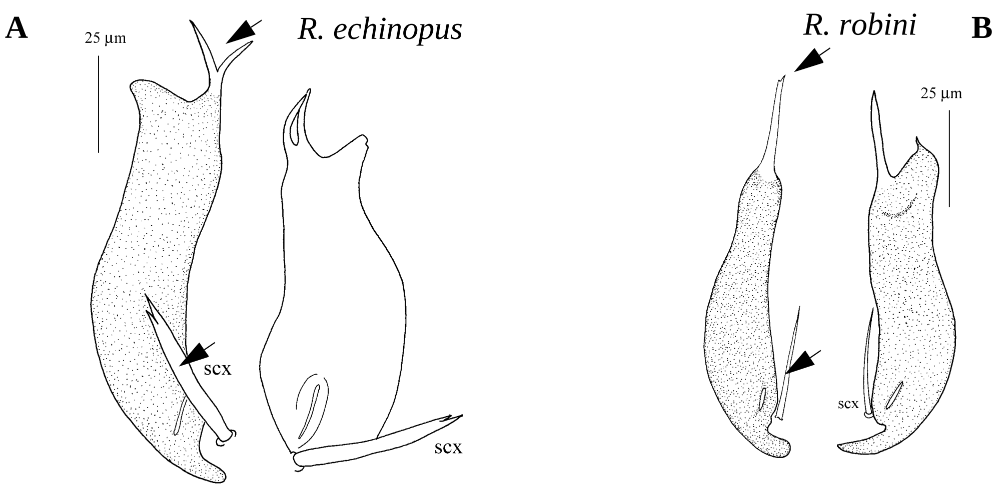

FIGURE 3. Lateral sclerite and associated stuctures. A, *Rhizoglyphus echinopus*; B, *Rhizoglyphus robini*.

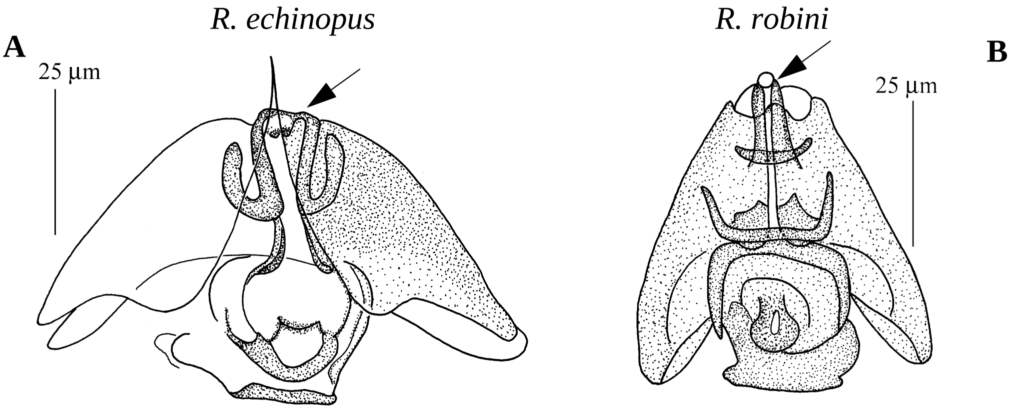

FIGURE 4. Genital opening and aedeagus of homeomorphic adult male. A, *Rhizoglyphus echinopus*; B, *Rhizoglyphus robini*.

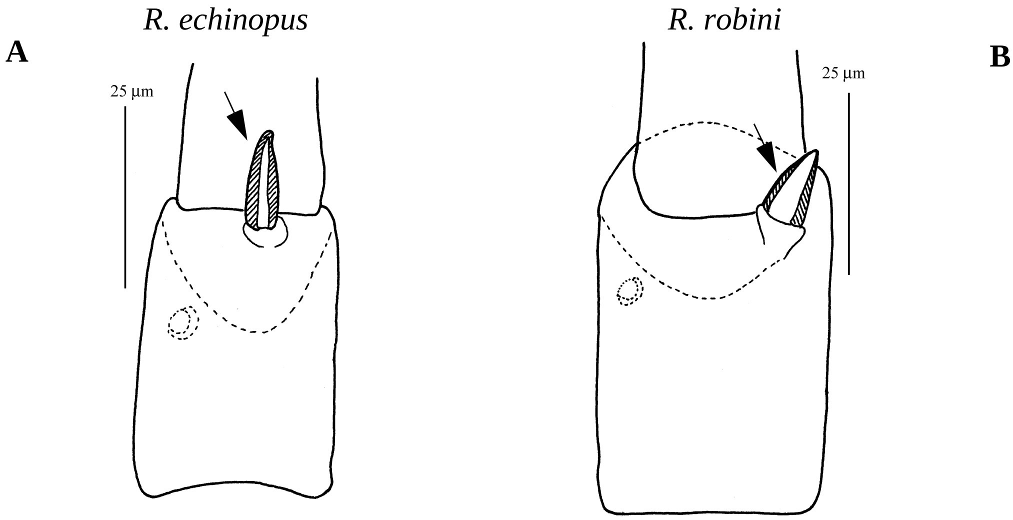

FIGURE 5. Tibia IV of homeomorphic adult males. A, *Rhizoglyphus echinopus*; B, *Rhizoglyphus robini*.

TABLE 1. Distribution and hosts of *R. echinopus*.

Country	Host	Author
Argentina	*Allium cepa*, *Gladiolus*, *Hyacinthus* sp.	Diaz *et al*. 2000
Australia	Plant material	Manson 1972
Adelaide, New South Wales, Victoria	*Amaryllis* sp. (amaryllis, on bulbs), *Ipomoea batatas* (sweet potato), seed in budgerigar cage	Current paper
Canada	*Narcissus* sp.	Diaz *et al*. 2000
China	Plant material (Hong Kong)	Manson 1972
	Lily bulb, rice straw (Taiwan)	Tseng 1979

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TABLE 1 (continued).

Country	Host	Author
	Allium cepa (onion), *Pinellia ternata* (pinellia), stored wheat	Bu and Li 1998
Fiji Suva	sweet potato	Current paper
France	*Solanum* sp.	Diaz *et al*. 2000
	Palaeopsylla minor ex *Talpa europaea*	Fain 1988
India	*Allium cepa*	Sandhu 1976
	Allium sativum, *Capsicum* sp., *Curcuma domestica*, *Solanum* sp.,	Diaz *et al*. 2000
Ireland	stored food	Hughes 1961
Japan	*Allium bakeri*	Diaz *et al*. 2000
Korea	*Allium sativum*	Diaz *et al*. 2000
New Zealand	*Allium sativum* (garlic), *Gladiolus*, *Hyacinthus* sp. (hyacinths), *Iris* (iris), *Narcissus* (daffodils), *Sinningia* (gloxinia), *Paeonia* sp. (paeony plants), *Tulipa*	Manson 1972
Blenheim, Christchurch, Palmerston North, Raumati Beach	*Allium cepa* var. *bulbiferum* (tree onion, on bulbs), *Allium sativum* (garlic, on bulbs), *Gladiolus* sp. (gladioli, on bulbs), *Hyacinthus* sp. (hyacinth, on bulbs), *Iris* sp. (iris, on bulbs), *Lachenalia pendula* (on roots), *Narcissus* sp. (on bulbs), *Sinningia speciosa (*gloxinia), *Paeonia* sp. (paeony, on root), *Oryza sativa* (rice, on straw), *Tulipa* sp. (tulip, on bulbs)	Current paper
Romania	*Allium sativum*	Diaz *et al*. 2000
Russia	*Allium cepa*	Diaz *et al*. 2000
	Hyacinthus sp., *Tulipa* sp.	Diaz *et al*. 2000
Spain	*Allium sativum*	Diaz *et al*. 2000
The Netherlands	Bulbs	Manson 1972
	Tulipa sp.	Diaz *et al*. 2000
	Hyacinthus sp. (hyacinths)	Fain 1988
	Narcissus sp. (daffodil), *Hyacinthus* sp. (hyacinths), *Tulipa* sp. (tulip)	Current paper
UK	Plant material	Manson 1972
	Freesia sp., *Narcissus* sp.	Diaz *et al*. 2000
USA	*Lolium longiflorum*	Diaz *et al*. 2000
	Solanum sp.	Diaz *et al*. 2000
	Plant material	Manson 1972
	Allium sativum corms	Current paper

***Rhizoglyphus robini* Claparède**
(Figs 1B, 2B, 3B, 4B, 5B, 6,B, 7B)

Rhizoglyphus robini Claparède, 1869: 506; Eyndhoven, 1968: 96; Manson, 1972: 630; Hughes, 1976: 121 (Chinese translation).
Rhizoglyphus echinopus: Michael, 1903: 84; Womersley, 1941: 465; Zakhvatkin, 1941: 182; Hughes, 1948: 41; Volgin, 1952: 249; Hughes, 1961: 74.
Rhizoglyphus solani Oudemans, 1924: 258; Eyndhoven, 1960: 275; synonymy by Eyndhoven, 1968: 95.
Rhizoglyphus hyacinthi Boisduval: Southcott, 1976: 150.

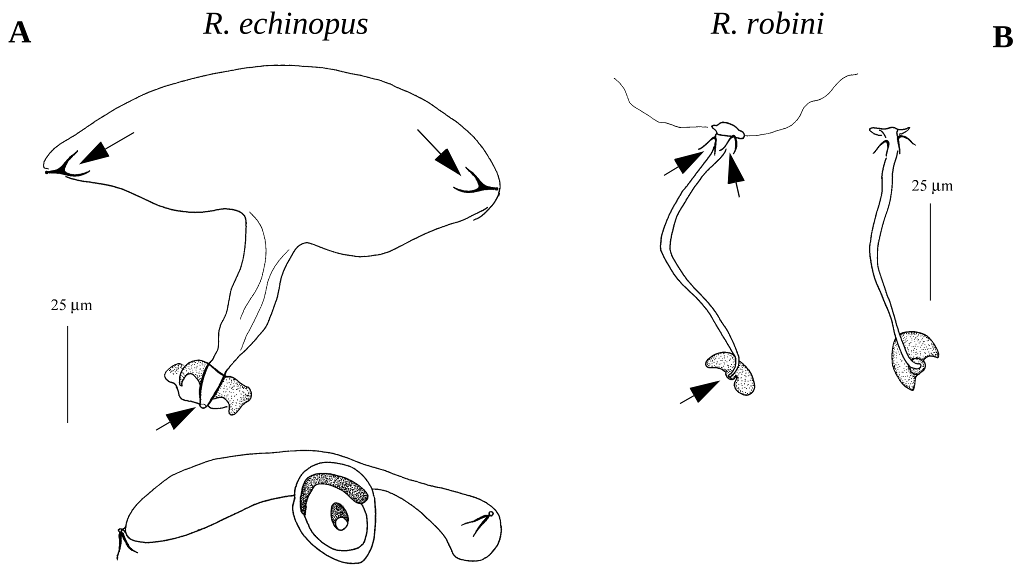

FIGURE 6. Opening of bursa copulatrix and receptaculum seminis of adult female. A, *Rhizoglyphus echinopus*; B, *Rhizoglyphus robini*.

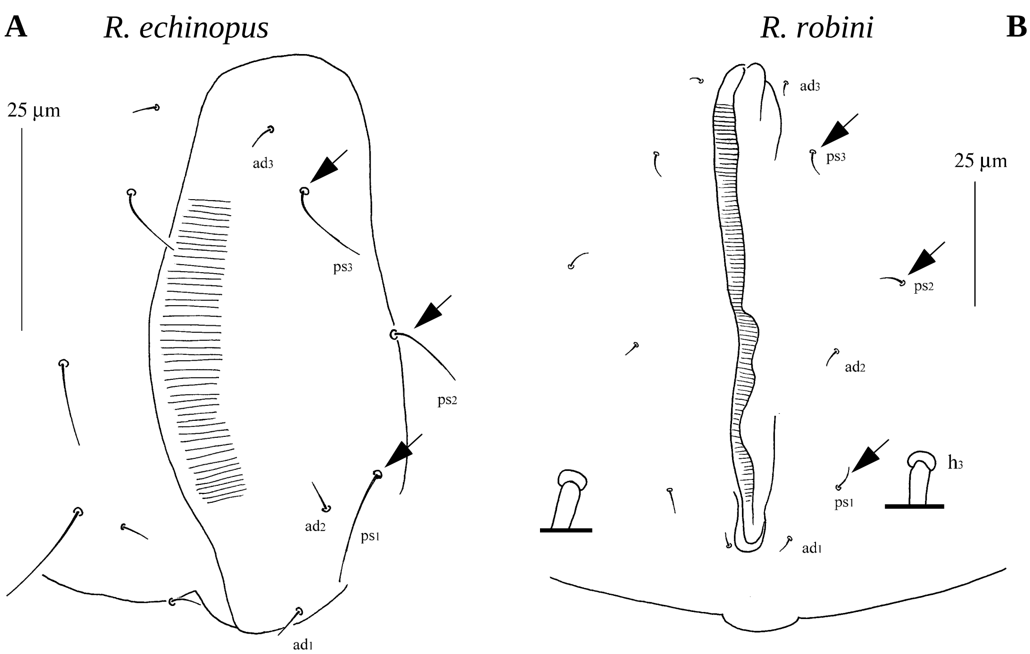

FIGURE 7. Anal area of adult female. A, *Rhizoglyphus echinopus*; B, *Rhizoglyphus robini*.

Diagnostic characters

The adult homeomorphic male is 603-671 µm long. The dorsal idiosomal setae are short (Fig. 1B); setae *sci* are minute (7-25 µm); the first two pairs of dorsomedian setae (c_1, d_1) are shorter than one-third of the distance between their bases. The supracoxal seta is slender, 14-39 µm long (Fig. 3B). The Grandjeanís organ does not have a distinct forked tip (Fig. 3B). The aedeagus is much narrower and more cone-shaped (Fig. 4B) than that in *R. echinopus*. The dorsal spine on tibia IV is stout, 10-13 µm long (Fig. 5B).

The adult female is 676-934 µm long. The bursa copulatrix has a relatively small opening at some distance from the anal slit and opens internally into the receptaculum seminis, with two V-shaped projections located close together (Fig. 6B). The supracoxal spine on palp is short (17-20 µm). Setae ps_{1-3} are as long as or slightly longer than ad_{1-3} (Fig. 7B).

Distribution and Host plants/habitats (Table 2)

This is probably a cosmopolitan species (Manson 1972). In Australia, it has been collected from Adelaide, New South Wales and Victoria. In New Zealand, we have seen specimens from around the country.

This species is primarily associated with bulbs, corms and tubers/roots of plants (Table 2). It is also found in seeds and the lower parts of plants. This species is common in compost and soil rich in organic matter.

TABLE 2. Distribution and hosts of *R. robini*

Country	Host	Author
Austria	Bulbs	Michael 1903
Australia	*Dahlia* sp. (dahlia)	Womersley 1941
	Crinum, *Lilium*, *Narcissus*	Manson 1972
Adelaide, New South Wales, Victoria, Sydney	*Allium cepa* (onion, on bulbs), *Amaryllis* sp. (amaryllis), *Crinum* sp., *Dahlia* sp. (dahlia), *Galtonia* sp. (Cape hyacinth, on bulbs), *Gladiolus*, *Hyacinthus* sp. (hyacinth), *Hypiastrum* bulbs (deformed and reddened areas), *Lillium speciosum* (oriental lily), *Lilium* sp. (potted), *Narcissus* sp. (daffodil, on bulbs), *Narcissus* sp. (narcissus, on bulbs), *Solanum tuberosum* (potato, stem and damaged root), *Zephgranthes* (Fairy lily, on bulbs), human (1 slide)	Current paper
Belgium	*Turdus philomelos*, *Fringilla coelebs*, *Passer montanus*	Fain 1988
Canada	*Narcissus* sp.	Diaz *et al*. 2000
China	*Allium sativum* (garlic), *Sasa* sp. (bamboo shoot), *Oryza sativa* (rice with husk)	Tseng 1979
	Allium fistulosum, *Allium porrum*	Chen and Lo 1989
	Allium cepa (onion), *Allium schoenoprasum* (chives), *Allium* sp. (scallion), *Pinellia ternata* (pinellia)	Bu and Li 1998
Egypt	*Allium sativum*	Diaz *et al*. 2000

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TABLE 2 (continued)

Country	Host	Author
England	Stored products	Michael 1903, Hughes 1948
France	Bulbs	Michael 1903
Germany	Bulbs	Michael 1903
Greece	*Dahlia* sp. (dahlia)	Manson 1972
Holland	*Amaryllis*, *Gladiolus* sp., *Iris* sp., *Lilium*	Manson 1972
Israel	*Allium cepa*	Gerson *et al*. 1985
Italy	Bulbs	Michael 1903
Korea	House dust	Ree *et al*. 1997
Japan	*Lyocoris squamigera*, *Lyocoris* sp.	Manson 1972
	Allium cepa	Diaz *et al*. 2000
	Allium chinense, *Allium tuberosum*, *Freesia* sp., *Lolium longiflorum*	Diaz *et al*. 2000
Mexico	*Allium cepa*	Diaz *et al*. 2000
New Zealand	Bulbs	Womersley 1941
	Aciphylla sp. (rotting basal material), *Allium cepa* (onions), *Allium sativum* (garlic), *Arthropodium cirrhatum* (decaying rhizome), *Daucus carota* (carrot), *Gladiolus* sp. (gladioli), *Iris* sp. (iris), *Lilium* sp. (lily), *Narcissus* sp. (narcissus.), *Solanum tuberosum* (potatoes)	Manson 1972
Auckland, Foxton, Blenheim, Hastings, Howick, Kaeo, Whangarei, Kauranga Valley, Levin, Lincoln, Martinsoille, Masterton, Nelson, New Plymouth, nr. Ohakune, Palmerston North, Pokekohe, Rapaura, Blenheim, Raratoga Cook Is, Taihape, Waihou Rd., Levin, Walk worth Whangarei, Wgtn., Whangarei	*Aciphylla* sp. (on rotting basal material), *Allium cepa* (onion, on bulbs), *Allium sativum* (garlic, on bulbs), *Allium ascalonicum* (shallot, on bulbs), *Amaryllis* sp. (amaryllis, on bulbs), *Arthropodium cirrhatum* (on decayinig rhizome), *Asparagus* sp. (rotting roots), *Auricula* sp. (on bulbs), *Brassica napus* (swedes, on roots), *Crinum* sp., *Cycus revoluta* (rotting seeds), *Dahlia* sp. (dahlia, on tubers), *Daucus carota* (carrot), *Freesia* sp. (freesia, on bulbs), *Gladiolus* sp. (gladioli, on corm), *Hordeum* sp. (barley), *Iris* sp. (iris, on bulbs), *Lilium* sp. (lily, on bulbs), *Lycoris squamigera* (magic lily, on bulbs), *Lycoris* sp. (on bulbs), *Narcissus* sp. (daffodil, on bulbs), *Narcissus* sp. (narcissus, on bulbs), *Nerine* sp. (on bulbs in shade house), *Nothofagus* sp., *Solanum tuberosum* (potato, infested with bacterial soft rot *Erwinia* spp.), *Tulipa* sp. (tulip, on bulb), *Zea mays* (maize, on seeds) and mushroom (in compost)	Current paper
Poland	*Secale cereale*	Diaz *et al*. 2000

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TABLE 2 (continued)

Country	Host	Author
Russia	Bulbs	Zakhvatkin 1941
South Africa	*Amaryllis*	Meyer 1981
Switzerland	*Dahlia* sp. (georgine), *Solanum tuberosum* (potato)	Claparède 1869
UK	*Freesia* sp., *Narcissus* sp.	Diaz *et al*. 2000
USA	*Allium cepa*	Diaz *et al*. 2000
	Gladiolus sp.	Diaz *et al*. 2000
	Lilium	Manson 1972
	Lolium longiflorum	Diaz *et al*. 2000
	Scalops aquaticus	Fain 1988

Discussion

Taxonomy

The revision of Manson (1972) provides a sound basis for the identification of these two species and has been followed by most acarologists, despite the influential book of Hughes (1976). The key characters for distinguishing females of *R. echinopus* and *R. robini* species are the structure of receptaculum seminis and bursa copulatrix (Fig. 6A, B), and the shape of supra coxal seta of leg I (Fig. 3A, B). We have examined many other characters. Some other useful characters are the length of supra coxal seta, the length of setae *sci*, *sce*, *scx*, c_1, c_2, *cp*, c_3, d_1, d_2, e_1, e_2, f_2, h_3, *1a*, *3a*, g_1, g_2 and g_3, and the length of leg I, leg II, leg IV, femora II, genua II, tarsi II, tibiae III and tarsi IV (Table 3).

TABLE 3. *Rhizoglyphus* females (n = 5) based on specimens from Australia, New Zealand and intercepted specimens from Europe and North America.

	R. echinopus	*R. robini*
Idiosoma-L	842 ± 29.0 (791-860)	795 ± 92.7 (676-934)
Idiosoma-W	583 ± 21.2 (487-607)	558 ± 63.5 (482-650)
Chelicera-L	159 ± 5.8 (137-168)	141 ± 0.8 (140-142)*
Elcp	34 ± 5.6 (27-42)	18 ± 1.3 (17-20)*
Shield-L	157 ± 7.8 (145-165)	146 ± 6.6 (142-155)
sce-sce	121 ± 5.1 (112-127)	122 ± 14.5 (109-145)
vi	130 ± 13..2 (102-150)	103 ± 5.9 (94-108) *
ve	17 ± 6.1 (7-23)	4 ± 1.4 (2-6)*
sci	86 ± 37.6 (40-143)	12 ± 1.4 (10-14)*
sce	268 ± 17.8 (248-298)	181 ± 30.7 (142-228)*
scx	59 ± 8.4 (48-70)	32 ± 9.1 (12-42)*

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TABLE 3 (continued)

	R. echinopus	*R. robini*
c_1	99 ± 23.7 (68-128)	22 ± 0.5 (21-22)*
c_2	105 ± 18.2 (85-125)	21 ± 0.9 (20-22)*
cp	223 ± 29.2 (183-255)	135 ± 19.0 (103-153)*
c_3	79 ± 39.3 (38-135)	22 ± 0.4 (22-23)*
d_1	92 ± 32.4 (48-130)	22 ± 0.4 (21-22)*
d_2	101 ± 22.1 (88-140)	23 ± 1.6 (22-25)*
e_1	136 ± 25.7 (115-178)	68 ± 12.4 (50-77)*
e_2	140 ± 25.5 (110-178)	75 ± 13.9 (57-80)*
f_2	133 ± 27.0 (103-173)	67 ± 18.4 (37-87)*
h_1	191 ± 16.0 (165-213)	134 ± 30.1 (87-171)
h_2	187 ± 28.3 (145-220)	138 ± 17.0 (113-161)
h_3	242 ± 33.7 (188-280)	130 ± 28.0 (88-156)*
ps_3	22 ± 4.9 (18-30)	14 ± 2.3 (12-17)*
ps_2	17 ± 3.1 (13-20)	11 ± 2.6 (8-15)
ps_1	21 ± 5.0 (7-28)	9 ± 2.6 (7-12)*
ad_3	7 ± 0.4 (7-8)	7 ± 0.9 (5-7)
ad_2	10 ± 5.7 (7-20)	11 ± 2.6 (7-17)*
ad_1	7 ± 0.4 (7-8)	7 ± 1.8 (5-10)
1a	78 ± 14.8 (60-100)	37 ± 2.7 (34-40)*
3b	82 ± 17.6 (53-100)	37 ± 3.0 (34-41)*
3a	38 ± 10.9 (20-48)	13 ± 1.6 (12-15)*
G	60 ± 20.2 (30-80)	20 ± 3.0 (15-22)*
4a	63 ± 14.4 (38-73)	29 ± 2.8 (27-34)*
d_2-gla	88 ± 5.0 (82-90)	56 ± 14.9 (47-82)
Distance between V-shaped projections	111 ± 9.3 (97-122)	7 ± 1.5 (6-8)*
Leg I	274 ± 14.3 (260-298)	238 ± 8.9 (230-248)*
Leg II	288 ± 18.8 (268-313)	233 ± 8.3 (225-246)*
Leg III	272 ± 29.1 (233-303)	223 ± 12.8 (207-236)
Leg IV	295 ± 24.0 (257-323)	227 ± 18.9 (205-253)*
Femora I	92 ± 9.7 (80-105)	75 ± 3.5 (72-81)
Genua I	48 ± 5.5 (42-52)	46 ± 13.8 (37-70)
Tibiae I	45 ± 4.1 (40-50)	38 ± 3.4 (35-42)
Tarsi I	96 ± 7.0 (87-103)	82 ± 4.8 (77-90)
Femora II	94 ± 8.1 (87-102)	76 ± 2.6 (75-81)*
Genua II	48 ± 4.1 (42-52)	36 ± 4.0 (32-42)*

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TABLE 3 (continued)

	R. echinopus	*R. robini*
Tibiae II	44 ± 3.9 (40-50)	35 ± 4.1 (32-42)
Tarsi II	109 ± 7.2 (92-120)	84 ± 2.2 (82-87)*
Femora III	70 ± 6.4 (62-75)	55 ± 10.7 (47-73)
Genua III	38 ± 2.2 (35-40)	31 ± 5.8 (27-41)
Tibiae III	38 ± 2.3 (35-40)	29 ± 6.0 (25-40)*
Tarsi III	106 ± 6.5 (97-112)	77 ± 5.2 (70-83)
Femora IV	74 ± 5.9 (65-80)	58 ± 10.4 (50-76)
Genua IV	45 ± 4.1 (40-50)	31 ± 7.0 (25-43)
Tibiae IV	43 ± 5.0 (37-50)	29 ± 7.0 (25-43)
Tarsi IV	113 ± 7.0 (103-122)	90 ± 4.3 (77-90)*
I ω_1	22 ± 2.2 (17-23)	20 ± 0.9 (19-21)
I ω_2	10 ± 0.5 (10-11)	9 ± 0.5 (9-10)
I e	6 ± 0.9 (5-7)	6 ± 1.1 (5-7)
I φ'	44 ± 2.8 (42-48)	40 ± 1.6 (38-42)
I φ”	41 ± 3.8 (37-47)	42 ± 0.4 (42-43)
II ω	21 ± 0.9 (18-22)	19 ± 1.3 (17-20)

Superscript * indicates mean of females of *R. robini* are significantly different (<0.01) from those of *R. echinopus* according to nonparametric tests (Kruskal-Wallis).

Characters for distinguishing homeomorphic males of the two species are the structure of the aedeagus (Fig. 4A, B), the shape of supra coxal seta and the size of the dorsal spine on tibia IV (Fig. 5A, B). Other useful characters are the lengths of the subcapitular seta, setae *ve*, *sci*, *sce*, *scx*, c_1, c_2, *cp*, c_3, d_1, d_2, ps_1, and tibiae II (Table 4; Figs. 1-2).

Characters to distinguish heteromorphic from homeomorphic males of *R. robini* are the enlarged leg III and tarsal claw. Other useful characters are the lengths of c_1, c_2, *cp*, c_3, d_1, d_2, e_1, e_2, f_2, leg I, leg III, femora I, genua I, tibiae I, femora II, tibiae II, femora III, genua III, tibiae III, and genua IV (Table 4).

Host plants, distribution and quarantine implications

The range of host plants in Tables 1-2 is probably just a reflection of the collecting efforts and will certainly increase with more sampling from other plants. Likewise, the current distribution is also a reflection of the collection effort. These mites have dispersed around the world with the movement of plants.

As far as Australia and New Zealand are concerned, this study shows that *R. robini* and *R. echinopus* are present in both countries. A special application of this is the export of carrots from New Zealand to Australia. Our examination of the material collected in New Zealand and intercepted in both New Zealand and Australia shows that the *Rhizoglyphus* found on carrots is exclusively *R. robini*. In the past, these intercepted mites were identified as undetermined *Rhizoglyphus*, which caused delays in processing of shipments at port or on occasion fumigation, with negative economic consequences, as well as environmental and human health concerns.

Table 4. *Rhizoglyphus* males (n = 5) based on specimens from Australia, New Zealand and intercepted specimens from Europe and North America.

	echinopus	*robini*	
	Homeomorphic	Homeomorphic	Heteromorphic
Idiosoma-L	678 ± 62.0 (590-756)	638 ± 31.2 (603-671)	640 ± 80.3 (512-721)
Idiosoma-W	441 ± 71.1 (357-523)	460 ± 33.6 (414-494)	422 ± 39.5 (375-456)
Chelicera-L	127 ± 7.9 (115-135)	120 ± 12.1 (112-141)	122 ± 13.0 (107-127)
Elcp	28 ± 3.3 (25-32)	14 ± 1.3 (12-15)*	16 ± 2.5 (14-20)
Shield-L	135 ± 13.2 (117-152)	124 ± 5.6 (115-130)	141 ± 11.4 (127-152)
sce-sce	107 ± 11.7 (90-122)	94 ± 5.3 (88-102)	90 ± 8.9 (88-102)
Vi	117 ± 15.3 (100-133)	103 ± 10.2 (94-118)	120 ± 11.1 (111-138)
Ve	16 ± 4.3 (10-20)	5 ± 1.7 (3-7)*	7 ± 1.4 (5-9)
Sci	66 ± 24.7 (45-95)	12 ± 7.6 (7-25)*	18 ± 7.4 (7-27)
Sce	235 ± 27.9 (212-278)	188 ± 13.0 (171-203)*	202 ± 23.2 (166-223)
Scx	45 ± 3.6 (45-50)	24 ± 9.8 (14-39)*	40 ± 5.6 (31-45)
c_1	78 ± 34.0 (53-125)	21 ± 3.5 (17-25)*	34 ± 5.1 (27-41) #
c_2	97 ± 35.5 (63-138)	24 ± 3.5 (20-29)*	43 ± 5.2 (37-51) #
cp	205 ± 36.1 (170-265)	146 ± 7.4 (141-158)*	185 ± 18.5 (161-203) #
c_3	74 ± 29.9 (35-112)	29 ± 4.9 (25-35)*	49 ± 10.4 (37-62) #
d_1	73 ± 32.0 (43-112)	22 ± 1.9 (20-25)*	35 ± 5.5 (27-41) #
d_2	98 ± 42.4 (60-155)	27 ± 6.4 (22-37)*	46 ± 6.3 (37-52) #
e_1	123 ± 28.6 (88-155)	75 ± 12.3 (64-94)	137 ± 22.9 (97-155) #
e_2	144 ± 38.0 (105-198)	101 ± 17.9 (79-125)	158 ± 17.2 (133-175) #
f_2	148 ± 44.3 (93-200)	89 ± 10.5 (72-97)	132 ± 27.6 (104-178) #
h_1	196 ± 59.0 (133-280)	151 ± 25.7 (111-175)	185 ± 14.6 (163-201)
h_2	211 ± 55.2 (152-281)	89 ± 10.5 (136-166)	132 ± 27.6 (92-210)
h3	235 ± 36.8 (193-278)	185 ± 18.4 (158-203)	217 ± 21.5 (195-248)
ps_3	10 ± 3.3 (6-13)	9 ± 1.1 (7-10)	8 ± 1.5 (7-10)
ps_2	45 ± 12.4 (37-60)	34 ± 2.8 (31-37)	42 ± 11.8 (25-52)
ps_1	197 ± 33.4 (165-250)	141 ± 3.6 (138-146)*	168 ± 24.8 (137-203)
1a	53 ± 11.7 (38-70)	32 ± 7.8 (25-41)	42 ± 7.2 (37-52)
3b	46 ± 17.8 (25-73)	35 ± 9.2 (25-47)	50 ± 5.4 (41-55)
3a	29 ± 2.2 (25-30)	21 ± 4.7 (15-27)	22 ± 6.1 (12-27)
g	46 ± 12.6 (32-63)	30 ± 5.1 (25-37)	31 ± 2.9 (27-35)
4a	55 ± 18.0 (37-75)	36 ± 13.1 (22-57)	51 ± 11.2 (36-62)
d_2-gla	68 ± 9.7 (60-85)	48 ± 4.8 (42-54)	42 ± 5.9 (37-51)
aedeagus	43 ± 2.2 (39-44)	46 ± 2.1 (45-50)*	46 ± 2.1 (46-51)

....continued on the next page

Table 4 (continued).

	echinopus	*robini*	
	Homeomorphic	Homeomorphic	Heteromorphic
Leg I	264 ± 33.9 (235-308)	234 ± 20.7 (213-268)	294 ± 25.9 (271-338) #
Leg II	268 ± 35.0 (237-313)	231 ± 21.0 (208-264)	287 ± 22.5 (263-323)
Leg III	263 ± 43.4 (222-310)	231 ± 22.3 (207-265)	284 ± 24.1 (267-327) #
Leg IV	279 ± 34.4 (247-313)	246 ± 15.8 (231-272)	287 ± 32.1 (267-342)
Femora I	88 ± 13.1 (75-105)	74 ± 3.5 (72-80)	89 ± 7.7 (82-102) #
Genua I	44 ± 5.3 (37-50)	39 ± 5.0 (32-45)	50 ± 4.8 (45-57) #
Tibiae I	42 ± 5.1 (37-50)	36 ± 2.9 (32-40)	46 ± 3.8 (42-51) #
Tarsi I	91 ± 14.8 (75-110)	86 ± 9.6 (77-102)	97 ± 14.1 (82-115)
Femora II	87 ± 10.1 (77-100)	76 ± 3.3 (71-80)	89 ± 6.3 (82-97) #
Genua II	43 ± 4.8 (40-50)	38 ± 5.6 (32-46)	48 ± 5.5 (42-57)
Tibiae II	41 ± 5.8 (35-50)	33 ± 1.6 (32-35)*	44 ± 4.2 (42-51) #
Tarsi II	99 ± 15.9 (80-120)	84 ± 5.8 (75-87)	96 ± 18.8 (72-122)
Femora III	69 ± 12.0 (57-82)	59 ± 4.0 (52-62)	104 ± 12.7 (91-125) #
Genua III	37 ± 5.4 (31-45)	31 ± 4.2 (27-37)	48 ± 7.0 (41-55) #
Tibiae III	36 ± 6.4 (31-47)	29 ± 3.5 (25-34)	46 ± 6.3 (37-52) #
Tarsi III	94 ± 16.0 (77-115)	82 ± 10.3 (72-97)	69 ± 5.3 (62-75)
Femora IV	77 ± 11.2 (65-92)	64 ± 2.5 (62-67)	78 ± 9.9 (65-92)
Genua IV	42 ± 6.2 (37-52)	38 ± 3.3 (35-42)	46 ± 5.1 (42-55) #
Tibiae IV	44 ± 9.0 (35-57)	36 ± 3.3 (34-42)	45 ± 3.9 (41-51)
Tarsi IV	93 ± 16.6 (79-115)	81 ± 7.0 (75-92)	102 ± 12.5 (87-116)
I ω_1	20 ± 1.0 (19-21)	18 ± 2.3 (15-20)	20 ± 0.5 (20-21)
I ω_2	9 ± 1.4 (7-10)	11 ± 2.5 (9-15)	11 ± 0.9 (10-12)
I e	8 ± 1.3 (7-10)	7 ± 0.4 (6-7)	7 ± 0.5 (6-7)
I φ'	42 ± 1.2 (40-43)	41 ± 0.9 (40-42)	42 ± 3.1 (39-47)
I φ”	40 ± 2.9 (35-42)	44 ± 1.8 (41-45)	45 ± 4.1 (42-52)
II ω	19 ± 1.9 (16-21)	18 ± 3.1 (13-20)	20 ± 0.5 (10-12)
Spine on tibiae IV	17 ± 1.1 (15-18)	12 ±1.3 (10-13)*	11 ±0.7 (10-12)

Superscript * indicates mean of *R. robini* are significantly different (<0.01) from those of *R. echinopus*. Superscript # indicates mean of heteromorphic males of *R. robini* are significantly different (<0.01) from those of homeomorphic males of *R. robini*.

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