CHAPTER THREE

Distribution, Host-Plant Relationships and Natural Enemies of *Rastrococcus iceryoides* Green (Hemiptera: Pseudococcidae) in Kenya and Tanzania

ABSTRACT

Rastrococcus iceryoides Green (Hemiptera: Pseudococcidae) is an invasive mango mealybug pest in Kenya and Tanzania. It is believed to be native to Southern Asia. A survey was carried out in Kenya and Tanzania from February 2008-July 2009 to study the geographical distribution of the pest, its host plant relationships and associated natural enemies. In both countries, our results showed that *R. iceryoides* is widely distributed across the coastal belt. Heavy infestations occurred on *M. indica* and *Parkinsonia aculeata* L. in Matuga and Kinango (Kenya); and Morogoro, Kinondoni, Tanga, Kibaha and Mkuranga (Tanzania). *Rastrococcus iceryoides* was recorded from 29 cultivated and non-cultivated host plants from 16 families. Twenty-one of these host plants are new records. Among the cultivated host plants, *M. indica* and *Cajanus cajan* (L.) Millspaugh recorded the highest levels of infestation. *Parkinsonia aculeata, Caesalpinia sepiaria* Roxb, and *Deinbollia borbonica* Scheft were found to be the most infested non-cultivated plants. Infestation levels across the different plant parts were generally significantly higher on the twigs compared to the leaves and fruits with a maximum of 8153 mealybugs/20 twigs and 6054 mealybugs/80 leaves of *M. indica* in Kibaha, Tanzania. A total of six parasitoid species were recovered from *R. iceryoides* with *Anagyrus pseudococci* Girault (Hymenoptera: Encyrtidae) predominating (21% parasitism on *M. indica* in Tanzania; 20% on *P. aculeata* in Kenya). Despite this level of parasitism, the ability of the parasitoid to regulate the population of *R. iceryoides* was inadequate. In addition, nineteen species of hyperparasitoids from six families and thirty-eight species of predators from fourteen families were recorded. Despite the diversity of these natural enemies, *R. iceryoides* has remained one of the most damaging pests of its preferred host (mango) in Kenya and Tanzania. Therefore, there is the need for foreign exploration and introduction of efficient coevolved natural enemies from its aboriginal home of Southern Asia to minimize its impact on horticulture in Africa.

Key-words: *Rastrococcus iceryoides*, distribution, host plants, biological control

3.1 Introduction

Mealybugs (Hemiptera: Pseudococcidae) are important group of phytophagous insects that cause significant damage on a variety of horticultural crops worldwide (Miller et al., 2002). In Africa, *Rastrococcus invadens* Williams and *Rastrococcus iceryoides* Green are regarded as two important exotic mealybug species native to Southern Asia that commonly infest mango, *Mangifera indica* Linnaeus (Anacardiaceae). The former devastated mango production in West and Central Africa but was brought under biological control through introduction of an exotic parasitoid *Gyranusoidea tebygi* Noyes from India (Noyes, 1988; Bokonon-Ganta and Neuenschwander, 1995). Based on its economic importance and the ease with which it colonised major part of West and Central Africa, *R. invadens* has been the subject of many studies, both descriptive and experimental, and its geographical distribution and host-plant relationships is well documented (Williams, 1986; Agounké et al., 1988; Willink and Moore, 1988; Bokonon-Ganta et al., 1995; Tobih et al., 2002). *Rastrococcus iceryoides* on the other hand is restricted to East Africa (mainly Tanzania and coastal Kenya) and northern Malawi where it has remained a major pest of mango (Williams, 1989; Luhanga and Gwinner, 1993; CABI, 2000). Compared with *R. invadens*, very little is known with regard to the ecology of *R. iceryoides* and no detailed studies have been conducted on the geographic distribution and abundance of this pest in Kenya and Tanzania.

As with other mealybug species, *R. iceryoides* sucks sap from leaves, young shoots, inflorescences and fruits and sometimes results in shedding of mango fruit-lets. It also excretes sugary honeydew on which sooty moulds develop thereby reducing fruit marketability. As a result of sooty mould, export opportunities are often impaired due to quarantine regulations (CPC, 2002). Sooty mould that fouls the leaves reduces photosynthetic efficiency and can cause leaf drop. In village homesteads, heavy infestation usually renders the trees unsuitable for shading. In Kenya, Tanzania and Malawi, damage can range from 30% to complete crop failure in unmanaged orchards (CABI, 2000; Tanga, unpublished data). In Tanzania, the pest has become the major target for majority of insecticidal sprays on mango, in addition to pruning and burning of infested plant's parts (Willink and Moore, 1988; Tanga, unpublished data), which is not an affordable solution. Unfortunately, insecticides do not generally provide adequate control of mealybugs owing to their waxy coating. Some growers have even resorted to cutting down mango trees as a result of *R. iceryoides* destruction while others have abandoned mango cultivation. It is speculated that the intensity of damage by *R. iceryoides* may have been due to the expansion of mango production and introduction of hybrid cultivars, which are highly susceptible to attack by the pest (Boussienguet and Mouloungou, 1993).

In Southern Asia, the putative aboriginal home of *R. iceryoides*, the pest is believed to be highly polyphagous and has been reported from over 65 host plants from 35 families (Williams, 1989; Ben-Dov, 1994). However, in Africa, there's still no comprehensive knowledge on the host plants of *R. iceryoides* apart from the damage observed on mango crop. To be able to make an informed decision to manage the pest effectively, with regard to trap placement within orchards, sanitation and mixed-cropping practices, the growers must be aware of the host-plant relationships of *R. iceryoides*.

Natural enemies play an important role in regulating the populations of mealybugs and globally there are several success stories of biological control of different species of mealybug including Africa (Neuenschwander, 2001; Bokonon-Ganta and Neuenschwander, 1995; Kairo et al., 2000; Meyerdirk et al., 2004). Despite the importance of natural enemies in suppressing population of mealybugs; and since the introduction of *R. iceryoides* into the continent in the late twentieth century (CABI, 2000), no information exists in literature on the natural enemy compositions of the pest in Africa. However, in India, a diversity of parasitoids and predators has been reported to regulate the populations of *R. iceryoides* (Tandon and Lal, 1978; CABI, 2000). To guide future management interventions, the indigenous natural enemies associated with *R. iceryoides* must be quantified. Information on the distribution, host range, abundance and associated natural enemies of *R. iceryoides* can provide basic information for developing reliable and cost-effective management method for the pest. As part of an ongoing larger project on integrated pest management (IPM) of major mango pests, the objectives of this study were to assess the geographic distribution of *R. iceryoides* in the coastal regions of Kenya and Tanzania, establish its host-plant relationships and document the natural enemies associated with the pest in these countries.

3.2 Materials and Methods

3.2.1 Field surveys

3.2.1.1 Sampling sites

Field surveys were conducted in twenty-two localities across the Coastal and Rift Valley Provinces of Kenya and twelve localities in five different Regions of Tanzania (Table 3.1, Figure 3.1) between February and June 2008. The sampling sites in both countries were chosen based on previous knowledge of horticultural production and especially mango in the various localities. These provinces and regions are regarded as the major mango production areas of Kenya and Tanzania (Greisbach, 2003; Nyambo and Verschoor, 2005). In both countries, sampling was carried out in cultivated fields, backyard gardens, woodlands, roadside, forested areas and protected reserves. At each location, the position of each sampled site (approximate latitude, longitude and altitude) was taken using a Global Positioning System (GPS) device (Table 3.1).

3.2.2 Plant collection, handling and assessment of infestation

Plants were sampled using the destructive sampling technique. At each location 80 leaves and, 20 twigs (≈10 cm length) were plucked or excised at random from different host plants records from literature. When available, 5 fruits were also randomly picked from target host plants. Plant parts were individually transferred to paper bags and transported to the laboratory in cool boxes. In the laboratory, tally counters were used to quantify the total number of *R. iceryoides* per sampled plants parts using a head lens and or stereomicroscope. Severity of mealybug infestation for each locality and host plant was scored from the sampled foliage, twigs, and fruits following the scale developed by Tobih et al. (2002) for *R. invadens* with slight modification (see Table 3.2). Infestation by *R. iceryoides* was also expressed as the total number of mealybugs of all developmental stages per plant part sampled for each locality.

From the field collected mealybug, three to five adult mealybug samples were randomly selected and slide-mounted using the methodology of Watson and Kubiriba (2005) at the *icipe* Biosystematics Unit to confirm their identity. Reference samples of the mealybugs were maintained at the Unit. Samples of leaf and or twig and fruit (for small fruit) from unknown plant species were collected, pressed and bagged. The collected plant samples were identified using the keys of Kenya trees, shrubs and lianas (Beenjte, 1994). Photographs were also taken of each plant and or fruit sampled to aid in plant identification and voucher specimens of all collections of the plant species are maintained at *icipe*. The plant nomenclature system used conforms to the International Plant Names Index database (IPNI, 2005) and the Missouri Botanical Garden database W^3 TROPICOS (MBOT, 2006).

3.2.3 Parasitoid, predator and ant species associated with *R. iceryoides*

After the census of mealybugs on infested plant parts, live and mummified specimens were transferred into plastic paper bags with well-ventilated tiny openings made using entomological pins # 000 (length 38 mm, 0.25 mm diameter) or transparent plastic rearing containers (22.5 cm height x 20 cm top diameter x 15 cm bottom diameter). An opening (10 cm diameter) was made on the front side of the cage to which a sleeve, made from very fine organza material (about 0.1 mm mesh size) was fixed. The same material was fixed to the opposite opening (10 cm diameter) of the cage to allow for ventilation. A third opening (13 cm diameter) was made on the roof of the cage, which was also screened with the same material. Streaks of undiluted honey were applied to the roof of the cages and maintained in the laboratory at 25 ± 2^{o}C, 70 ± 10% RH, photoperiod of 12:12 (L: D) h and ambient temperatures (26-28^{0}C) until parasitoid emergence. Mummies with emergence holes were discarded after counting. Mummified mealybugs from each infested host plant species and locality were maintained separately. Parasitoids that emerged from the mealybug cultures were collected daily and counted. All parasitoids that emerged were initially identified at Annamalai University, India and later confirmed at the National collection of Insects, PPRI-Agricultural Research Council (ARC), Pretoria, South Africa.

At each sampling date and site, predators of *R. iceryoides* were sampled by beating 10 randomly selected branches of each host plants over a 1 – m^2 cloth screen using a 60 cm long stick. The sampling was done during the early hours of the morning of 8:30-9:30 am. The predators that were dislodged onto the cloth were then recorded and preserved in 70 % ethyl alcohol. Immature stages of predators were reared on mealybugs in transparent plastic rearing containers (22 cm length x 15 cm width x 15 cm height) with an opening (10 cm diameter) made on the front side of the plastic container to which a sleeve, made of organza material was fixed. The set up was maintained at 26-28˚C, 60 - 80% relative humidity (RH), under a photoperiod of

12L: 12D in the laboratory at the National Biological Control Programme (NBCP), Kibaha, until they developed to the adult stage and later counted.

For ant sampling, surveys were carried out weekly during the dry season (December to March) in a 10 hectres mango orchard grown according to standard agronomic practices with no pesticides application in Kibaha. The orchard was selected on the basis of availability and accessibility of major ant species observed. The interactions between ant and mealybug populations in the orchard were randomly assessed by means of visual inspection. Thereafter, two ant-infested plants with mealybugs were randomly selected on each survey date for the incidence of mummified mealybugs, as affected by the presence of ant species. On each plant, 2 twigs (≈20 cm length) having ants tending mealybugs were cut and placed individually in plastic bags, and taken to the laboratory for examination. All mealybugs (life stages and mummified mealybugs) and ants found on each twig was counted and recorded. Mummified mealybugs from each sampled twig were kept in closed polyethylene containers (2.5 cm diameter x 6 cm height) with perforated lids for ventilation. Samples were maintained under laboratory conditions of 26 ± 2°C, 60–80% RH, and 12:12 (L:D) h for possible emergence of parasitoids. During the survey, care was taken to make sure that no tree was sampled twice within the same month. Ants were identified by Dr. Seguni Z.S.K, Mikocheni Agricultural Research Institute, Dar es Salaam, Tanzania.

3.2.4 Statistical analysis

Data for field surveys are presented according to plant species, family, location, infestation levels, severity of attack, number of emerged parasitoids, percentage parasitism and number of predators. Infestation by *R. iceryoides* was expressed as the total number of mealybugs of all developmental stages per number of plant part sampled for each locality. Parasitism was expressed as percentage of the number of emerged parasitoid species to the total number of hosts in the samples for each locality. The data on mealybug infestation and parasitism rates were compared across plant parts by subjecting the data to t test or one-way ANOVA using the generalized linear model (Proc GLM) after log (x + 1) and angular transformation, respectively to normalize variance before statistical analysis. Means were separated by Tukey honestly significant difference (HSD) test (P = 0.05). The overall effect of ant presence was calculated from the regression between ant species on mealybug colony size and number of mummified mealybugs. All computations were performed using SAS 9.1 software (SAS Institute, 2010).

Table 3. 1: Sampling sites for *Rastrococcus iceryoides* and associated natural enemies with geo-referenced positions and altitude

Country/locality	Longitude	Latitude	Eleveation (m a. s. l)
Kenya			
Galana	03° 11' 89" S	040° 06' 86" E	8
Mombasa	04° 03' 61" S	039° 40' 21" E	12
Loka-Chumani	03° 28' 84" S	039° 53' 77" E	14
Lamu	02° 16' 07" S	040° 54' 01" E	18
Mtangani	03° 11' 77" S	040° 05' 25" E	34
Malindi	03° 10' 74" S	040° 07' 23" E	40
Matuga	04° 11' 02" S	039° 33' 38" E	109
Kinango	04° 07' 05" S	039° 25' 27" E	121
Kilifi	03° 42' 01" S	039° 49' 44" E	136
Shimba Hills	04° 15' 24" S	039° 27' 19" E	363
Maungu	03° 33' 45" S	038° 44' 91" E	523
Voi	03° 27' 04" S	038° 22' 02" E	591
Ikanga	03° 22' 61" S	038° 34' 02" E	591
Mwatate	03° 30' 08" S	038° 22' 43" E	843
Kigala	03° 22' 18" S	038° 28' 54" E	854
Ndome	03° 17' 65" S	038° 28' 59" E	866
Kamleza	03° 27' 02" S	037° 41' 65" E	887
Taveta	03° 23' 52" S	037° 40' 61" E	901
Madabogo	03° 27' 12" S	038° 27' 11" E	943
Dembwa	03° 27' 05" S	038° 22' 03" E	1049
Wundanyi	03° 23' 61" S	038° 22' 08" E	1323
Kungu	03° 25' 01" S	038° 21' 09" E	1480
Tanzania			
Bagamoyo	06˚ 36' 23" S	039˚ 05' 13"E	26
Tanga	04˚ 58' 91" S	039˚ 05' 24" E	47
Kibaha	06˚ 43' 84" S	038˚ 46' 07" E	79
Mkuranga	07˚ 04' 05" S	039˚ 15' 63" E	93
Kinondoni	06˚ 45' 80" S	039˚ 06' 25" E	162
Vomero	06˚ 14' 71" S	037˚ 33' 25" E	364
Turiani	06˚ 16' 29" S	037˚ 32' 68" E	366
Mikese	06˚ 45' 04" S	037˚ 52' 46" E	423
Kilosa	06˚ 41' 44" S	037˚ 07' 47" E	441
Ilonga	06˚ 46' 35" S	037˚ 02' 46" E	489
Kyela	09˚ 28' 10" S	033˚ 53' 16" E	503
Morogoro	06˚ 50' 69" S	037˚ 39' 83" E	522

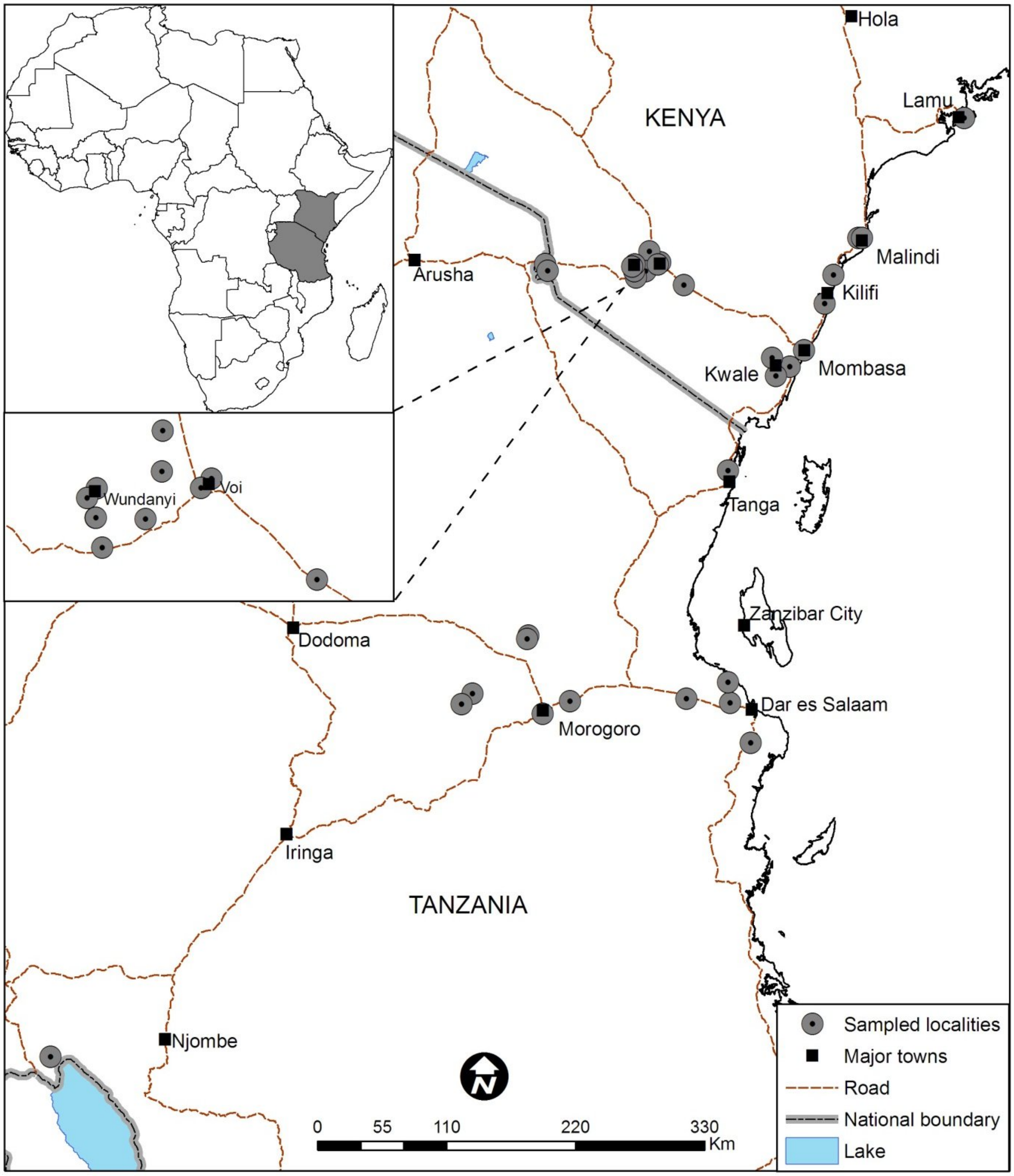

Figure 3. 1: Map of Kenya and Tanzania showing locations of sites sampled for mealybug.

Table 3. 2 Classification of severity of host plant infestation by *Rastrococcus iceryoides* in the field during the survey

Degree of infestation	Description of severity of infestation
I: Uninfested	0% infestation observed
II: Low	1 – 25% of the host part showed infestation by the mealybug usually on the abaxial surfaces of the foliage
III: Moderate	26–60% of the host part showed mealybug infestation together with sooty mould on both surfaces of foliage or twig
IV: Severe	61–100% of entire foliage, twigs, inflorescences and sometimes fruits, are completely covered by the mealybugs and sooty mould

3.3 Results

3.3.1 Distribution

In the Coast Province of Kenya, out of the 22 localities sampled, *R. iceryoides* was recorded from 12 sites—Mombasa, Malindi, Matuga, Kinango, Kilifi, Voi, Ikanga, Mwatate, Kigala, Ndome, Kamleza and Taveta—but with varying degrees of infestation (Table 3.3). The heaviest infestation on twig of *P. aculeata* was recorded in Kinango (7892 mealybugs/20 twigs). The heaviest infestation on twigs of *M. indica* was recorded in Matuga (3654 mealybugs/20 twigs) followed by Mombasa (971 mealybugs/20 mango twigs) and Malindi (881 mealybugs/20 mango twigs) (Table 3.3).

In Tanzania, *R. iceryoides* was recorded from all localities sampled (Tables 3.1 and Table 3.3). Among all the locations sampled, infestation was heaviest in Morogoro and Kibaha (8325 and 8153 mealybugs/20 mango twigs, respectively) followed by Kinondoni (6868 mealybugs/20 mango twigs) and lowest in Vomero (142 mealybugs/20 twigs) (Table 3.3).

3.3.2 Host-plants

During the survey, *R. iceryoides* was recorded from 29 plant species from 16 families. Twenty-one of these plant species are new records for Africa and the world. Host plants positive for *R. iceryoides* included both cultivated and wild host plants (Table 3.3).

In Kenya, among the plant species sampled, *R. iceryoides* was recorded from only six host plants. These are: *Parkinsonia aculeata* L. [Fabaceae], *M. indica* [Anacardiaceae], *Ficus benghalensis* L. [Moraceae.], *Manilkara zapota* L. [Sapotaceae], *Psidium guajava* L. [Myrtaceae] and *Citrus aurantifolia* Swingle [Rutaceae] (Table 3.3). Among the cultivated host plants, severe infestation was recorded on mango, *M. indica,* in all the localities with mealybugs (nymphs and adults) ranging from 215 to 516 mealybugs/80 leaves and 568 to 3654 mealybugs/20 twigs (Table 3.3). The most important wild host plant was *P. aculeata* with infestation ranging from 11–17 mealybugs/80 leaves and 3467–7892 mealybug/20 twigs (Table 3.3). In the heavily infested plants such as mango and *P. aculeata*, twigs recorded significantly higher mealybugs than the other plant parts: Matuga on *M. indica* (t = -6.94; df = 21; P < 0.0001) and *P. aculeata* (t = -6.96; df = 23; P < 0.0001), Mombasa on *M. indica* (t = -2.85; df =

12; *P* = 0.0146), Malindi on *M. indica* (*t* = -5.11; *df* = 25; *P* < 0.0001), and Kinango on *P. aculeata* (*F* = 12.25; *df* = 2,51; *P* < 0.0001) (Table 3.3).

In Tanzania, *R. iceryoides* attack was noted on 27 host plants. Host plants with heavy infestations included *M. indica*, *P. aculeata*, *Osyris lanceolata* Hochst & Steud [Santalaceae], *Caesalpinia sepiaria* Roxb. [Fabaceae], *Artocarpus heteophyllus* Lam., *Cajanus cajan* (L.) Millsp. [Fabaceae], *Annona muricata* L. [Annonaceae] and *Deinbollia borbonica* Scheff. [Anacardiaceae]. Among the cultivated host plants, infestation was severe on mango (211–6054 mealybugs/80 leaves, 142–8325 mealybugs/20 twigs, 2979 mealybugs/5 fruits) and *C. cajan* (87–1452 mealybugs/80 leaves, 457–4672 mealybugs/20 twigs) followed by *P. guajava* (218–435 mealybugs/5 fruits) across localities compared with the other cultivated host plants sampled (Table 3.3). On heavily infested mango (in Morogoro) and pigeon pea (in Kibaha), twigs recorded significantly higher mealybugs than the other plants parts, (*t* = -2.89; *df* = 67; *P* = 0.0051 and *t* = -4.19; *df* = 39; *P* = 0.0002, for mango and pigeon pea, respectively) (Table 3.3).

Other host plants of low to moderate importance in Tanzania include *Artocarpus heterophyllus* Lam. [Moraceae], *Harrisonia abyssinica* Oliv. [Simaroubaceae], *Indigofera spicata* Forsk [Papilionaceae], *Annona squamosa* Linn.[Annonaceae], *Dialium holtzii* Harms [Caesalpiniaceae], *Lecaniodiscus fraxinifolius* Baker [Sapindaceae], *C. aurantifolia*, *C. sinensis* Linn. and *Solanum indicum* Linn. [Solanaceae] with infestation ranging from 34 - 129 mealybugs/80 leaves and 221 - 321 mealybugs/20 twigs, across the various localities sampled.

Rastrococcus iceryoides was also recorded from *Morus alba* Linn. [Moraceae], *Sorindeia madagascariensis* Thou. [Ancardiaceae], *Annona stenophylla* Engl. & Diels. [Annonaceae], *Musca paradisiaca* Linn. [Musaceae], *Annona senegalensis* Pers. [Annonaceae], *Ficus vallis-choudae* Delile [Moraceae], *Dalbergia melanoxylon* Guill & Perr [Papilionaceae], *Flueggea virosa* Voigt [Euphorbiaceae], and *Clerodendrum hohnstonii* Oliv. [Verbenaceae] but infestation on these host plants did not exceed 66 mealybugs/20 twigs.

Other mealybug species were also encountered, although at negligible levels on mango and included: *Icerya seychellarum* (Westwood), *Pseudococcus longispinus* (Targioni-Tozzetti), *Planococcus citri* (Risso), *Ferrisia virgata* (Cockerell), *Icerya aegyptiaca* (Douglas), *Phenococcus solenensis* (Tinsley), *Nipaecoccus nipae* (Maskell) and *Planococcus kenyae* (Le Pelley).

Table 3. 3: Distribution, host plants and infestation of *R. iceryoides* in Kenya and Tanzania

Country/ Locality	Plant species	Plant family	No. of *R. iceryoides*			Severity of attack			Statistics		
			Leaves	Twigs	Fruits	S	M	L	*T* or *F*	*df*	*P*
Kenya											
Mombasa	*Mangifera indica* Linn.	Anacardiaceae	422	971	-		+		-2.85	12	0.0146
	***Ficus benghalensis* Linn.	Moraceae	190	358				+	-1.56	14	0.1423
Malindi	*Manilkara zapota* Linn.	Sapotaceae	7	69	-			+	-2.97	8	0.0178
	Mangifera indica Linn.	Anacardiaceae	374	881	-		+		-5.11	25	<0.0001
Matuga	*Mangifera indica* Linn.	Anacardiaceae	516	3654	-	+			-6.94	21	<0.0001
	Citrus aurantifolia Swingle	Rutaceae	3	27	-			+	-2.70	4	0.0539
	Psidium guajava Linn.	Myrtaceae	66	271				+	-0.03	17	0.9729
	Parkinsonia aculeata Linn.	Fabaceae	17	3467	-	+			-6.96	23	<0.0001
Kinango	*Parkinsonia aculeata* Linn.	Fabaceae	11	7892	42	+			12.25	2,51	<0.0001
Kilifi	*Mangifera indica* Linn.	Anacardiaceae	215	568	-		+		-4.25	14	0.0008
Voi	*Mangifera indica* Linn.	Anacardiaceae	161	723	-		+		-3.01	29	0.0021
Ikanga	*Mangifera indica* Linn.	Anacardiaceae	9	23	-			+	-2.11	17	0.0441
Mwatate	*Mangifera indica* Linn.	Anacardiaceae	34	101	-			+	-0.21	21	0.6043
Kigala	*Parkinsonia aculeata* Linn.	Fabaceae	13	3101	-		+		-7.03	32	<0.0001
Ndome	*Mangifera indica* Linn.	Anacardiaceae	26	115	-			+	-2.76	11	0.0201
Kamleza	*Mangifera indica* Linn.	Anacardiaceae	17	72	-			+	-2.18	10	0.0167
Taveta	*Mangifera indica* Linn.	Anacardiaceae	43	215	-			+	-2.44	14	0.0232
Tanzania											
Bagamoyo	*Mangifera indica* Linn.	Anacardiaceae	455	674	-		+		-0.51	17	0.6169
Tanga	*Mangifera indica* Linn.	Anacardiaceae	3603	5154	-	+			-3.55	39	0.0010
	Cajanus cajan Linn.	Fabaceae	98	1578	-		+		-3.86	19	0.0011

Plants parts samples based on 80 leaves, 20 twigs of 10 cm length and 5 fruits; ** = New record for *R. iceryoides* in Africa; - = plants were either not infested and omitted from analysis or not available during sampling; [a]Severity of attack: S = Severe; M = Moderate; L = Low; + = degree of attack.

Table 3.3 continues. Distribution, host plants and infestation of *R. iceryoides* in Kenya and Tanzania

Country/ Locality	Plant species	Plant family	No. of *R. iceryoides*			Severity of attack			Statistics		
			Leaves	Twigs	Fruits	S	M	L	*T* or *F*	*df*	*P*
Tanzania											
Tanga	*Psidium guajava* Linn.	Myrtaceae	54	213	218			+	1.51	2,13	0.2567
	Citrus aurantifolia Swingle	Rutaceae	8	38	5			+	16.43	2,7	0.0023
Kibaha	** *Sorindeia madagascariensis* Thouars	Anacardiaceae	4	39	-			+	-5.56	5	0.0026
	** *Annona stenophylla* Engl. & Diels.	Annonaceae	15	66	-			+	-0.99	6	0.3589
	** *Phyllanthus engleri* Pax	Euphorbiaceae	112	837	-		+		-3.15	18	0.0055
	***Artocarpus heterophyllus* Lam.	Moraceae	77	321	-			+	-1.90	20	0.0721
	** *Annona squamosa* Linn.	Annonaceae	13	278	-			+	-3.97	13	0.0016
	Psidium guajava Linn.	Myrtaceae	6	123	435		+		3.33	2,18	0.0587
	Musca paradisiaca Linn.	Muscaeceae	8	0	-			+	1.86	2	0.2036
	** *Annona senegalensis* Pers.	Annonaceae	2	11	-			+	-0.76	2	0.5264
	** *Ficus vallis-choudae* Delile	Moraceae	0	25	-			+	-1.79	3	0.1713
	** *Dialium holtzii* Harms	Caesalpiniaceae	127	566	-		+		-1.51	11	0.1604
	Cajanus cajan (L) Millsp.	Fabaceae	388	3359	-	+			-4.19	39	0.0002
	***Annona muricata* Linn.	Annonaceae	234	1334	-		+		-2.94	9	0.0165
	***Dalbergia melanoxylon* Guill & Perr	Papilionaceae	0	66	-			+	-1.75	3	0.1778
	** *Flueggea virosa* Voigt	Euphorbiaceae	0	23	-			+	-2.49	4	0.0675
	** *Clerodendrum johnstonii* Oliv.	Verbenaceae	1	4	-			+	-0.50	2	0.6667
	** *Lecaniodiscus fraxinifolius* Baker	Sapindaceae	44	231	-			+	-1.60	10	0.1403
	Mangifera indica Linn.	Anacardiaceae	6054	8153	-	+			-2.25	68	0.0277
	** *Solanum indicum* Linn.	Solanaceae	63	314	-			+	-0.86	9	0.4124
	** *Deinbollia borbonica* Scheff.	Sapindaceae	215	2253	-			+	-2.73	36	0.0099
Mkuranga	*Mangifera indica* Linn.	Anacardiaceae	1223	3417	-	+			-2.39	32	0.0231

Plants parts samples based on 80 leaves, 20 twigs of 10 cm length and 5 fruits; ** = New record for *R. iceryoides* in Africa; - = plants were either not infested and omitted from analysis or not available during sampling; [a]Severity of attack: S = Severe; M = Moderate; L = Low; + = degree of attack.

Table 3.3 continues. Distribution, host plants and infestation of *R. iceryoides* in Kenya and Tanzania

Country/			No. of *R. iceryoides*			Severity of attack			Statistics		
Locality	Plant species	Plant family	Leaves	Twigs	Fruits	S	M	L	*T* or *F*	*df*	*P*
Tanzania											
Kinondoni	*Mangifera indica* Linn.	Anacardiaceae	3865	6868	2979	+			4.70	2,73	0.0120
	Citrus aurantifolia Swingle	Rutaceae	34	122	-			+	-0.53	7	0.6150
	Citrus sinensis Linn.	Rutaceae	118	313	-			+	-1.81	12	0.0952
	***Artocarpus heterophyllus* Lam.	Moraceae	129	326	-			+	-2.23	20	0.0372
	***Morus alba* Linn.	Moraceae	1	5	-			+	-1.0	2	0.4226
	Parkinsonia aculeata Linn.	Fabaceae	24	5567	-	+			-4.82	47	<0.0001
	** *Osyris lanceolata* Hochst. & Steud.	Santalaceae	2	2356	-	+			-3.25	13	0.0063
	** *Harrisonia abyssinica* Oliv.	Simaroubaceae	57	358	-			+	-4.70	7	0.0022
	***Indigofera spicata* Forsk	Papilionaceae	34	221	-			+	-1.57	9	0.1518
	** *Caesalpinia sepiaria* Roxb.	Fabaceae	266	3116	-	+			-3.97	35	0.0003
Vomero	*Mangifera indica* Linn.	Anacardiaceae	335	142	-			+	1.14	20	0.2695
Turiani	*Mangifera indica* Linn.	Anacardiaceae	211	967	-		+		-3.56	26	0.0015
	***Annona muricata* Linn	Annonaceae	5	49	-			+	-3.47	5	0.0179
	Citrus aurantifolia Swingle	Rutaceae	3	21	-			+	-2.47	3	0.0903
Mikese	*Mangifera indica* Linn.	Anacardiaceae	814	3578	-	+			-4.88	41	<0.0001
Kilosa	*Mangifera indica* Linn.	Anacardiaceae	87	237	-			+	0.64	15	0.5326
	Psidium guajava Linn.	Myrtaceae	9	40	-			+	-1.44	6	0.2002
Ilonga	*Mangifera indica* Linn.	Anacardiaceae	62	421	-			+	-4.92	19	<0.0001
Kyela	*Mangifera indica* Linn.	Anacardiaceae	263	1700	-		+		-5.96	23	<0.0001
	Cajanus cajan Linn.	Fabaceae	87	457	-			+	-2.70	14	0.0171
Morogoro	*Mangifera indica* Linn.	Anacardiaceae	2563	8325	-	+	+		-2.89	67	0.0051
	Cajanus cajan (L) Millsp.	Fabaceae	1452	4672	-	+			-2.0	35	0.0530
	Citrus aurantifolia Swingle	Rutaceae	2	28	-			+	-2.67	5	0.0446

Plants parts samples based on 80 leaves, 20 twigs of 10 cm length and 5 fruits; ** = New record for *R. iceryoides* in Africa; - = plants were either not infested and omitted from analysis or not available during sampling; [a]Severity of attack: S = Severe; M = Moderate; L = Low; + = degree of attack.

3.3.3 Damage symptoms

Increased severity of attack on the abaxial and adaxial surfaces of the leaf led to distorted, stunted, withering and yellow leaves, which gradually dried up with ultimate premature shedding occurring (Figure 3.2a and Figure 3.2b). During the flowering period, affected panicles were observed to practically dry-up eventually causing the flowers to drop off prematurely as a result of the severe tip die-back effects (Figure 3.2c). On the other hand, immature fruits (less than a month old) were observed to shrivel and dry-up ultimately falling off in due course (Figure 3.2d). High incidence of reduced fruit-settings was commonly observed in heavily infested orchards with shedding of young fruits as a result of early ripening due to increased pressure exerted by the sucking pest on the fruit peduncle (Figure 3.2e and Figure 3.2f). During population outbreaks, high populations of *R. iceryoides* were observed to spread to mature fruit bunches (Figure 3.2g). Intense feeding by the mealybug on fruits resulted in rind pitting and scarring. In cases where the young branches supporting the leaves were heavily infested leaf drop occurred along with twig dieback. The incidence of heavily infested plant's parts drying up was also observed on other host plants, *C. sepiaria*, *O. lanceolata*, *I. spicata*, *P. aculeata,* and *C. cajan*. Symptoms of slow growth, lack of vigour and subsequent plant death under moisture-stress conditions was also observed in the field especially on newly planted mango seedlings in the orchards.

Copious amounts of sugary honeydew were also produced by *R. iceryoides*, which caused blackened-malformed and discolored fruits with severe cracks on the skin upon exposure to intense sunlight (Figure 3.2i and Figure 3.2h). In severe cases, it rendered the leaves completely black (Figure 3.2j), forcing most of the leaves to turn yellow and finally drying up.

Figure 3. 2: Damage symptoms of the mango mealybug *R. iceryoides*, on the leaves (A, B & J), Inflorescence (C), immature fruits (D-The arrows indicate shriveled or drop-off immature dried fruits) and mature fruits (E, F, G, H & I).

3.3.4 Parasitoid species associated with *R. iceryoides* on different host plants in Kenya and Tanzania

In Kenya, out of 20,021 *R. iceryoides* collected from the six host plant species, 4228 mealybugs were parasitized and yielded a parasitism rate of 21%. Among the mummified mealybugs collected in the field, 76% yielded adult parasitoids. The parasitoid community was composed of three parasitoid species: *Anagyrus pseudococci* Girault (Hymenoptera: Encyrtidae), *Leptomastrix dactylopii* Howard (Hymenoptera: Encyrtidae) and *Leptomastidea tecta* Prinsloo (Hymenoptera: Encyrtidae) with *A. pseudococci* accounting for 99% of the overall percentage parasitism on *R. iceryoides* on the different host plant species sampled. The level of parasitism varied across host plants as well as also host plant parts (Table 3.4). For example, in Matuga, parasitism rate on mango was at 5% on leaves and 20% on twigs with an overall rate of 17%. While at Kinango, parasitism rate on *P. aculeata* was 73% on leaves and 20% on twigs with an overall rate of 20% (Table 3.4).

In Tanzania, a total of 109,824 *R. iceryoides* were collected from 27 host plant species out of which 8529 were parasitized giving a percentage parasitism of 8%. Among the mummified mealybugs, 70% yielded adult parasitoids. Out of these emerged parasitoids, 80% were from *M. indica*. The parasitoid community was composed of five species, *Anagyrus aegyptiacus* Moursi, *Leptomastrix dactylopii* Howard, *Agarwalencyrtus citri* Agarwal, *Aenasius longiscapus* Compere and *A. pseudococci* Girault. The latter accounted for 95% of the overall percentage parasitism of *R. iceryoides* on all the host plant species sampled. The percentage parasitism of the different parasitoid species also varied considerably among the different host plant species and host plant parts (Table 3.4). For example, in Kilosa highest percent parasitism by *A. pseudococci* on *M. indica* was 3 and 27%, followed by Kibaha at 11 and 18% on leaves and twigs, respectively. Overall parasitism rate was 21% in Kilosa and 15% in Kibaha (Table 3.4).

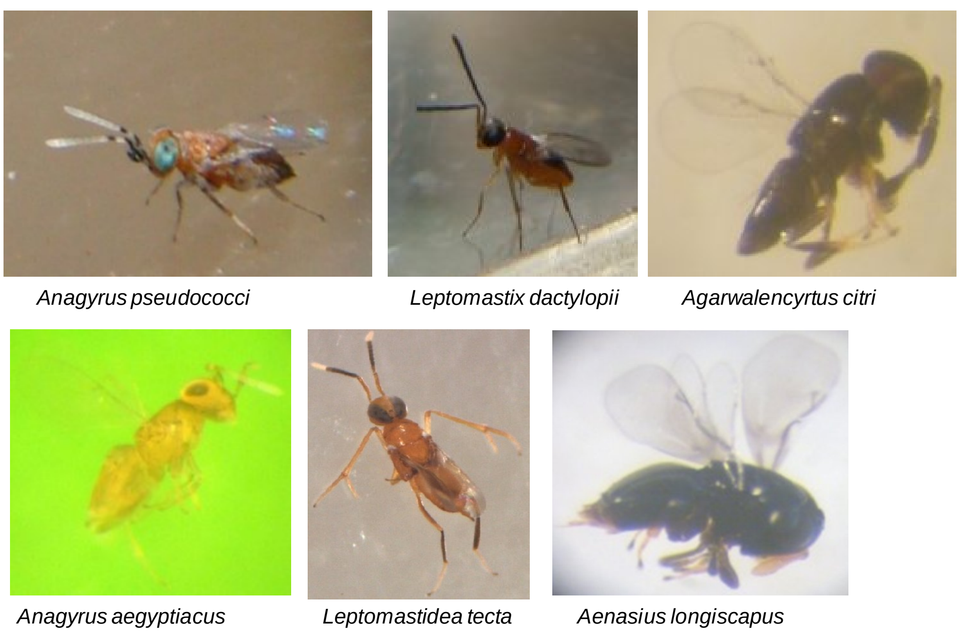

Figure 3. 3: Catalogue of indigenous primary parasitoids recovered from *R. iceryoides* in Kenya and Tanzania.

Ninteen species of hyperparasitoids were recorded in Kenya (1 species) and Tanzania (18 species). These included, 5 Encyrtidae (*Achrysopophagus aegyptiacus* Mercet, *Cheiloneurus carinatus*, sp.nov, *Cheiloneurus angustifrons* sp.nov, *Cheiloneurus cyanonotus* Waterston and *Cheiloneurus latiscapus* Girault); 7 Aphelinidae (*Promuscidea unfasciativentris* Girault, *Coccophagus gilvus* Hayat, *Coccophagus pseudococci* Compere, *Coccophagus bivittatus* Compere, *Marietta leopardina* Motschulsky, *Coccophagus lycimnia* (Walker) and *Coccophagus nigricorpus* Shafee); 2 Signiphoridae (*Chartocerus conjugalis* Mercet and *Chartocerus* sp); 1 Elasmidae (*Elasmus* sp.); 3 Pteromalidae (*Pachyneuron* sp. and 2 unidentified species) and 1 Eulophidae (*Tetrastichus flaviclavus* La Salle & Polaszek).

The number of hyperparasitoids found during the survey accounted for 7.57% (n = 487/6432) of the total parasitoid populations collected throughout the survey. Hyperparasitism was sporadic with the dominant species being *C. conjugalis* and *C. cyanonotus*. Among these hyperparasitoids, *Cheiloneurus cyanonotus* Waterston was the only polyphagous species observed to attack parasitized *R. iceryoides* and the pupae of the coccinelid, *Chilocorus nigrita* (Fabricus) with a total of 12 adults parasitoids recovered from 1 pupa of the coccinelid.

Figure 3. 4: Catalogue of indigenous hyperparasitoids recovered from *R. iceryoides* in Kenya and Tanzania.

Several parasitoid species were also recovered from other mealybug species found co-existing with *R. iceryoides* on mango. The most important primary parasitoid recovered from *Icerya seychellarum* (Westwood) was a parasitic Diptera, *Cryptochetum iceryae* (Williston) (Diptera: Cryptochetidae) and a hyperparasitoid, *Pachyneuron* sp. (Hymenoptera: Pteromalidae) (Figure 3.5). The primary parasitoid of *Ferrisia virgata* (Cockerrel) was *Aenasius advena* Compere (Hymenoptera: Encyrtidae) and from *Nipaecoccus nipae* (Maskell) was *Euryishomyia washingtoni* Girault.

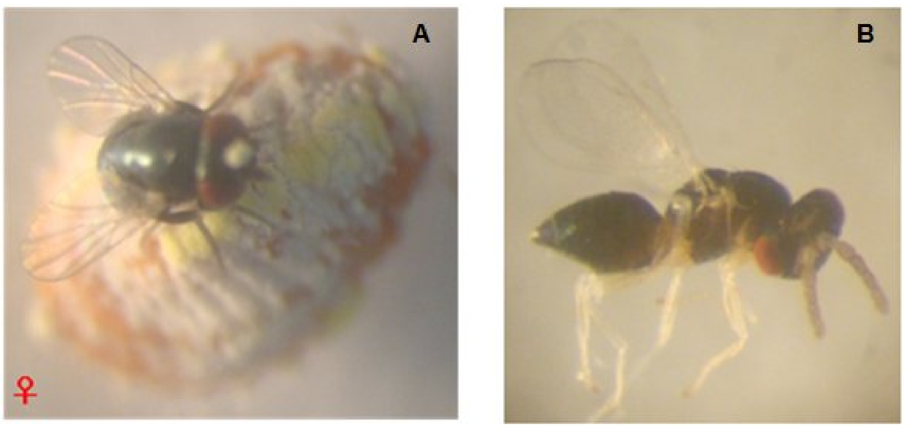

Figure 3. 5: (A) Parasitic Diptera, *Cryptochetum iceryae* (Williston) parasitizing *I. seychellarum*; (B) Hyperparasitoid, *Pachyneuron* sp. recovered from parasitized *I. seychellarum*.

Table 3. 4 Parasitoid complex associated with *R. iceryoides* on different host plants in Kenya and Tanzania

Country/ Locality	Parasitoid species	Plant species	Percentage parasitism			Overall % parasitism
			Leaves	Twigs	Fruits	
Kenya						
Mombassa	*Anagyrus pseudococci* Girault	*Mangifera indica* Linn.	12.32 (422)	8.75 (971)	-	9.83 (1393)
	Anagyrus pseudococci Girault	*Ficus benghalensis* Linn.	4.21 (190)	4.75 (358)	-	4.56 (548)
Matuga	*Anagyrus pseudococci* Girault	*Mangifera indica* Linn.	5.43 (516)	19.65 (3654)	-	17.89 (4170)
	Anagyrus pseudococci Girault	*Psidium guajava* Linn.	3.03 (66)	6.64 (271)	-	5.93 (337)
	Anagyrus pseudococci Girault	*Parkinsonia aculeata* Linn.	17.65 (17)	14.05 (3467)	-	14.06 (3484)
Kilifi	*Anagyrus pseudococci* Girault	*Mangifera indica* Linn.	3.72 (215)	12.68 (568)	-	10.22 (783)
Malindi	*Anagyrus pseudococci* Girault	*Mangifera indica* Linn.	8.29 (374)	10.78 (881)	-	10.04 (1255)
Kinango	*Anagyrus pseudococci* Girault	*Parkinsonia aculeata* Linn.	72.73 (11)	20.12 (7892)	-	20.19 (7903)
	Leptomastrix dactylopii Howard	*Parkinsonia aculeata* Linn.	18.18 (11)	0.09 (7892)	-	0.10 (7903)
	Leptomastidea tecta Prinsloo	*Parkinsonia aculeata* Linn.	9.09 (11)	0.13 (7892)	-	0.14 (7903)
Tanzania						
Kinondoni	*Anagyrus pseudococci* Girault	*Mangifera indica* Linn.	8.38 (3865)	3.13 (6868)	5.1 (2979)	5.04 (13712)
	Anagyrus aegyptiacus Moursi	*Mangifera indica* Linn.	0.21 (3865)	0.31 (6868)	0.10 (2979)	0.15 (13712)
	Leptomastrix dactylopii Howard	*Mangifera indica* Linn.	0.05 (3865)	0.19 (6868)	-	0.14 (10733)
	Agarwalencyrtus citri Agarwal	*Mangifera indica* Linn.	0.08 (3865)	-	-	0.08 (3865)
	Anagyrus pseudococci Girault	*Artocarpus heterophyllus* Lam.	5.43 (129)	2.76 (326)	-	3.52 (455)
	Anagyrus pseudococci Girault	*Parkinsonia aculeata* Linn.	20.83 (24)	5.64 (5567)	-	5.71 (5591)
	Anagyrus pseudococci Girault	***Indigofera spicata* Forsk	5.88 (34)	2.71 (221)	-	3.14 (255)
	Anagyrus pseudococci Girault	*Caesalpinia sepiaria* Roxb.	4.14 (266)	1.64 (3116)	-	1.83 (3382)
Mkuranga	*Anagyrus pseudococci* Girault	*Mangifera indica* Linn.	10.96 (1223)	9.45 (3417)	-	9.85 (4640)
Kibaha	*Anagyrus pseudococci* Girault	** *Phyllanthus engleri* Pax.	7.14 (112)	8.84 (837)	-	8.64 (949)
	Anagyrus pseudococci Girault	*Artocarpus heterophyllus* Lam.	2.60 (77)	4.98 (321)	-	4.52 (398)
	Anagyrus pseudococci Girault	** *Annona squamosa* Linn.	7.69 (13)	12.95 (278)	-	12.71 (291)
	Anagyrus pseudococci Girault	*Psidium guajava* Linn.	0	3.25 (123)	2.53 (435)	2.69 (558)
	Anagyrus pseudococci Girault	** *Dialium holtzii* Harms	5.51 (127)	3.36 (566)	-	3.75 (693)
	Anagyrus pseudococci Girault	*Cajanus cajan* (L) Millsp.	8.51 (388)	2.44 (3359)	-	3.07 (3747)
	Anagyrus pseudococci Girault	** *Lecaniodiscus fraxinifolius* Baker	4.55 (44)	2.60 (231)	-	2.91 (275)
	Anagyrus pseudococci Girault	*Mangifera indica* Linn.	11.22 (6054)	18.43 (8153)	-	15.36 (14207)

Table 3.4 Continues. Parasitoid complex associated with *R. iceryoides* on different host plants in Kenya and Tanzania

Country/ Locality	Parasitoid species	Plant species	Percentage parasitism			Overall % parasitism
			Leaves	Twigs	Fruits	
Tanzania						
Kibaha	*Anagyrus aegyptiacus* Moursi	*Mangifera indica* Linn.	0.38 (6054)	0.07 (8153)	-	0.20 (14207)
	Leptomastrix dactylopii Howard	*Mangifera indica* Linn.	0.18 (6054)	0.27 (8153)	-	0.23 (14207)
	Agarwalencyrtus citri Agarwal	*Mangifera indica* Linn.	0.03 (6054)	0.06 (8153)	-	0.05 (14207)
	Aenasius longiscapus Compere	*Mangifera indica* Linn.	0.03 (6054)	0.18 (8153)	-	0.12 (14207)
	Anagyrus pseudococci Girault	** *Solanum indicum* Linn.	3.17 (63)	6.69 (314)	-	6.10 (377)
	Anagyrus pseudococci Girault	** *Deinbollia borbonica* scheft	17.21 (215)	13.14 (2253)	-	13.49 (2468)
Bagamoyo	*Anagyrus pseudococci* Girault	*Mangifera indica* Linn.	9.67 (455)	16.62 (674)	-	13.82 (1129)
Morogoro	*Anagyrus pseudococci* Girault	*Mangifera indica* Linn.	2.61 (2563)	5.48 (8325)	-	4.80 (10888)
	Anagyrus pseudococci Girault	*Cajanus cajan* (L) Millsp.	3.86 (1452)	2.10 (4672)	-	2.51 (6124)
Mikese	*Anagyrus pseudococci* Girault	*Mangifera indica* Linn.	9.58 (814)	5.93 (3578)	-	6.60 (4392)
Turiani	*Anagyrus pseudococci* Girault	*Mangifera indica* Linn.	2.37 (211)	5.48 (967)	-	4.92 (1178)
Vomero	*Anagyrus pseudococci* Girault	*Mangifera indica* Linn.	6.57 (335)	9.15 (142)	-	7.34 (477)
Kilosa	*Anagyrus pseudococci* Girault	*Mangifera indica* Linn.	3.45 (87)	27.17 (237)	-	20.68 (324)
Ilonga	*Anagyrus pseudococci* Girault	*Mangifera indica* Linn.	8.06 (62)	9.98 (421)	-	9.73 (483)
Tanga	*Anagyrus pseudococci* Girault	*Mangifera indica* Linn.	5.91 (3603)	19.94 (311)	-	7.03 (3914)
	Anagyrus pseudococci Girault	*Cajanus cajan* (L) Millsp.	3.06 (98)	8.43 (1578)	-	8.11 (1676)
Kyela	*Anagyrus pseudococci* Girault	*Mangifera indica* Linn.	2.66 (263)	4.65 (1700)	-	4.38 (1963)
	Anagyrus pseudococci Girault	*Cajanus cajan* Linn.	8.05 (87)	7.00 (457)	-	7.17 (544)

** = indicate host plants native to Africa; - = indicates infested plant portions that were not available at the time of sampling. Numbers in parentheses represent the actual number of mealybug collected per plant portion during the survey.

3.3.5 Predator species associated with *R. iceryoides* on different host plants in Kenya and Tanzania

During the survey in Kenya and Tanzania, a total of 38 species of predators belonging to 14 families, Coccinellidae, Lycaenidae, Noctuidae, Hemerobiidae, Chrysopidae, Drosophilidae, Chamaemyiidae, Cecidomyiidae, Miturgidae, Salticidae, Sparassidae, Thomisidae, Oxyopidae and Nephilidae (Table 3.5) were found preying on *R. iceryoides* on different host plant. Figure 3.6, illutrates the different predatory beetles recorded during the survey in Kenya and Tanzania. Among the twenty species of predatory beetles, only 4 species were found in Kenya. *Chilocorus nigrita* Fabricus was the most abundant predatory beetle recorded in both countries, followed by *Chilocorus renipustulatus* Scriba, which was restricted to Tanzania. However, *Cacoxenus perspicax* Knab (Diptera: Drosophilidae) (Figure 3.7) was the most widespread and abundant predator species accounting for 78.8 and 89.3% of total predator collections in Kenya and Tanzania, respectively.

The predatory lepidoterans found preying on *R. iceryoides* during the survey were from two families: Lycaenidae and Noctuidae. *Spalgis lemolea* Druce (apefly) (Figure 3.8) was the the only species in the family Lycaenidae. Generally, *S. lemolea* activity was rarely noticed in the field probably because of its ability to camouflage with the mealybug colonies. Among the family Noctuidae, *Pyroderces badia* Hodges and *Thalpochares* sp. were recorded, with their larvae voraciously preying on the eggs (Figure 3.9) and on all the different stages of *R. iceryoides*, respectively. The mealybug-destroying moth, *Thalpochares* sp. builds itself a house, with fine silky webs interwoven with remains of the eaten-out mealybugs. With this protection against its enemies, it is able to walk over the trees and thus devours large number of mealybug populations daily (Figure 3.10).

Figure 3. 6: Catalogue of indigenous predatory beetles of *R. iceryoides* in Kenya and Tanzania.

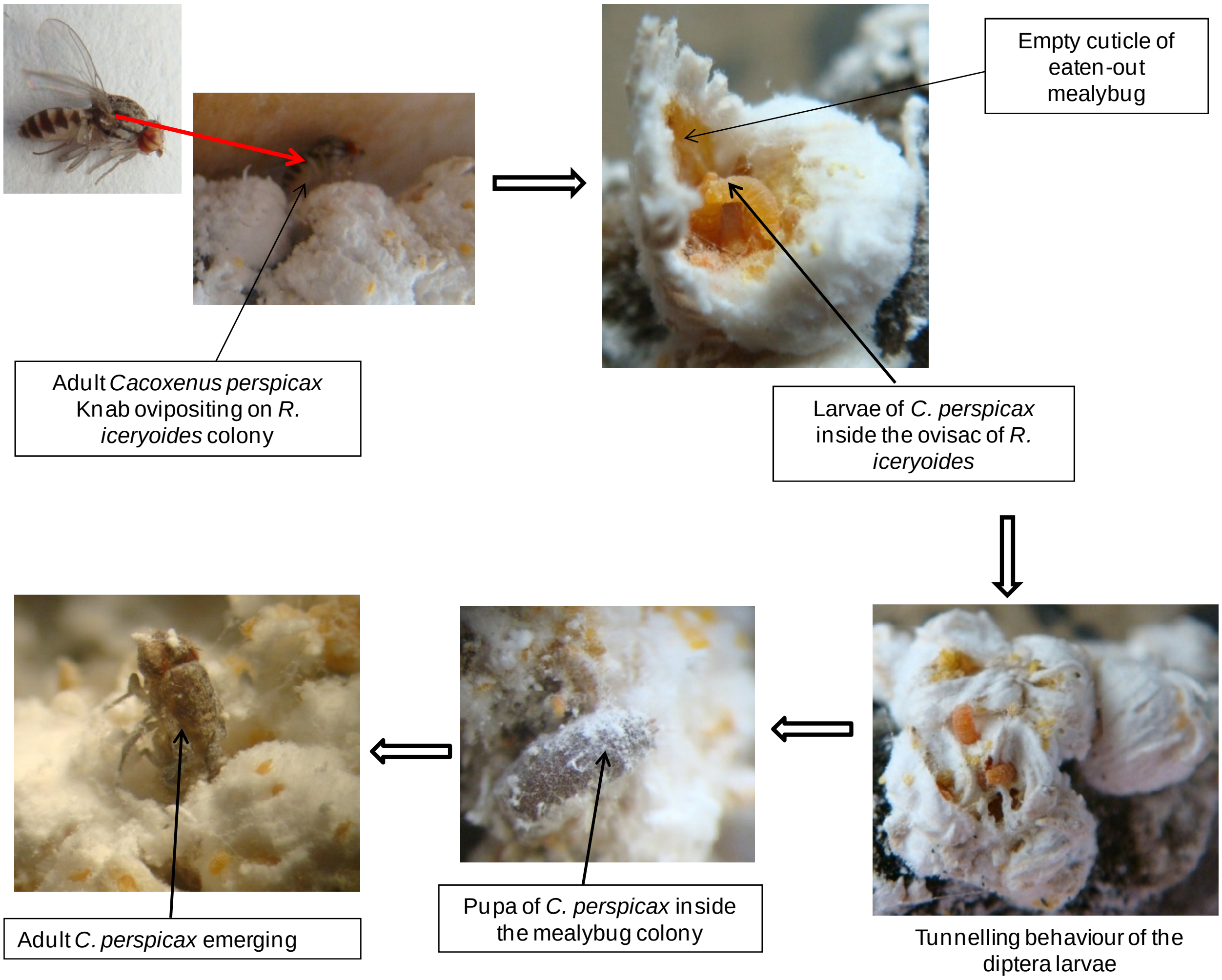

Figure 3. 7: Predatory Diptera, *Cacoxenus perspicax* Knab (Diptera: Drosophilidae) of *R. iceryoides*.

Fourteen species of spiders were collected during the study, with *Cheiracanthium inclusum* Hentz, *Orthrus* sp., *Thiodina* sp., *Peucetia viridians* Hentz, *Nephila clavipes* Lat. clavis and *Phidippus audax* Hentz being the most frequently encountered species. The two-clawed hunting spiders, *C. inclusum* (Family Miturgidae) exhibited a remarkable behavioural pattern in their association with *R. iceryoides*. They were found to construct tubular silken retreat along the midrib of mango leaves that were heavily colonized by *R. iceryoides*, as this allowed them to prey on *R. iceryoides* without having to expend energy (Figure 3.11).

Figure 3. 8: Larval, pupa and adult form of the predatory moth *Spalgis lemolea* Druce

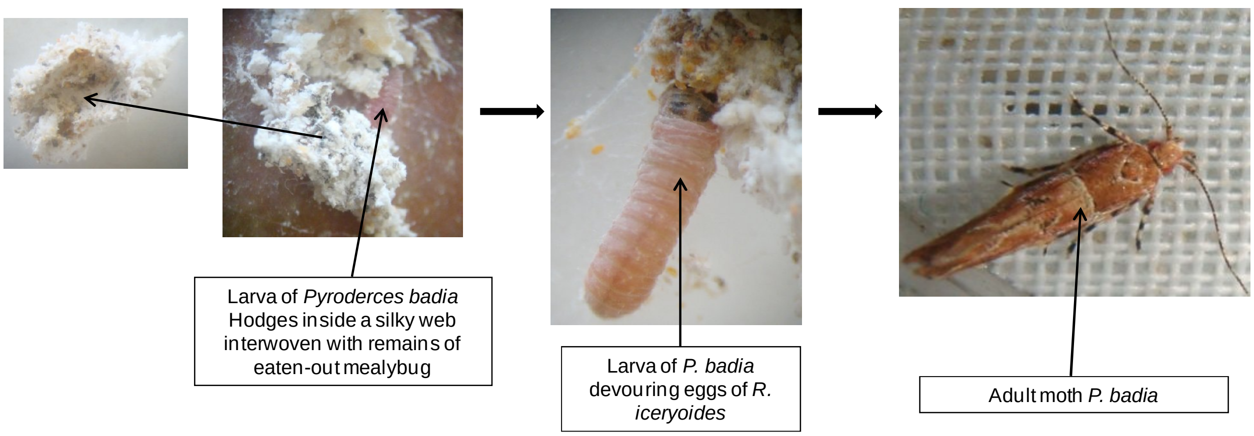

Figure 3. 9: Larva of *Pyroderces badia* Hodges feeding voraciously on eggs of *R. iceryoides*.

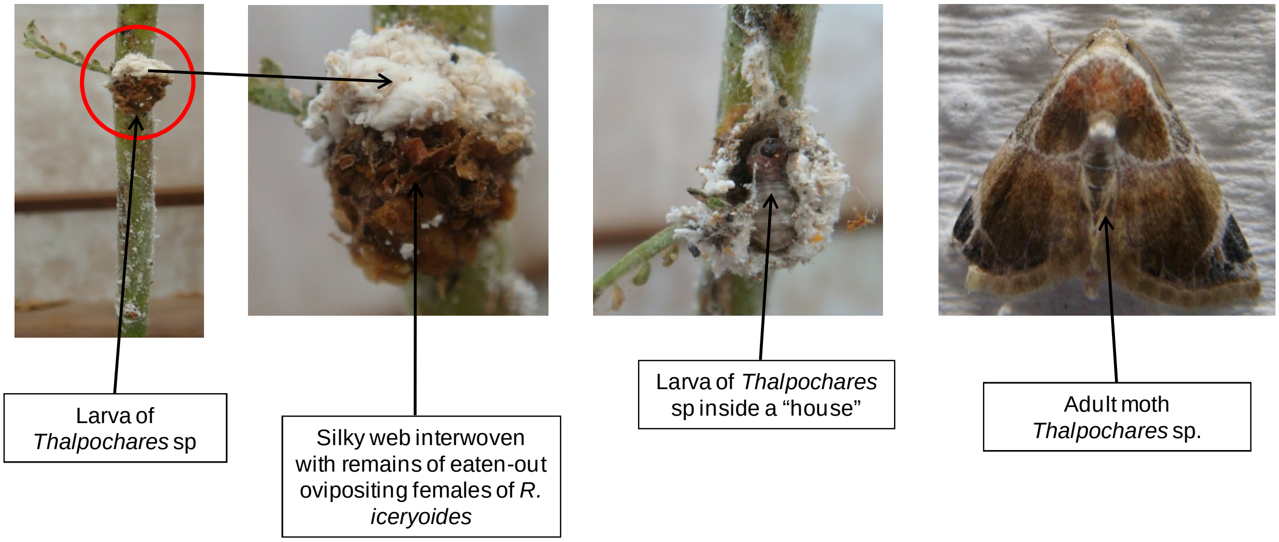

Figure 3. 10: Larva of *Thalpochares* sp. after devouring ovipositing females of *R. iceryoides* on a *P. aculeata* plant.

Species of Neuroptera (Table 3.5) were also recorded with the most important familes being Chrysopidae and Hemerobiidae. In this study, three Neuroptera species (*Mallada baronissa* (Navás), *Chrysop*a (*Suarius*) *jeanneli* (Navás) (Chrysopidae) and *Hemerobius* sp. (Hemerobiidae)) were recorded, with the most common being *Hemerobius* sp. Larvae of this species were observed in colonies of *R. iceryoides*, feeding on different nymphal stages as well as on adult mealybug females (Figure 3.12).

Figure 3. 11: Two-clawed hunting spider, *Cheiracanthium inclusum* Hentz preying on *R. iceryoides* colony on the abaxial surface of the leaf.

Figure 3. 12: *Hemerobius* sp. larva after devouring an adult oviposition female of *R. iceryoides*.

Table 3. 5: Predators associated with *R. iceryoides* on various host plants in Kenya and Tanzania

Country	Plant species	Family	Predator species	Abundance
Kenya	*Mangifera indica L.*	Chrysopidae	*Mallada baronissa* Navás	3
	Mangifera indica L.	Chrysopidae	*Chrysopa* (*Suarius*) *jeanneli* Navás	8
	Parkinsonia aculeata	Coccinellidae	*Exochomus nigromaculatus* Goeze	35
	Parkinsonia aculeata	Coccinellidae	*Cryptolaemus montrouzieri* Mulsant	7
	Parkinsonia aculeata	Coccinellidae	*Chilocorus nigrita* Fabricius	84
	Ficus benghalensis	Coccinellidae	*Chilocorus nigrita* Fabricius	6
	Parkinsonia aculeata	Coccinellidae	*Propylea dissecta* Mulsant	2
	Mangifera indica L.	Drosophilidae	*Cacoxenus perspicax* Knab	126
	Parkinsonia aculeata	Drosophilidae	*Cacoxenus perspicax* Knab	231
	Mangifera indica L.	Chamaemyiidae	*Leucopis* (Leucopella) *africana* Malloch	11
	Parkinsonia aculeata	Chamaemyiidae	*Leucopis* (Leucopella) *africana* Malloch	27
	***Annona muricata*	Chamaemyiidae	*Leucopis* (Leucopella) *africana* Malloch	5
	***Annona muricata*	Lycaenidae	*Spalgis lemolea* Druce	13
	Parkinsonia aculeata	Salticidae	*Phidippus audax* Hentz	7
	Parkinsonia aculeata	Miturgidae	*Cheiracanthium inclusum* Hentz	4
Tanzania	*Mangifera indica* L.	Coccinellidae	*Chilocorus nigrita* Fabricius	334
	Parkinsonia aculeata	Coccinellidae	*Chilocorus nigrita* Fabricius	63
	Citrus aurantifolia	Coccinellidae	*Chilocorus nigrita* Fabricius	102
	***Annona muricata*	Coccinellidae	*Chilocorus nigrita* Fabricius	15
	Mangifera indica L.	Coccinellidae	*Chilocorus renipustulatus* Scriba	214
	Citrus aurantifolia	Coccinellidae	*Chilocorus runipustulatus* Scriba	56
	Mangifera indica L.	Coccinellidae	*Hyperaspis bigeminata* Randall	178
	Mangifera indica L.	Coccinellidae	*Hyperaspis amurensis* Weise	41
	Mangifera indica L.	Coccinellidae	*Telsimia nitida* Chapin	5
	Mangifera indica L.	Coccinellidae	*Cryptolaemus montrouzieri* Mulsant	65

** = indicate host plants native to Africa

Table 3.5 continues: Predators associated with *R. iceryoides* on various host plants in Kenya and Tanzania

Country	Plant species	Family	Predator species	Abundance
Tanzania	*Mangifera indica* L.	Coccinellidae	*Propylea 14-punctata* Linnaeus	3
	Mangifera indica L.	Coccinellidae	*Micraspis vincta* Gorham	14
	Mangifera indica L.	Coccinellidae	*Henosepilachna vigintioctopunctata* Fabricius	2
	Mangifera indica L.	Chrysomelidae	*Nisotra gemella* Erichson	11
	Mangifera indica L.	Coccinellidae	*Rodolia fumida* Mulsant	23
	Mangifera indica L.	Coccinellidae	*Cryptogonus* sp.	7
	Mangifera indica L.	Coccinellidae	*Henosepilachna argus* Geoffroy,	1
	Mangifera indica L.	Coccinellidae	*Hyperaspis* sp.	1
	Morus alba	Coccinellidae	*Rodolia pumila* Weise	22
	Morus alba	Coccinellidae	*Rodolia limbata* Motschulsky	13
	Mangifera indica L.	Coccinellidae	*Rodolia* sp	6
	Mangifera indica L.	Coccinellidae	*Rodolia pumila* Weise	8
	Morus alba	Coccinellidae	*Cycloneda* sp.	19
	Mangifera indica L.	Coccinellidae	*Platynaspis luteorubra* Goeze	4
	Mangifera indica L.	Lycaenidae	*Spalgis lemolea* Druce	38
	Mangifera indica L.	Noctuidae	*Pyroderces badia* Hodges	11
	Mangifera indica L.	Noctuidae	*Thalpochares* sp.	189
	Parkinsonia aculeata	Noctuidae	*Thalpochares* sp.	46
	Mangifera indica L.	Hemerobiidae	*Hemerobius* sp.	3
	Mangifera indica L.	Drosophilidae	*Cacoxenus perspicax* Knab	1267
	Mangifera indica L.	Chamaemyiidae	*Leucopis* (*Leucopella*) *africana* Malloch	145
	Cajanus cajan L.	Chamaemyiidae	*Leucopis* (*Leucopella*) *africana* Malloch	32
	** *Dialium holtzii*	Chamaemyiidae	*Leucopis* (*Leucopella*) *africana* Malloch	55
	Mangifera indica L.	Chamaemyiidae	*Leucopis* (*Leucopella*) *ardis* Gaimari & Raspi	41
	Cajanus cajan L.	Chamaemyiidae	*Leucopis* (*Leucopella*) *ardis* Gaimari & Raspi	72
	Mangifera indica L.	Cecidomyiidae	*Coccodiplosis* sp.	66
	Morus alba	Cecidomyiidae	*Diadiplosis* sp.	13

** = indicate host plants native to Africa

Table 3.5 continues: Predators associated with *R. iceryoides* on various host plants in Kenya and Tanzania

Country	Plant species	Family	Predator species	Abundance
Tanzania	*Morus alba*	Miturgidae	*Cheiracanthium inclusum* Hentz	47
	Mangifera indica L.	Salticidae	*Orthrus* sp.	15
	Mangifera indica L.	Salticidae	*Opisthoncus* sp.	3
	Mangifera indica L.	Salticidae	*Thiodina* sp.	8
	Mangifera indica L.	Salticidae	*Salticus* sp.	5
	Mangifera indica L.	Salticidae	*Lyssomanes* sp.	3
	Mangifera indica L.	Salticidae	*Phidippus audax* Hentz	23
	Mangifera indica L.	Sparassidae	*Micrommata rosea* Clerck	4
	Mangifera indica L.	Thomisidae	*Thomisus spectabilis* Dolesch	2
	Mangifera indica L.	Oxyopidae	*Peucetia viridians* Hentz	7
	Mangifera indica L.	Oxyopidae	*Oxyopes* sp.	2
	Mangifera indica L.	Nephilidae	*Nephila clavipes* Lat. clavis	6

** = indicate host plants native to Africa

3.3.6 Ant species associated with *R. iceryoides*

Eleven different ant species were found to be closely associated with *R. iceryoides*. These included *Anoplolepis custodiens* (Smith), *Camponotus flavomarginatus* Mayr, *Crematogaster tricolor* st. rufimembrum Santschi, *Linepithema humile* Mayr, *Oecophylla longinoda* Latreille, *Pheidole megacephala* Fabricius, *Atopomyrmex mocquerysi* Bolton, *Lepisiota depressa* (Santschi), *Polyrhachis schistacea* (Gerstäcker), *Iridomyrmex purpureus* (F. Smith) and *Camponotus pennsylvanicus* De Geer. These ants were actively found milking honeydew from the mealybugs (Figure 3.13). Populations of *O. longinoda* and *P. megacephala* had a very strong positive association with *R. iceryoides* as they protected the mealybugs from adverse weather conditions by building tents using plant leaves and organic debris (soil and plant debris) around them**,** respectively. However, *P. megacephala* was frequently observed contructing semi-soil tent buildings around *R. iceryoides* to prevent them from going distances while they frequently visit them from time to time to collect honeydew (Figure 3.14). *Oecophylla longinoda* and *P. megacephala* were also observed transporting *R. iceryoides* from plant to plant or within plant parts (Figure 3.15). On the other hand, *P. megacephala* was also found to transport *R. iceryoides* down to the roots of the plant *O. lanceolata*.

Pheidole megacephala was observed pulling out predatory larvae of *C. perspicax* from the ovisac of gravid females of *R. iceryoides* (Figure 3.16). *Oecophylla longinoda* foragers were also observed to capture and immobilize adult coccinelids (Figure 3.16). *Pheidole megacephala* was the only ant species observed to occasionally prey on *R. iceryoides* and the main predator of *O. longinoda* under field condition. In the absence of ant-attending *R. iceryoides* in the field large numbers of immature life stages were found trapped in excess amount of honeydew produce by the mealybug (Figure 3.17).

The relationship between mealybug colony size and populations of *P. megacephala* and *O. longinoda* is shown in Figure 3. 18. There was a significant negative correlation between percentage parasitism and populations of *P. megacephala* and *O. longinoda* (Figure 3. 18).

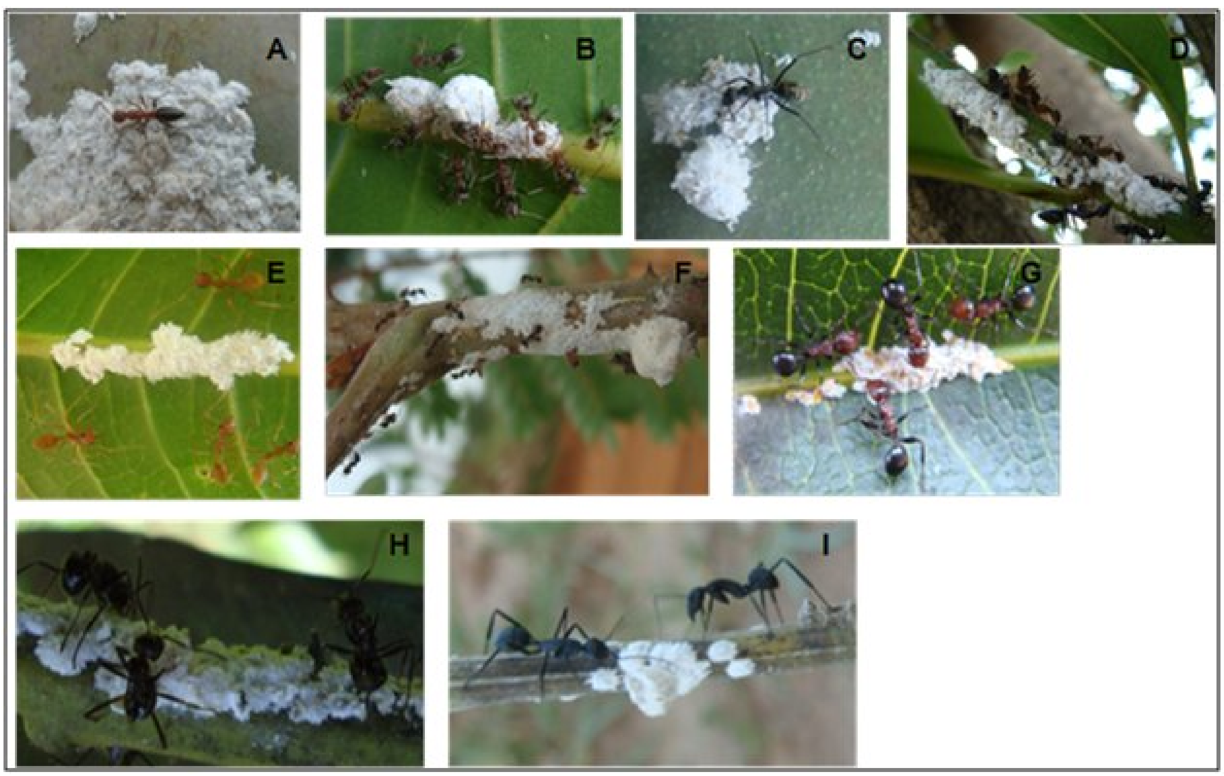

Figure 3. 13: Ant species tending *R. iceryoides* for honey dew on different host plants, (A) *I. purpureus*; (B) *A. custodiens*; (C) *C. flavomarginatus*; (D) *L. humile*; (E) *O. longinoda*; (F) *P. megacephala*; (G) *A. mocquerysi*; (H) *L. depressa* and (I) *C. pennsylvanicus*.

Figure 3. 14: Adult *R. iceryoides* enclosed in an earth-constructed nest of *P. megacephala* to serve as a regularly source for honeydew.

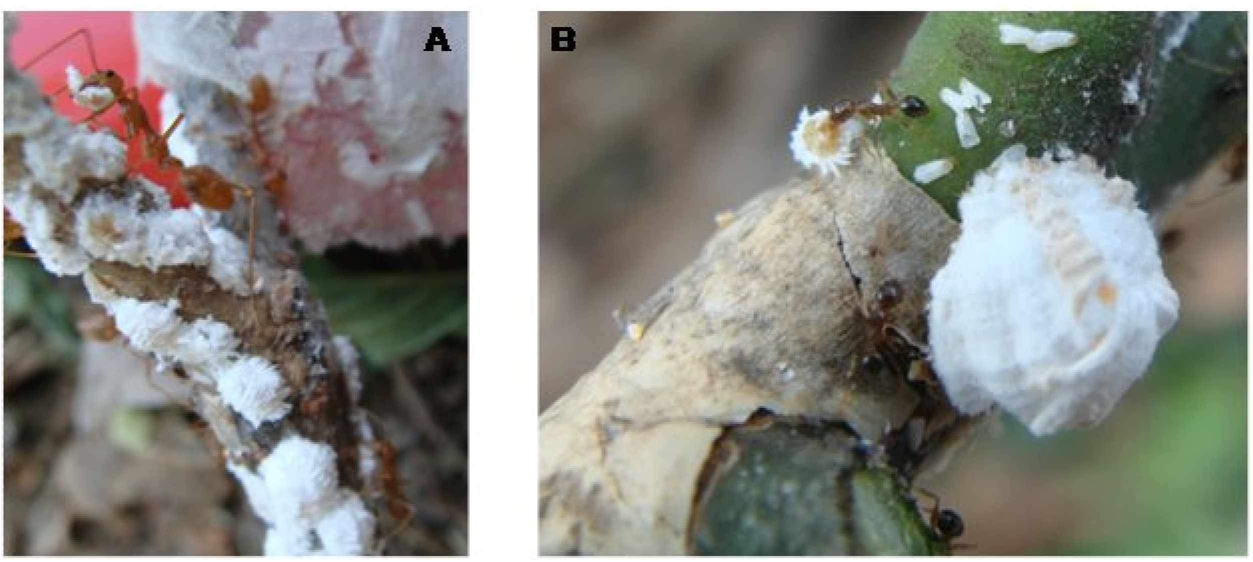

Figure 3. 15: The red weaver ant, *O. longinoda* (A) and *P. megacephala* (B) transporting *R. iceryoides* within the same host plant.

Figure 3. 16: (A): *Pheidole megacephala* foraging for larvae of *C. perspicax* within the ovisac of female *R. iceryoides*; (B): transporting them away as complementary food source and (C) Captive adult coccinelid and attacking *O. longinoda* foragers at the beginning of the immobilization phase of predatory attack.

Figure 3. 17: Immature stages of *R. iceryoides* trapped in excess amount of honeydew.

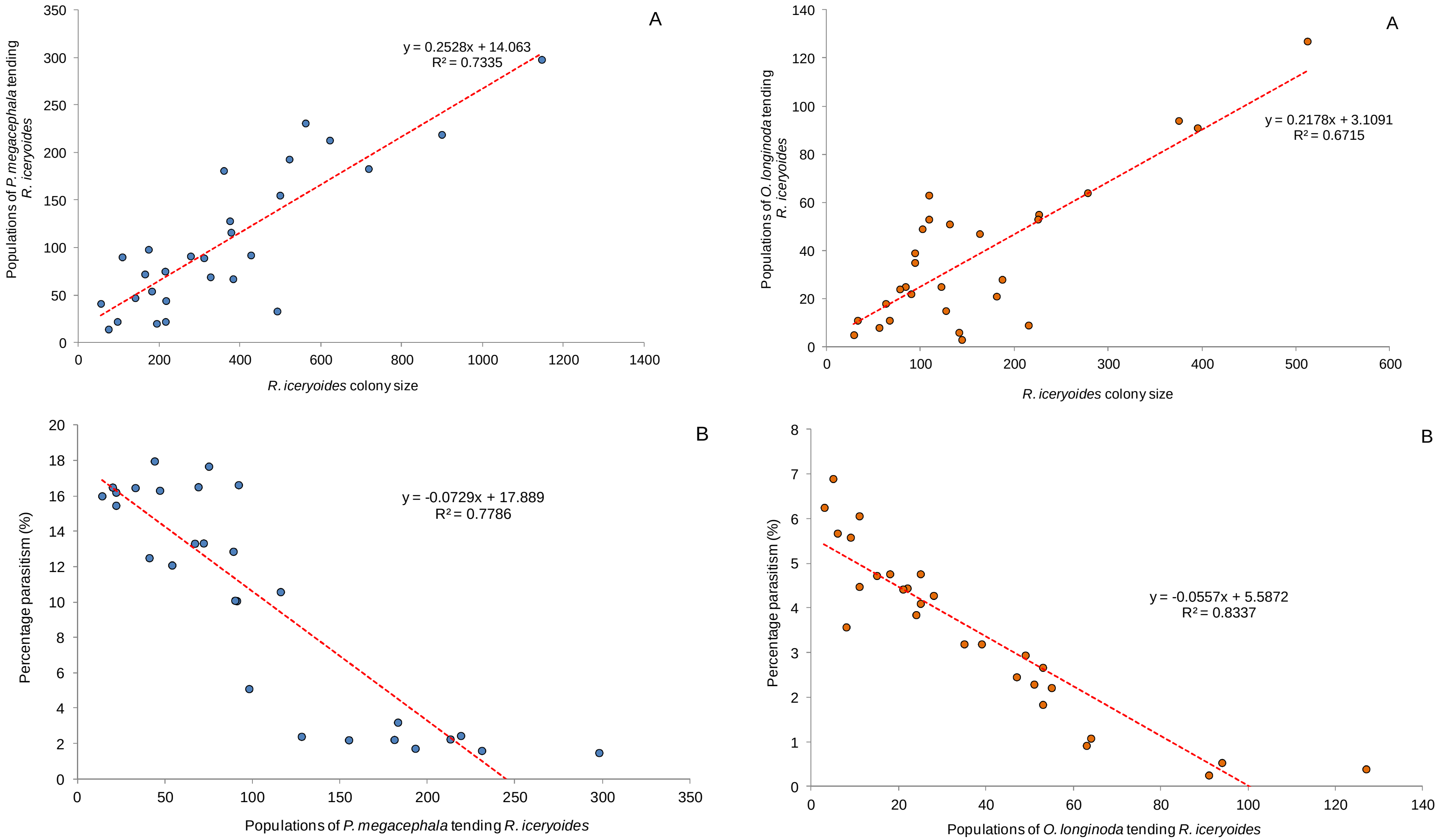

Figure 3. 18: Linear regressions of mealybug colony size (A) and mummified *R. iceryoides* (B), on *P. megacephala* and *O. longinoda* populations in the field.

3.4 Discussion

3.4.1 Distribution

These results showed that *R. iceryoides* is widely distributed across the coastal belt of Kenya and Tanzania. In Kenya, mango infestation extended up to 145 km inland while in Tanzania the pest was found as far as 851 km southwest of the coastal region. In Kenya, heavy infestation was confirmed in Matuga and Kinango both on mango and *P. aculeata*. The high level of *R. iceryoides* infestations in Matuga is particularly disturbing because the locality represents one of the key mango production areas in the country (Griesbach, 2003). Multiple patches of moderate infestation on mango in Mombasa, Kilifi, and Malindi were also observed in Kenya. It is uncertain whether the infestation in these locales is contiguous with that of Matuga or whether they represent discrete populations with limited gene pool but overall, the spread warrants careful attention. In Tanzania, heavy infestations were recorded in Morogoro, Kinondoni, Tanga, Kibaha and Mkuranga on mango (*M. indica*) and three alternative wild host plants, *P. aculeata, O. lanceolata* and *C. sepiaria*. The high level of attack on mango in Kinondoni and Mkuranga demands urgent management attention given the ongoing expansion of the horticulture industry and particularly mango in the region (Nyambo and Verschoor, 2005; Madulu and Chalamila, 2007). These results also provide some evidence of the altitudinal limits of distribution of *R. iceryoides* in both countries. The pest was recorded from as low as 26 meters above sea level (m a.s.l) in Bagamoyo, Tanzania to as high as 901 m a. s. l in Taveta, Kenya.

Although the distribution of insect pests is affected by different abiotic and biotic factors (temperature, humidity, host plants and presence of competitors), despite the wide availability of preferred host plants (*M. indica* and *P. aceleata*) in Madabogo, Dembwa, Wundanyi and Kungu (located at 943 to 1480 m a.s.l), *R. iceryoides* was absent at these sampling sites suggesting that the pest may not occur above these altitudes. The data suggest that *R. iceryoides* may be pre-adapted to surviving in low and mid altitudes similar to its native range of India (Rawat and Jakhmola, 1970; Williams, 1989; Narasimham and Chacko, 1991; Narasimham and Chacko, 1988; Tanga, unpublished data). Although the precise date of introduction of *R. iceryoides* to both Kenya and Tanzania is unknown (Williams, 1989), it is highly probable that current widespread distribution and spread of the mango mealybug populations is assisted by fruit and plant material transported across the region in commercial and private vehicles as is the case with the introduction of *R. invadens* into West and Central Africa (Agounké et al. 1988).

3.4.2 Host plants

Rastrococcus iceryoides was recorded from 29 plants species including cultivated and wild host plants from 16 families, 21 of which are new records for Kenya and Tanzania. The major plant families infested based on level and severity of attack includes Anacardiaceae, Fabaceae, Sapindaceae and Santalaceae. Plants from the family Annonaceae, Euphorbiaceae and Caesalpiniaceae were moderately infested while attack on the Moraceae, Solanaceae, Myrtaceae, Rutaceae, Muscaeceae, Papilionaceae, Simaroubaceae, Verbenaceae, and Sapotaceae was generally low. In its first description, CABI (1995) listed six host plants of *R. iceryoides* in Tanzania namely mango (*M. indica*), cacao (*Theobroma cacao* Linn.), *Albizia lebbeck* Linn. (Indian siris), cotton (*Gossypium* spp.) and rain-tree (*Samanea saman* (Jacq.) Merr.). The additional host plant records from this survey clearly suggests that *R. iceryoides* is an emerging polyphagous invasive mealybug pest in Tanzania and Kenya. Several *Rastrococcus* species have been reported from the different host plant families listed in this study. For example, following the invasion of *R. invadens* in West Africa, Agounké et al. (1988) recorded 45 plant species from 22 families as host of the insect in Togo and Benin. In Nigeria, Ivbijaro et al. (1992) reported *R. invadens* from over 20 species of host plants in 12 different plant families. Host status is a dynamic phenomenon and this list is by no means exhaustive and given that the genus *Rastrococcus* to which *R. iceryoides* belongs attack several host plant species (Williams, 1989; Williams, 2004; Ben-Dov, 1994), it is envisaged that this list is likely to increase.

Mangifera indica recorded the heaviest attack by *R. iceryoides* from among the host plants sampled within the family Anacardiaceae. In *R. invadens*, out of the 45 plant species recorded by Agounké et al. (1988), the author also found that attack on mango was usually high in addition to citrus, banana, breadfruit and guava. Based on the severity of attack, Ivbijaro et al. (1992) also reported that mango breadfruit, guava, sweet orange, lime and grapefruit was the most preferred host plants of *R. invadens* in Nigeria.

Heavy infestation of *R. iceryoides* was recorded among all the plant species sampled from the family Fabaceae. This included *P. aculeata, C. cajan* and *C. sepiaria* in order of severity of attack. In Asia, *P. aculeata* and *C. cajan* are known to be heavily infested by *R. iceryoides* (Ben-Dov, 1994) and these findings concur with previous observations. The heavy infestation of *P. aculaeta* is perhaps surprising given that the plant is not native to Asia, rather an invasive tree indigenous to tropical America (Cochard and Jackes, 2005). Nevertheless, plants that are generally water stressed easily favour high populations of mealybug (Calatayud et al., 2002; Shrewsbury et al., 2004; Lunderstadt, 1998; Gutierrez et al., 1993) and *P. aculeata* is known to thrive in drought prone environment with limited amount of water (Floridata, 2001). Fully grown *P. aculeata* can flower throughout the year (WNS, 2011) and can harbor several successive generations of the pest that will ultimately move to mango, pigeon pea and other cultivated host plants when conditions become favourable. In Kenya and Tanzania, *P. aculeata* also thrives as an ornamental tree, mostly utilized as shade trees around the homesteads and sometimes in close proximity to mango orchards. Management methods targeting *R. iceryoides* must also take into cognizance the presence of *P. aculeata* and possible infestation by *R. iceryoides*.

The cat's claw, *C. sepiaria* is recorded here for the first time as a preferred host harboring large populations of *R. iceryoides*. The observed high levels of infestation on *C. sepiaria* although remarkable is perhaps not surprising given that the plant species is native to tropical Southern Asia. It is an Indo-Malayan species, indigenous to India (the putative home aboriginal of *R. iceryoides*) and Burma, Sri Lanka, eastern China and South-east Asia down to the Malay Peninsular (Brandis, 1907). The observed high levels of infestation on the Fabaceae can also be generally attributed to nitrogen accumulation in the plant family (Harris, 1982). For example, Hogendrop et al. (2006) and, Rae and Jones (1992) reported that the life history parameters of the citrus mealybug, *Planococcus citri* Risso and pink sugar-cane mealybug, *Saccharicoccus sacchari* (Cockerell) were affected by increase level of plant nitrogen content. Hogendrop et al. (2006) demonstrated that higher nitrogen concentrations, in the form of supplemental fertilizers led to an increased in the performance of citrus mealybugs as defined by increased egg loads, larger mature females, and shorter developmental times.

Among the Sapindaceae, *D. borbonica* was heavily infested during the survey and can be considered as important reservoir host plant for *R. iceryoides*. High infestation levels were especially recorded in Kibaha, Tanzania (2253 mealybug/10 cm twig). *Deinbollia borbonica* is a perennial tree that occurs throughout the year and found to be a crucial off-season host plant for *R. iceryoides* particularly when mango, the primary cultivated host plants was off-season. Several plant species from the Sapindaceae family (e.g., *Nephelium lappaceum* Linnaeus, *Harpullia* sp., *Guioa pleuropteris* Blume, *Heterodendrum* sp., and *Nephelium lappaceum* Linnaeus) have also been found to be heavily infested by different *Rastrococcus* species including *R. jabadiu* Williams, *R. neoguineensis* Williams & Watson, *R. spinosus* Robinson, *R. stolatus* Froggatt and *R. tropicasiaticus* Williams, respectively (Williams, 1989; Ben-Dov, 1994; Williams, 2004).

Osyris lanceolata from the family Santalaceae was observed to be heavily attacked by *R. iceryoides*. From literature, there are no records of mealybug attack from this plant species and this report is perhaps the first record of *R. iceryoides* infestation from this plant family. On young plants, in addition to the leaves and twigs, heavy infestation was observed on the stem at 10 cm above the ground level. In Kenya, a root decoction of *O. lanceolata* is used to treat diarrhea while in Tanzania, a decoction of the bark and heartwood is used to treat sexually transmitted diseases and anaemia (Orwa et al., 2009).

In the Annonaceae, *R. iceryoides* was found to attack *A. stenophylla*, *A. senegalensis*, *A. muricata* and *A.squamosa*. Ben-Dov (1994) reported *A. squamosa* as a major host plant of *R. iceryoides* in India but the occurrence of the mealybug on *A. stenophylla*, *A. senegalensis*, *A. muricata* is a new record for the insect. Studies elsewhere have shown that other species of *Rastrococcus* such as *R. invadens*, *R. spinosus* are pestiferous on this family (Ben-Dov, 1994; Boussienguent and Mouloungou, 1993; Williams, 2004). Plant species belonging to the family Annonaceae (and especially *A. muricata*) are economically important export horticultural crops in Kenya and Tanzania. In fact numerous Annonaceous acetogenins from these plants have been reported to possess insecticidal, pesticidal, antimalarial, cell growth inhibitory, antiparasitic, antimicrobial and cytotoxic activities (Fujimoto et al., 1998; Colman-Saizarbitoria et al., 1995; Oberlies et al., 1997; Chih et al., 2001). Recently, these compounds have attracted increased attention as potential antineoplastic agents due to their ability to kill tumour cells (Fang et al., 1993). During the survey, infestations on *A. muricata* and *A. squamosa* by *R. iceryoides* on the stem and leaves was associated with noticeable deformation and distortion of the terminal growth, twisting and curling of leaves, leaf wrinkling and puckering and premature fruit drop. The damage on these important plant species therefore requires careful attention.

Phyllanthus engleri and *F. virosa* from the family Euphorbiaceae were observed to be moderately infested by *R. iceryoides*. This plant species is very common and scattered throughout the Tanzania mainland, Mozambique, Zambia and Zimbabwe (Christopher et al., 2002). There are no records of mealybug attack from these plant species in literature and this is perhaps the first record of *R. iceryoides* attack on this family in Africa. Among the two plant species, *P. engleri* was more infested compared to *F. virosa,* but infestation levels were generally low. In Tanzania, *P. engleri* is an important medicinal plant; the leaves and fruits are chewed together for treating cough and stomach-ache while the roots are boiled and the concoction is drank to treat bilharzias, sexually transmitted diseases (STDs), menstrual problems and abdominal and chest pain (Christopher et al., 2002).

Two crops in the family Myrtaceae and Rutaceae that had low to moderate infestation records namely *Citrus* spp. and *C. aurantifolia*; and *P. guajava*, respectively warrant discussion. The family Myrtaceae is known to host a variety of mealybug species worldwide including several species of *Rastrococcus* (Williams, 2004; Ben-Dov, 1994) but *P. guajava* was the only plant species sampled in our study. Moderate infestation of *R. iceryoides* was recorded on this plant in Kenya and Tanzania. In West and Central Africa, *P. guajava* has also been reported as a major host plant of *R. invadens* (Ivbijaro et al., 1992). In the Rutaceae, *R. iceryoides* was only recorded from *C. aurantifolia* in Kenya while in Tanzania; the insect was recorded from *Citrus sinensis* and *C. aurantifolia.* Although infestation was generally low in this study, reports from other studies indicate that several citrus species have been recorded as major host plants of mealybugs from the genus *Rastrococcus*. For example, *R. invadens* is reported to be a major host of *Citrus paradisi* Macfad, *C. maxima* Merr., *C. limon* (L.) Burm. f., *C. reticulata* Blanco, *C. grandis* Osbeck (Williams, 1989; Ben-Dov, 1994; Boussienguent and Mouloungou, 1993), in addition to *C. sinensis* and *C. aurantifolia*, (Ivbijaro et al., 1992).

3.4.3 Parasitoids

Several parasitoid species have been reared from *R. iceryoides* (Tandon and Lal, 1978; Narasimham and Chako, 1988). In this study a total of six indigenous parasitoid species were recovered from *R. iceryoides* in Kenya and Tanzania with *A. pseudococci* clearly the most dominant and widespread in both countries. Despite its widespread distribution across the different localities sampled, percentage parasitism did not exceed 20%. Tandon and Lal (1978) listed *R. iceryoides* as host mealybug of *A. pseudococci*, however, Noyes and Hayat (1994) noted that this was a misidentification. The current study however confirms that *R. iceryoides* is an important host insect of *A. pseudococci* and should be considered a suitable candidate for biological control of the insect pest. Globally, *A. pseudococci* have been reported from twelve countries (Noyes and Hayat, 1994) excluding the countries of this survey, which implies that the results presented herein add Kenya and Tanzania to the list of countries where the parasitoid exists. In Texas, Europe and Pakistan, *A. pseudococci* has been credited with successful biological control of *Planococcus citri* on citrus and grapes (Tingle and Copland, 1989; Noyes and Hayat, 1994). Among all the host plant species sampled, the highest percent parasitism by *A. psuedococci* on *R. iceryoides* was from mealybugs infesting mango and *P. aculeata*. This study provides information that predicts the distribution of parasitism across host plants, which is crucial for rational conservation and augmentation of the parasitoid. Therefore, management of this parasitoid, through either augmentation and or conservation may be able to concentrate parasitism where and when it will exert the most control. In the case of *R. iceryoides*, one such target location would be *P. aculeata* (since it is used as ornamental shade plants by growers) in the vicinity of mango orchards. Augmentative releases and or conservation of *A. pseudococci* directed at *R. iceryoides* before their spread into mango crop should be both an effective and timely strategy for suppressing the population of the mealybug.

Parasitism by the other parasitoid species encountered during the survey did not exceed 1%. The reason for the general low level of parasitism by the parasitoid species is not well understood. Many factors including host and parasitoid suitability, age, sex, climatic conditions and host plants influence parasitism success. Indeed, all these factors have been found to be crucial for successful parasitism by most encyrtid parasitoids on mealybugs (Blumberg, 1997; Islam and Copland, 1997; Sagarra and Vincent, 1999; Daane et al., 2004a; Daane et al., 2004b; Karamaouna and Copland, 2000, Cross and Moore, 1992; McDougall and Mills, 1997; Persad and Khan, 2007). Although the need to conserve all the natural enemies reared from *R. iceryoides* will be critical for the overall management of the insect, the lack of efficient coevolved natural enemies capable of suppressing *R. iceryoides* populations to levels below economically damaging levels calls for exploration for natural enemies in the putative aboriginal home of Southern Asia and their introduction into Africa for classical biological control of the pest. Such an approach should be considered as high priority in seeking a long term solution to the management of *R. iceryoides* in Africa.

Ninteen hyperparasitoid species attacked *R. iceryoides* parasitized by the primary parasitoids with *C. conjugalis* and *C. cyanonotus* developing high populations. Field survey of *R. invadens* in West Africa also revealed several hyperparasitoids attacking mealybugs parasitized by *G. tebygi* with four species developing high populations (Boavida and Neuenschwander, 1995). In West Africa, Moore and Cross (1992) identified *Chartocerus hyalipennis* as the major secondary parasitoids associated with *Anagyrus mangicola* Noyes and *G. tebygi*. In a similar study on the hyperparasitism of both *G. tebygi* and *Epidinocarsis lopezi* (DeSantis) in Togo, *C. hyalipennis* rather than *M. leopardina* contributed mainly to hyperparasitism of the two parasitoids (Agricola and Fisher, 1991). *Cheiloneurus* species, *Marietta leopardina* and *Pachyneyron* species are believed to be hyperparasites through *Anagyrus* spp. and *L. dactylopii* (Whitehead, 1957) while the *Tetrastichus* sp has been reported as hyperparasites of *R. invadens* through *G. tebyi* in Africa (Ukwela, 2009). Most of the hyperparasitoid species from the family Aphilinidae recorded in our study has been reported as hyperparasites of *R. iceryoides*, among other species of mealybugs in India (Hayat, 1998). Low parasitism of *R. iceryoides* by the primary parasitoids can be attributed in part to the presence of hyperparasitoids. Similar findings of low parasitism of *R. invadens* by *G. tebygi* due to activities of hyperparasitoids under laboratory and field conditions have been reported (Agricola and Fischer, 1991; Moore and Cross, 1992). Secondary parasitism (hyperparasitism) is a common phenomenon in insect host-parasitoid systems and a high percentage of secondary parasitism of Pseudococcidae is not unusual in natural and agricultural habitats with economically important crops like mango and citrus orchards (Ukwela, 2009). Secondary parasitoids are generally assumed to have major implications for the biological control of pest insects because of their negative effects on the population dynamics of the beneficial primary parasitoids (Lucky et al., 1981; May and Hassell, 1981; Hassell and Waage, 1984; Hassel, 1978; Greathead, 1986), although few studies have demonstrated this conclusively (Sullivan, 1987). The knowledge of the level of hyperparasitism of the primary parasitoids by the hyperparasitoids can be useful in planning further biological control activities on *R. iceryoides*.

3.4.4 Predators

Among the predators recovered from *R. iceryoides* colonies the predaceous drosophilid *C. perspicax* was the most abundant species. *Cacoxenus perspicax* has also been reported to be associated with only high pink hibiscus mealybug, *Maconellicoccus hirsutus* (Green) (Hemiptera: Pseudococcidae) densities in Australia (Goolsby et al., 2002), which is in accordance with our observations. However, the host range of *C. perspicax* and its impact on *M. hirsutus* is not known. An extensive search of the literature failed to reveal any published work why these flies are strongly attracted to high density mealybug colonies except that by Nicholas and Inkerman (1989). Nicholas and Inkerman (1989) explains that mealybug exudates are highly acidic (pH 3) and their continuous production allows ethanol production by yeast cells, which in turn promotes the rapid growth of acetic acid bacteria. The coproduction of ketogluconic acids and γ-pyrones with associated lowering of the pH also increases the selection against most other microorganisms, including the mealybug parasite *Aspergillus parasiticus*. In contrast to suppressing mold attack, the acetic acid bacteria and yeast cells stimulate the predation of mealybug by larvae of *C. perspicax* (Inkerman et al., 1986). If a parallel can be drawn with the fruit fly larvae that feed on necrotic prickly-pear (*Opuntia* spp.) tissues (Baker et al., 1982), then acetic acid bacteria alone could be sufficient for the complete development of the flies (Vacek, 1982). Baker et al., (1982) further reported that yeast species can sustain flies, and yeast produce volatile compounds that are particularly important attractant to fly. This report by Baker et al. (1982) confirms the possible reason why these flies were mostly found in heavily infested orchard with significant impact on the populations of *R. iceryoides*.

The larvae of *C. perspicax* were particularly active voracious predators of eggs within the ovisac to free-living adults in undisrupted colonies. Within the ovipositing female mealybug ovisac, 5 to 8 larvae were recovered. However, significant behavioural similarities were observed between *Cacoxenus* sp., *Leucopis (Leucopella) africana* Malloch and *Leucopis (Leucopella) ardis* Gaimari & Raspi. The 1st and 2nd instar larvae were observed to have low dispersal capacity and both stages tend to stay within *R. iceryoides* colony, while the 3rd instar larvae were more mobile tunnelling through the ovisac and exposing the *R. iceryoides* eggs to adverse weather conditions. As a result, the real mortality rates inflicted by colony disruptive behaviour by these predatory larvae were probably higher than their simple consumption rate. At present, difficulty in rearing these predators is the major obstacle in their study to ascertain their principal role in biological control.

Coccinellidae (Coleoptera) was the major group with the highest number of species but showed a highly generalistic feeding behaviour. This could probably be the reason why coccinelids are rarely as successful in the biological control of mealybug as hymenopterous parasitoids (Moore, 1988). Among the predatory beetles, the only species that showed some level of host specificity was *Hyperaspis bigeminata* Randall, whose larvae and adults chewed holes through the felt-like test of the ovisac and feeding exclusively on the eggs within the ovisac of gravid female *R. iceryoides*. Apart from *Chilocorus nigrita* and *Cryptolaemus montrouzieri,* the other 16 species are new records for the East Africa fauna preying on *R. iceryoides*. The presence of the *Rodalia* sp. was probably due to infestation by *I. seychellarum*, since they have been widely used in the control of *I. seychellarum* in other parts of the world (Butcher, 1983; Caltagirone and Doutt, 1989; Waterhouse, 1993).

3.4.5 Ants association with *R. iceryoides*

Eleven species of ants were found to be closely associated with *R. iceryoides* in the field. Several authors have already pointed out the negative impact of ants, notably, *L. humile*, *Crematogaster* spp. and *Anoplolepis* spp. on mealybug parasitoids (Horton, 1918; Kriegler and Whitehead, 1962; Smit and Bishop, 1934; Steyn, 1954; Samways et al., 1982). For example, Joubert (1943) noted that the parasite *Coccophagus gurneyi* Compere was severely hindered by *L. humile* in controlling *P. maritimus* (Ehrhorn) and Compere (1940) with the incidence of *Saisetia oleae* Olivier in the Cape between 1936 and 1937 greatly increasing due to the presence of *L. humile*. This implies that ants might have interfered with the parasitoid activities either by direct attack (including consumption of adults, larvae or eggs) or incidental disturbance, as such causes them to lay fewer eggs than would probably happen in the absence of ants (Martinez-Ferrer et al., 2003; Barlett, 1961). Samways et al. (1982) found that *A. custodiens*, while tending soft brown scale on citrus trees caused incidental increases in the population of red scale

Aonidiella aurantii (Maskell). This observation is in accordance with our findings, as mealybug populations tended by *P. megacephala* and *O. longinoda* was found to increase with increased ant density. Percentage parasitism on the other hand was found to reduce significantly with increase in *P. megacephala* and *O. longinoda* density. However, there is unequivocal evidence that ants can protect scale insects from natural enemies, especially parasitic wasps (Bartlett, 1961; Buckley and Gullan, 1991; Bach, 1991) and predatory beetles (Das, 1959; Bartlett, 1961; Burns, 1973; Bradley, 1973; Hanks and Sadof, 1990; Bach, 1991).

The different ant species recorded during the study were observed tending the mealybug for honey. Several other studies confirm that honeydew produced by many mealybugs, provides ants of numerous species with a stable source of energy (Way and Khoo, 1992; Nixon, 1951; Way, 1963; Buckley, 1987a; Buckley, 1987b). Most associations are facultative for both partners but some associations are apparently obligate (Tho, 1978; Ward, 1991) and many ants that tend mealybugs to obtain honeydew have also been reported to prey on them, either regularly or only under particular circumstances (Shanahan and Compton, 2000; DeBach et al., 1951; Folkina, 1978). However, ants whether regarded as pest species or not, frequently affect plant health and reproductive output indirectly via the phytophagous insect that they tend and defend. The mealybugs remove plant sap, which led to damaged plant tissues or injection of toxins (Nixon, 1951; Steyn, 1954; Briese, 1982), and generally contaminate fruit and foliage with honeydew that becomes blackened with sooty moulds which may impair photosynthesis and sometimes lead to leaf abscission.

In this study, it was also found that the different ant species removed honeydew, which improved the sanitation of the mealybug aggregations by reducing physical fouling caused by both the honeydew and the sooty moulds that grew on them. In colonies of mealybug that were not attended by ants, younger nymphal stages (particularly, crawlers) become engulfed in their own honeydew and die in large numbers. Several authors have confirmed these findings and demonstrated that the removal of honeydew prevent contamination, which is especially detrimental to first-instar nymphs (Cudjoe et al., 1993; Daane et al., 2006b; Daane et al., 2007; Gullan and Kosztarab, 1997; Moreno et al., 1987; Flander, 1951; Way, 1954b; Bess, 1958; Das, 1959). However, it is not clear whether death of the mealybugs resulted from asphyxiation or from some effect of the fungal growth which usually follows honeydew contamination.

During this survey *O. longinoda* and *P. megacephala* were observe to transport *R. iceryoides* to new feeding sites on the same plants or to uninfested plants, thus greatly facilitating the spread of *R. iceryoides* populations. Records of scale insect transport by *O. smaragdina* and *O. longinoda* has been reported by Das (1959) and Way (1954b). When mealybug populations were low, *P. megacephala* and *O. longinoda* built protective structures over *R. iceryoides*, which they were attending possibly to limit predatory and parasitic attacks. Smit and Bishop (1934) argued that the shelters were of primary benefit for the ants although they also conferred limited benefit to the mango mealybug by reducing exposure to natural enemies. This could be true because on many occasions during this study, parasitized mealybugs were collected from them and even predatory beetle larvae fed on adult female ovisacs underneath these shelters, particularly within fruit bunches. Other authors have reported that these shelters are of benefit to the scale insects by providing protection from bad weather (Briese, 1982; Way, 1954b), excluding predators and parasitoids (Wheeler, 1910; Strickland, 1950; Way, 1954b; Clarke et al., 1989; Nixon, 1951; Das, 1959; Way, 1963; Sugonyayev, 1995) and reducing the incidence of disease.