

**COMPARATIVE LIFE HISTORY OF COCONUT SCALE INSECT,
Aspidiotus rigidus Reyne (HEMIPTERA: DIASPIDIDAE),
ON COCONUT AND MANGOSTEEN**

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ABSTRACT

The devastation of millions of coconut palms caused by outbreak infestation of the invasive Coconut Scale Insect (CSI) *Aspidiotus rigidus* Reyne, has posed a serious threat to the industry in the Philippines. The life history of *A. rigidus* on coconut and mangosteen was comparatively studied to understand the effects of host-plant species on its development, to investigate potential host-suitability factors that contributed to its outbreak infestation, and to gather baseline information on the development and characteristics of this pest. The study was conducted at the Institute of Plant Breeding, College of Agriculture and Food Science, University of the Philippines Los Baños. Insect size (body and scale) was not significantly different on both hosts during egg, crawler, white cap, pre-second and second instar stages, as well as during male pre-pupal, pupal and adult stages. The female third instars and adults, however, were bigger on mangosteen than on coconut. At the end of second instar, sexual differentiation was very visible wherein parthenogenic females further undergone two developmental stages: third instar and adults that feed permanently on the leaves. Males undergone three stages: pre-pupa, pupa and winged adults. Males normally have shorter life cycle and smaller bodies than the females. Developmental rate of *A. rigidus* before second instar was not significantly different on both hosts. However, stages approaching to insect maturity of both males and females developed faster on coconut. As a result, *A. rigidus* life cycle was shorter on coconut than on mangosteen. Moreover, insect fecundity was higher on coconut due to longer female longevity. More females than males were observed on mangosteen while the sex ratio was almost equal on coconut. These results suggest that coconut provides better nourishment and living conditions that support shorter life cycle and augment insect development, longevity and reproduction which are potential host-suitability factors that contributed to the outbreak. Mangosteen is an effective host-plant to rear *A. rigidus* pure culture as validated also by DNA sequence analysis. Information generated can be used for monitoring and timely management of the pest, in studying host-insect interaction, and in mass rearing for future studies.

Key words: CSI, *Cocos nucifera*, *Garcinia mangostana*, morphometry, developmental rate

INTRODUCTION

So called as the ‘Tree of Life’, the coconut (*Cocos nucifera* L.) is an important economic crop largely grown in tropical and subtropical countries. The Philippines considerably has the world’s largest agricultural area devoted to coconut farming and next only to Indonesia in terms of production. The country has about 12 million hectares of agricultural land and 3.25 million hectares of which is planted with coconut. From these coconut farms, about 330 million fruiting trees producing 15,207 billion nuts per year was reported (PSA, 2016). From 1997 to 2014, the highest copra production was recorded in 2010 with an average of 3.03 million metric tons. The Philippine Coconut Authority (PCA) also reported that 26 million Filipinos rely on the coconut industry. However, the devastation of millions of

palms caused by outbreak infestation of Coconut Scale Insect (CSI) species *Aspidiotus rigidus* has posed a serious threat to the coconut industry in the Philippines. This invasive species of CSI voraciously sucks the leaf sap resulting to yellowing and drying of leaves and eventually, plant death. The insect species was initially observed in 2009 in Tanauan, Batangas (Adalla and Sison, 2014) and was initially misidentified as *Aspidiotus destructor* (Molet, 2015) since it was the only previously known CSI species in the country. This species, however, is not considered detrimental to crops due to the presence of natural enemies (Watsons et al. 2015). Further investigations in the outbreak areas especially in the south of Luzon island (CALABARZON) and Basilan province in Mindanao revealed that *A. rigidus*, an introduced CSI species, was the cause of severe damage on coconut palms (Adalla and Sison, 2014; Watsons et al. 2015). This insect is not preferred by the natural enemies of *A. destructor* due to its tough scale covering that is difficult to pierce with their mandibles (Reyne, 1948). *A. destructor* and *A. rigidus* are closely related CSI species and only differ on few traits. *A. rigidus* was originally classified as a subspecies of *A. destructor* and was elevated later on as a new species (Reyne, 1947; Molet, 2015). *A. rigidus* had also caused severe outbreak in the Sangi Island (North Celebes) in Indonesia when it was still a subspecies (Reyne, 1948). Monocotyledonous plants such as palms and *Musa* sp. are generally the host plants of this sucking insect and so far, mangosteen (*Garcinia mangostana*) is the only known dicotyledonous alternate host plant (Watsons et al. 2015).

Coconut is a favored host of both *A. rigidus* and *A. destructor* but on mangosteen, only *A. rigidus* thrives (Cayabyab et al. 2016; Reyne, 1948; Watsons et al. 2015). The *A. rigidus* outbreak has also imposed a serious threat on mangosteen farms in the Philippines. It was even surmised that *A. rigidus* was first observed on this plant before on coconut. Mangosteen is an industrial crop regarded for its delicious fruit and principally, for its important pharmaceutical uses e.g., as food supplements, giving it the popular moniker ‘Queen of fruit’. Majority of growing areas and vast plantations of this crop in the Philippines are found in the Mindanao island, the southern part of the archipelago. Due to its vital economic and nutritional value, this crop is now being planted in Luzon, the northern Philippines. On coconut palms and mangosteen trees, the coconut scale insect is commonly found on the lower surface or underside (abaxial) of the leaves. The presence of stomata in this area create a humid environment which favors insect growth and development (Reyne, 1948). In coconut, the insects target first the lower fronds keeping the upper fronds green, but in extremely heavy attacks (20-30 scales per cm² or 40-60 million insects per coconut palm; Reyne, 1948), all parts of the coconut shoot including sometimes the seednuts are encrusted by *A. rigidus*. Despite the severity of the issue, there is still scarce knowledge about the scale insect and its host preference which can be of help in understanding the irregularity on host range (e.g., mangosteen) (Watsons et al. 2015).

As an essential approach towards full understanding of this invasive species, life history of *A. rigidus* on coconut and mangosteen was comparatively studied in this paper, to understand the effects of two different host-plant species on the development, morphometry and other traits of *A. rigidus*; to investigate potential host-suitability factors that contributed to its outbreak infestation; and to gather baseline information on the development and characteristics of this pest. These are the information that can be used for effective pest monitoring and in adopting timely management strategies to mitigate the infestation, especially on these two important industrial crops.

MATERIALS AND METHODS

Collection and identity validation of *Aspidiotus rigidus*. *A. rigidus*-infested coconut leaves were collected from the IPB Coconut experimental field at Brgy. Tranca, Bay, Laguna which was characterized with high *A. rigidus* infestation (Fig. 1a). To further assure that *A. rigidus* was the predominant species, if not the only CSI species present, the infested leaves were first examined for the distinct morpho-characteristic of female *A. rigidus* before using it as source of insect crawlers (1st instar). The identity of the insects was validated through the presence of egg casings that arrange in white crescent shape/formation near the pygidium under one-half of the scale cover of typical healthy

adult female insects (Watsons et al., 2015) (Fig. 2g). This is one unique characteristic that differentiates *A. rigidus* from other species of CSI such as *A. destructor*.



Fig. 1. Infestation of *A. rigidus* on host plants. (a) Crawler source palms in IPB Coconut experimental field, Brgy. Tranca, Bay, Laguna, (b) *A. rigidus*-infested coconut leaves clipped on the underside leaves of mangosteen host, and (c) *A. rigidus*-infested mangosteen leaves clipped on the underside leaves of coconut host to introduce crawlers inside a glasshouse.

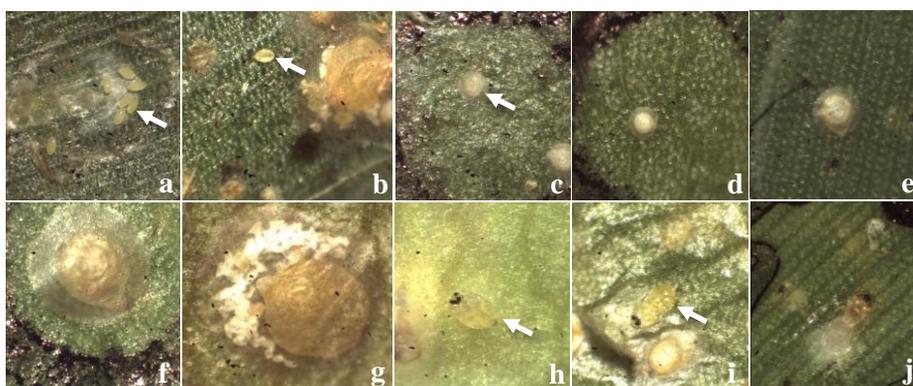


Fig. 2. Life cycle of *A. rigidus*. (a) Eggs, (b) crawler, (c) white cap stage, (d) pre-second instar, (e) second instar; Female: (f) third instar, (g) egg-laying adult; Male: (h) pre-pupa*, (i) pupa*, (j) winged adult (45x magnification). *scales removed.

Rearing of *A. rigidus* on mangosteen and introduction to host plants. Clean and uninfested coconut (Laguna Tall variety) and mangosteen (unknown farmer's variety) seedlings of one year of age were used as host plants in this study. Since *A. rigidus* may live in complex with other CSI species in the collected coconut leaves, pure culture of *A. rigidus* was first conducted through differential rearing using separate mangosteen seedlings. Through this, contamination of *A. destructor* was avoided during crawler introduction to coconut host. Pure culture is possible since only *A. rigidus* thrives on mangosteen (Reyne, 1948; Watsons et al., 2015). Inside the glasshouse, *A. rigidus* rearing was established by clipping (using paper clips) the infested coconut leaves (cut in approximately 7 inches long) on the abaxial or underside leaves of mangosteen seedlings, where the insect could favorably grow and reproduce (Fig. 1b). Mangosteen seedlings were placed on top of grill benches wherein nets were installed as cover/roofing to provide slight shading from sunlight. Boxes filled with water were placed underneath the benches to maintain a high relative humidity (RH) which is preferred by the insect (Reyne, 1948). The second generation *A. rigidus* crawlers from mangosteen rearing was introduced to coconut seedlings following the same clipping method previously described (Fig. 1c). Alongside, infestation on mangosteen seedlings was also done following the same procedures except that the infested leaves from the IPB coconut field (Fig. 1a) were the source of crawlers. After 48 hours, the clipped leaves were removed to obtain crawlers with uniform age that have transferred on both hosts. At this period, insects were permanently attached in the underside of the host's leaves. Seedlings

with good infestation of healthy *A. rigidus* were selected and brought inside the rearing laboratory for observation, data gathering, and documentation at the Entomology Section, Institute of Plant Breeding, College of Agriculture and Food Science, University of the Philippines Los Baños, College, Laguna. The infested seedlings used were returned to the glasshouse every after data gathering/documentation to allow insect development.

Life history monitoring and documentation. Thirty (30) live insects, well-spaced on the leaves, were selected and encircled using a fine marker pen for the ease of observation. The insects were regularly monitored and documented throughout their life cycle by viewing them directly under a digital dissecting microscope (Optika microscope model SZM-LED1, Italy) while still attached on the host's leaves. Images were taken and measurements were performed using the microscope's software (OptikaISview v.3.6.6). Morphometry (length and breadth/width in millimeter, mm) of the various instars or stages of *A. rigidus* were measured and their corresponding developmental rates (in days) were counted. In addition, data regarding the number of eggs laid (fecundity), male to female ratio, female longevity, as well as other notable observations or changes on the insect's characteristics at different life stages were recorded throughout the experiment. Data gathered were statistically analyzed using RStudio v.1.0.136. The estimated insect and scale size/area (computed by multiplying the length and width) and the developmental rate were graphed using GraphPad Prism v.8.1.1.

RESULTS AND DISCUSSION

Life cycle

Eggs and crawler emergence. Inside the scale, eggs were laid one at a time by the adult female at a regular interval through a single large opening at the pygidium. Freshly laid eggs were light yellow and as they mature, black eye spots can be observed under the microscope (Fig. 2a). Mean length and width of eggs observed on coconut was 0.20mm and 0.10mm, respectively which were slightly bigger than on mangosteen with 0.18mm and 0.10mm, respectively (Table 1). Hence, crawlers that emerged were also slightly bigger on coconut (0.21mm and 0.13mm, respectively) than on mangosteen (0.20mm and 0.13mm, respectively) (Table 1). However, statistical analysis implicates that egg and crawler sizes were not significantly different on both hosts (Fig. 3). The crawlers (Fig. 2b) emerged by breaking the anterior of the egg casing and gradually pushed themselves out, sometimes with in-between breaks. They stayed inside the mother's scale for up to 24 hours before exiting through the scale cover. When expelled forcefully through removal of the mother's scale, some of them crawled to the nearest adult females and attempted to enter their scales. Though not significantly different on both hosts, eggs produced by female insects reared on mangosteen hatched slightly faster (2 days average) while on coconut, eggs usually hatch after 3 days (2.5 days average) (Table 2). Compared to *A. destructor*, eggs of *A. rigidus* hatch generally faster since they are laid at an advanced developmental stage (Watsons et al., 2015). When the crawlers were out of the scale covering, they crawled over the leaves quite actively to search for a suitable place to attach themselves and often made circular movements. During crawler development, the egg size increased and after hatching, white, semi-transparent and thin empty egg casings were collected near the pygidium and formed a crescent shape (Fig. 2g). This is one characteristic that distinguishes *A. rigidus* from other CSI species and is widely used to morphologically validate its identity. In contrast, the empty egg casings of *A. destructor* are scattered in the surrounding of mother's body. Crawlers are characterized with well-developed appendages, antennae and eyes; oblong shaped and yellowish in color. Crawler or 1st instar stage is the major dispersal phase of CSI since they are very lightweight and can freely move. They are easily carried or transported by wind which facilitates widespread infestation of this insect pest. Some crawlers that failed to exit from the mother's scale died inside, probably, due to the strong attachment of the scale unto the leaves and the crowding of eggs, crawlers, and egg casings. In severe infestation, overlapping of scales can be observed wherein some insects are buried under many scales.

Comparative life history of coconut scale insect.....

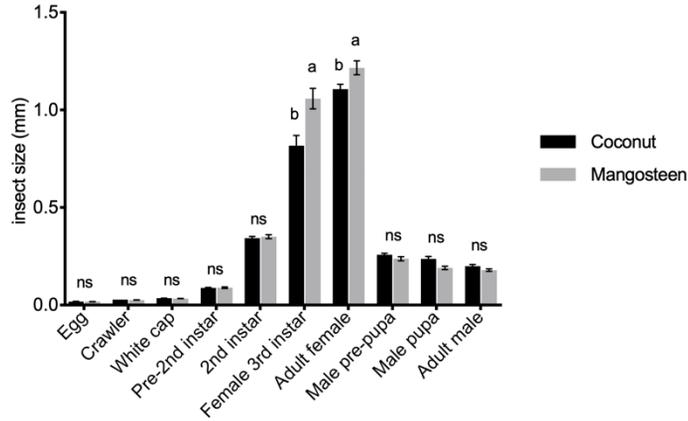


Fig. 3. Insect size/area (mean±SEM) of different developmental stages of *A. rigidus* reared on coconut and mangosteen host plants. Means with different letters for each developmental stage differ significantly at $\alpha=5\%$; ns=not significant.

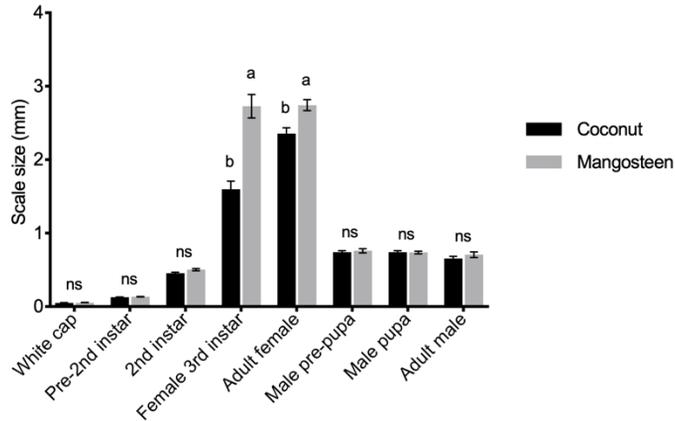


Fig. 4. Scale size/area (mean±SEM) of different developmental stages of *A. rigidus* reared on coconut and mangosteen host plants. Means with different letters for each developmental stage differ significantly at $\alpha=5\%$; ns=not significant.

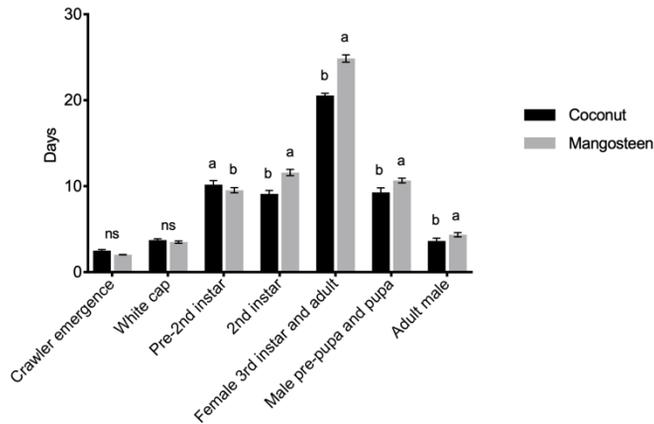


Fig. 5. Developmental rate (mean±SEM) of *A. rigidus* reared on coconut and mangosteen host plants. Means with different letters for each developmental stage differ significantly at $\alpha=5\%$; ns=not significant.

Table 1. Morphometry (mm) of *A. rigidus* on mangosteen and coconut hosts ($n=30$).

Developmental stages	Mangosteen				Coconut			
	Scale (mm)		Body (mm)		Scale (mm)		Body (mm)	
	L±SD	W±SD	L±SD	W±SD	L±SD	W±SD	L±SD	W±SD
Egg	-	-	0.18±0.01	0.10± 0.01	-	-	0.20±0.01	0.10±0.01
Crawler (1st instar)	-	-	0.20±0.01	0.13± 0.01	-	-	0.21±0.01	0.13±0.01
White cap	0.24±0.03	0.23±0.03	0.21±0.02	0.16± 0.02	0.23±0.02	0.22±0.03	0.21±0.02	0.16±0.01
Pre-2nd instar	0.38±0.04	0.36±0.03	0.33±0.04	0.27± 0.03	0.37±0.03	0.35±0.03	0.33±0.02	0.27±0.02
2nd instar	0.74±0.07	0.68±0.07	0.64±0.06	0.54± 0.05	0.71±0.03	0.64±0.04	0.64±0.03	0.54±0.03
♀3rd instar	1.71±0.33	1.55±0.31	1.13±0.18	0.92± 0.14	1.37±0.31	1.13±0.22	1.00±0.19	0.80±0.15
♀Adult	1.80±0.15	1.52±0.15	1.21±0.14	1.00± 0.07	1.70±0.14	1.38±0.16	1.17±0.07	0.95±0.07
♂Pre-pupa	0.96±0.08	0.79±0.07	0.65±0.06	0.37± 0.03	1.01±0.04	0.74±0.06	0.66±0.04	0.39±0.02
♂Pupa	0.96±0.08	0.77±0.06	0.63±0.08	0.30± 0.04	1.02±0.04	0.73±0.06	0.70±0.06	0.34±0.04
♂Adult (inside scale)	0.94±0.06	0.75±0.09	0.81±0.05	0.22± 0.02	1.01±0.07	0.65±0.09	0.85±0.05	0.23±0.03

SD=standard deviation; L=length; W=width

Table 2. Developmental rate (days) of *A. rigidus* on mangosteen and coconut hosts ($n=30$).

Developmental stages	Mangosteen	Coconut
	Days±SD	Days±SD
Crawler emergence	2.03±0.18 ^{ns}	2.50±0.72 ^{ns}
White cap	3.50±0.81 ^{ns}	3.73±0.85 ^{ns}
Pre-2nd instar	9.53±1.61 ^b	10.20±2.5 ^a
2nd instar	11.60±1.91 ^a	9.11±2.08 ^b
♀3rd instar and adult	24.87±2.32 ^a	20.57±1.33 ^b
♀Total life cycle	52	46
♂Pre-pupa and pupa	10.67±1.01 ^a	9.29±1.87 ^b
♂Adult (inside scale)	4.36±0.77 ^a	3.64±1.07 ^b
♂Total life cycle	42	38

SD=standard deviation; ns=not significant; mean values followed by different letters differ significantly at $\alpha=5\%$

White cap stage and pre-second instar. Crawlers were allowed to establish for 48 hours in the abaxial side of the leaves of both hosts. After they found suitable areas in the leaf for fixation and insertion of rostrum, the white cap stage started wherein they produced whitish thread of wax intertwined together through body movements especially in the pygidium. This turned into a thin waxy scale covering upon incorporation of some fluid secreted by the insect (Reyne, 1948) (Fig. 2c). At this stage, they became immobile and their body sizes increased. Though not significantly different on both hosts, this stage lasted for an average of 3.5 days on mangosteen which was slightly faster than on coconut with 3.7 days average (Table 2; Fig. 5). Hereafter, the insect undergone pre-second instar period (also referred as ‘nipple stage’) wherein concentric circles on the scale became discernible, scale and body sizes increased, body appeared greenish and somewhat swollen, and the insect prepared for its first molt to develop into second instar (Fig. 2d). Pre-second instar on mangosteen completed in 9.53 days average which was significantly faster than on coconut with 10.2 days average (Table 2, Fig. 5). In terms of body size (mean length and width), it was quite equal on both hosts during white cap stage (0.21mm and 0.16mm, respectively) and pre-second instar (0.33mm and 0.27mm, respectively) (Table 1; Fig. 3). Though not significantly different on both hosts, scale coverings were slightly bigger on mangosteen during white cap stage (0.24mm and 0.23 mm, respectively) and pre-second instar (0.38mm and 0.36mm, respectively) than on coconut (Table 1; Fig. 4). During pre-second instar, yellow spots due to feeding can be seen already on the upper part of the leaves (adaxial). Generally, the insects preferred the folded areas of the leaves such as on coconut, most of them attached near the midrib or veins; while on mangosteen, the insects were found near the midrib and linings, and close to the petioles of the leaves. Under normal field conditions, they are typically observed on the underside of the leaves due to its preferable humid environment caused by the presence of stomates (Reyne, 1948). They attack first the lower fronds of coconut palm keeping the upper fronds green (Fig. 1a). However, in serious outbreaks, all parts of the coconut shoot (sometimes including the seednuts) are attacked.

Second instar. After the first molt, the insect entered second instar wherein they appeared yellowish (somewhat transparent in some insects), their appendages and antennae were lost, and a subcentral molt ring (exuviae; casted or shed skin from the 1st instar) was incorporated on the scale (Fig. 2e). During the molting process, the insect developed body ridges and the color changed to yellowish orange with reddish pygidium (Fig. 6a). After the molting process, a new body was seen inside the scale, under the exuviae (Fig. 2e). Body size of insect (mean length and width) at this stage was the same on both hosts (0.64mm and 0.54mm, respectively) (Table 1; Fig. 3). Though not significantly different on both hosts,

scale coverings were slightly bigger again on mangosteen (0.74mm and 0.68mm, respectively) than on coconut (Table 1; Fig. 4). This trend was the same as in white cap and pre-second instar, however, development into second instar was significantly faster on coconut with 9.11 days average than on mangosteen with 11.6 days average (Table 2; Fig. 5).



Fig. 6. Molting of *A. rigidus* towards (a) second instar, (b) female third instar, and (c) male pupal stage showing expelled exuviae (45x magnification).

Male *A. rigidus*: Pre-pupal, pupal, and adult stages. At the later stage of second instar, male *A. rigidus* started to appear slender or tapered (v-shaped) towards the posterior end with scale covering looked elliptical, body turned light yellow with pygidial structure quite retained; but the most prominent feature was the presence of two developed black eye spots (pre-pupa) (Fig. 2h). Though not significantly different on both hosts, mean length and width of males during pre-pupal period were slightly bigger on coconut (0.66mm and 0.39mm, respectively) than on mangosteen (0.65mm and 0.37mm, respectively) (Table 1 & Fig. 3). After this stage, the males molted and entered pupal stage in which genitalia and appendages started to develop, body and scale further elongated, and pygidial structure was lost. Initial antennae were formed, and male body appeared already separated from the host leaf (Fig. 2i). During molting towards pupal stage, the exuviae or casted skin was deposited on the posterior end and expelled out of the scale cover (Fig. 6c). Thus, only the exuviae at first molt (from crawler) can be seen incorporated in the scale of males. Though not significantly different on both hosts, mean length and width of pupa were slightly bigger on coconut (0.7mm and 0.34mm, respectively) than on mangosteen (0.63mm and 0.3mm, respectively) (Table 1; Fig. 3). The average days of males to complete both pre-pupal and pupal stages were significantly shorter on coconut (9.29 days) than on mangosteen (10.67 days) (Table 2; Fig. 5). The pupa molted again and further transformed into yellow colored adult male, with fully developed antennae, eyes, appendages and wings (Fig. 2j). Females did not undergo these stages. Instead, females undergone third instar and then, as egg-laying adults that feed permanently on the leaves. Though not significantly different on both hosts, mean length and width of winged adult male (under scale cover) were slightly bigger on coconut (0.85mm and 0.23mm, respectively) than on mangosteen (0.81mm and 0.22mm, respectively) (Table 1; Fig. 3). Scale size of males at all developmental stages was not significantly different on both hosts (Table 1; Fig. 4). Adult males emerged by making a longitudinal cut on the posterior part of the scale wherein the wings were once situated. Some adult males emerged by moving backwards through the opening in the posterior end of the scale created during wing development. Some males, however, died with their wings trapped (or glued) in the scale or in the unexpelled exuviae, thus disabling them to fly as their wings were deformed or destroyed. Adult males crawl with their wings pointed upward and sometimes move by flying and jumping. The same as in pre-pupal and pupal stages, development to adult male was significantly faster on coconut (3.64 days) than on mangosteen (4.36 days) (Table 2; Fig. 5). In total, male *A. rigidus* completed its life cycle faster on coconut with 38 days average than on mangosteen with 42 days average (Table 2). *A. rigidus* males were thus generally healthier on coconut host supporting shorter life cycle and slightly bigger bodies.

Female *A. rigidus*: Third instar and adult stages. *Aspidiotus rigidus* is most destructive as females since they permanently attach and feed on the leaves and produce eggs. Females continued secreting waxy thread to produce bigger scale to accommodate the growing body. After the second instar and second molt (Fig. 6b), the females entered third instar or pre-oviposition stage wherein they prepare to

develop and produce eggs (Fig. 2f). At this stage, both body and scale sizes increased rapidly and the pygidium was further developed. The second exuviae was incorporated in the scale just below the first exuviae. In some insects, the eye spots from the crawler stage (1st instar) were still visible (under the microscope) even up to this stage though these were initially seen on the dorsal part of the head, now seemed to have moved to the sides of the enlarged insect's head. It was observed that the insect generally changes position at various developmental stages as shown by different orientation of first and second exuviae, and the third instar body. The female body was very delicate containing largely yellowish fluid which gives its characteristic color. The 'up and down' movement of the pygidium at this stage seemed to be more distinguishable and continuous. This was probably because, aside from its preparing to develop and lay eggs, it continuously secreted waxy fluid while moving its body. At third instar, the abdominal tip was usually observed at or close to the periphery of the scale covering (Fig. 2f). Mean length and width of third instar females were significantly bigger on mangosteen (1.13mm and 0.92mm, respectively) than on coconut (1mm and 0.8mm, respectively) (Table 1; Fig. 3). After the third instar, the insect transformed into gravid female adults (Fig. 2g). This is the last developmental stage of female *A. rigidus* which is also referred to as oviposition stage. Unlike in third instar, the adult female produced more scale covering at the abdominal tip to make enough room for laying and incubation of eggs. After several ovipositions, the scale covering was usually crowded with eggs, newly emerged crawlers, and egg casings. The same goes in the adult females, they were significantly bigger (mean length and width) on mangosteen (1.21mm and 1mm, respectively) than on coconut (1.17mm and 0.95, respectively) (Table 1; Fig. 3). Likewise, significantly bigger scales (mean length and width) were observed on mangosteen during third instar (1.71mm and 1.55mm, respectively) and adult stage (1.8mm and 1.52mm, respectively) (Table 1; Fig. 4). The scale cover was opaque and largely oval or circular shaped on both hosts. When removed from the leaves, the rostrum (feeding tube) inserted by *A. rigidus* in the leaf tissues for sucking sap was located at the center of the upper half of the insect's ventral part. This hair-like structure appeared to grow longer as it explored the internal leaf tissues and consumed the sap resulting to leaf yellowing. The female body has many grooves, especially near the pygidium, which also facilitated body movement. Females molted twice (second and third instars) and no further molting was observed when approaching the adult stage. Also, they are parthenogenic and thus can develop and lay eggs even with the absence of males. Between the two hosts, female *A. rigidus* (body and scale) were therefore significantly bigger on mangosteen but contrastingly in males, though not significantly different on both hosts, they were slightly bigger on coconut. However, in spite of the seemingly healthy status of females on mangosteen, insect development under these two stages were significantly faster on coconut (20.57 days) than on mangosteen (24.87 days) (Table 2; Fig. 5). Thus, insect developmental stages before second instar may be slightly slower on coconut, however, stages approaching to female maturity developed faster. Hence, life cycle of female *A. rigidus* was significantly shorter on coconut (46 days average) suggestive to its outbreak characteristic in this host (Table 2). On mangosteen, the life cycle completed in the average period of 52 days long (Table 2). The duration of female life cycle on coconut confirmed the report of Reyne (1948) in which, if compared to *A. destructor* life cycle, is about 1.5 times longer (Watsons et al., 2015). Salahud and Arthurs (2015) also reported that *A. destructor* has a very short life cycle of 35 days on coconut. The shorter developmental stages of *A. rigidus* at second instar to adult females resulted to shorter life cycle on coconut which indicates adequate nutrition. Regardless of hosts, female insects were generally bigger than males but male insects matured earlier than the females (Table 1 and 2; Fig. 3 and 5).

Fecundity, longevity and sex ratio of *A. rigidus* on both hosts. As mentioned, female *A. rigidus* can reproduce through parthenogenesis. Reyne (1948) never observed copulation (or mating) in both *A. rigidus* and *A. destructor* though adult males are oftenly seen amongst female insects. In the present study, copulation in *A. rigidus* was also not observed but in the case of *A. destructor*, Tabibullah and Gabriel (1975) were able to observe copulation in this species. Insect fecundity recorded on coconut was higher (75 eggs average) than on mangosteen (48 eggs average) ($n=30$). One factor that might have contributed to this was the longevity of female *A. rigidus* which was longer on coconut (up to 3.5 months) compared to mangosteen (up to 2.5 months) leading also to much higher fecundity. In *A.*

destructor, eggs could range from 40-60, and in some cases 75-100 (Reyne, 1948) which means this species generally lays more eggs than *A. rigidus*. In this study, by counting 100 insects, more females were observed on mangosteen (1:3.11 male to female ratio) while the sex ratio was almost equal on coconut (1:1.14). The male and female ratio of *A. rigidus*, however, may be highly variable but most of the time, male insects comprise 25-50% of the colony (Reyne, 1948). The effect of sex ratio in terms of egg production of *A. rigidus* is not clearly understood. In *A. destructor*, there was no considerable difference when it comes to egg production between mated (by males) and unmated (parthenogenic) female scale insect as reported by Reyne (1948).

A. rigidus pure culture rearing and natural enemies. Rearing pure culture of *A. rigidus* was successfully done using mangosteen seedlings kept inside the glasshouse as this species may live in complex with *A. destructor* in the collected coconut leaves. Pure culture was possible due to non-preference of *A. destructor* on mangosteen (Reyne, 1948; Watsons et al. 2015; Cayabyab et al. 2016) and avoided contamination of this species during introduction of *A. rigidus* to coconut host. *A. destructor* is a polyphagous pest attacking coconut and banana, including major tropical fruits and ornamental crops (Lal, 2004). Rearing was initially carried-out using squash fruits as it was conducted by Tabibullah and Gabriel (1975) on *A. destructor*. However, *A. rigidus* was not successfully reared on squash fruits. Crawlers infested the fruit and successfully established but insect development was delayed after reaching second instar. Instead, mangosteen seedlings were used to mass rear *A. rigidus* and in studying its life cycle. The average temperature of the rearing set-up in the glasshouse was 26°C with an average RH of 76%. Source material (coconut leaves) infested with many gravid females, eggs and crawlers of *A. rigidus* was selected and used during rearing establishment to ensure good insect transfer on the mangosteen leaves. Samples of reared CSI were also submitted for molecular identification and confirmation. DNA sequence analysis confirmed the identity of the scale insect on mangosteen as *A. rigidus* only (Latina 2016; Galvez et al. 2018).

As the *A. rigidus* in the rearing set-up grew in number, natural enemies including predatory mites and the newly discovered *Comperiella calauanica* (Fig. 7a) (Barrion et al. 2016) were observed on newly infested plants. Natural enemies are naturally occurring biological control agents which regulate pest population at a level not causing serious economic loss on crops. The female *C. calauanica* oviposits on the body of the coconut scale insect and its egg develops into adult through consumption of the insect's tissues (Fig. 7b).

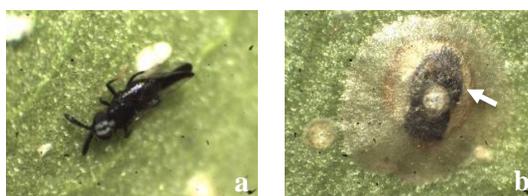


Fig. 7. (a) Adult female *Comperiella calauanica* Barrion, Almarinez, Amalin & Carandang and (b) its parasitism (45x magnification).

The mature *C. calauanica* emerged by making exit holes on or near the pygidium of the parasitized body of *A. rigidus*. This parasitoid posed the most significant parasitism which is a problem when rearing *A. rigidus*, but this also implies its effectiveness as a biological control agent for *A. rigidus* (Almarinez et al., 2015). In Oman, a coccinellid beetle, *Chlorocorus nigrinus*, introduced from India was successfully used to control *A. destructor* (Kinawy, 1991). In the Philippines, *Scymnus* coccinellid species were effective predators of *A. destructor* (Palacio et al. 1984).

CONCLUSION

The various information generated in this study suggest that coconut as host of *A. rigidus*, compared to mangosteen, provides better nourishment and living conditions that support faster life cycle and development, longer female longevity, and higher insect fecundity which are potential host-suitability factors that contributed to the outbreak infestation. Mangosteen, on the other hand, supports bigger *A. rigidus* females and slightly faster developmental rate prior to second instar. This means that different host-plant species have effects on the growth, development, and reproduction of *A. rigidus* which may be augmented due to better host suitability. Such host suitability could be regarded as one of the determinants of the insect's outbreak potential. Mangosteen is an effective host-plant to mass rear pure culture of *A. rigidus* since *A. destructor* could not be reared on this crop. Successful mass rearing of *A. rigidus* is also necessary in the conduct of host resistance confirmatory tests for selected promising coconut varieties. The findings of this paper could also be used as baseline information for studying host-insect interaction and in conceptualizing timely management and effective monitoring strategies to mitigate pest infestation especially on these two valuable industrial crops.

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