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Biology and ecology of scale insects

Aspects of the biology, ecology and parasitism of *Acanthomytilus sacchari* (Hall) (Hemiptera: Diaspididae) on sugarcane in Egypt

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Abstract: The armoured scale, *Acanthomytilus sacchari* (Hall) (Hemiptera: Diaspididae), attacks sugarcane, *Saccharum officinarum* L., in Egypt. A diagnosis and taxonomic illustration are provided to aid identification of this insect, and its host range and distribution are given. The biology was studied in an untreated sugarcane field at Al-Aiat (Giza govenorate) in 2000. Scales appeared in early May; by the end of July, 72% of the leaves bore 5-24 scales each. By late August, every leaf was infested, each with an average of about 25 scales. Scale numbers peaked at an average of about 40 per leaf in the third week of September. Significantly more scales were found on the upper leaf surface than the lower, and on the middle third of the leaf than at either end. In late July, the average number of eggs and first-instar larvae found under a female's scale cover was 39; reproduction peaked at an average of 48 eggs and larvae per female in early September. In the outdoor insectary, four generations (egg to egg) occurred between late July and mid-December. The shortest generation time (27 days), oviposition period (7 days), and highest fecundity (6.86 eggs/day) occurred at an average temperature of 29.0°C and relative humidity (RH) of 62.2% in August. The longest generation time (48 days), oviposition period (16 days) and lowest fecundity (3.69 eggs/day) occurred in December at an average temperature of 22.6°C and RH of 67.4%. Reproductive capacity ranged between 25-67 (average 50) eggs per female. The sex ratio was about 1:1. Parasitism of *A. sacchari* by *Metaphycus flavus* (Howard) (Hymenoptera: Encyrtidae) was recorded for the first time. The average level of parasitism for July-September was 22%, with peaks recorded in late July, mid-August and late September (about 28, 39 and 25% respectively).

Key words: scale, *Acanthomytilus sacchari*, sugarcane, parasitism.

Introduction

Sugarcane is thought to have originated from the island of New Guinea (Artschwager & Brandes, 1958). It is widely grown around the world in Mediterranean and tropical climates, and is increasing in importance with the trend towards production of ethanol biofuel. On different continental land masses, native grass-feeding scale insects (Hemiptera:

Coccoidea) have moved onto sugarcane and have become pests, e.g. *Melanaspis glomerata* (Green) (Hemipera: Diaspididae) in India (Watson, 2002). Movement of planting material between continents carries the risk of accidental introduction of phytophagous pests. Sugarcane pests need to be well-documented to facilitate identification.

The armoured scale, *Acanthomytilus sacchari* (Hall) (Diaspididae), attacks sugarcane, *Saccharum officinarum* L., in Middle Egypt. The scales feed on leaf mesophyll cells and damage their host plants directly by removing fluid and nutrients. Indirect damage is caused by toxicity of the saliva injected into the tissues, and by perforation of the cuticle and epidermis, through which pathogens may gain access to the living tissues (Beardsley & Gonzalez, 1975). *A. sacchari* was described from Egypt (Giza and Embaba regions) on sugarcane (Hall, 1923), and is probably native to Africa; it has also been recorded from Central Africa, Kenya, Guinea, Sierra Leone and Tanzania. It has been accidentally introduced to other countries, probably on sugarcane or grass planting material, and has been recorded from Cyprus, Hungary, Italy (including Sicily), India, Pakistan and Taiwan (Miller & Gimpel, 2001; Watson, 2002). However, little has been documented of its biology and natural enemies (Watson, 2002). This paper provides a more thorough diagnosis and illustration of the adult female of *A. sacchari* than was provided in the original description, and documents some aspects of its biology, ecology and parasitism.

Materials and methods

Diagnosis

Adult females of *A. sacchari* were stained and prepared on microscope slides using the method described by Watson & Chandler (2000), to facilitate morphological study using a compound microscope with phase contrast illumination. The morphology was compared with Hall's (1923) description and illustration. Hall's illustration was digitally scanned and updated to conform with present-day conventions of scale insect taxonomic illustration, using Adobe Photoshop software.

Assessment of incidence, density and distribution of infestation

A sugarcane field at Al-Aiat (Giza govenorate, Atfieh province, west of the River Nile and 40 km south of Cairo) known to be infested by *A. sacchari* was chosen in 2000. Each week between July 20 and September 29, twenty-five leaves were collected randomly. Each leaf was examined with a x10 hand lens and classed as infested and non-infested. To assess the level of infestation, 10 infested leaves were selected randomly. Each leaf was divided into three equal parts (basal, middle and apical) and the numbers of females and males on both surfaces of each third were recorded using a dissection microscope.

Assessment of reproductive activity in the field

At the end of each field sampling session, 20 female *A. sacchari* attached to leaves were transported to the laboratory. For each female, under a dissection microscope the scale cover was carefully lifted with a needle, and the numbers of eggs and first-stage larvae (crawlers) present under the scale cover were recorded.

Number of generations and fecundity under insectary conditions

Generation time was studied for each of four generations, by transferring newly-laid eggs to the upper leaf surface of sugarcane plants grown in plastic pots (30 × 30 cm) in the outdoor insectary. Once the resultant females were about to start laying eggs, they were gently removed from the leaves and each was placed in a petri dish (15 cm in diameter) under a plastic cover (3 cm in diameter), and examined once a day. The date at which a female began to lay eggs was considered the end of the generation.

The females used for the generation study above were subsequently used to assess fecundity. For each of the four generations, females (12, 14, 18 and 16 respectively) at the start of egg laying were checked with a dissection microscope to count the number of eggs laid each day until the insect died.

Assessment of parasitism of female scales in the field

On each field sampling date, females collected in the field were taken back to the laboratory for examination and assignment to one of the following categories: unparasitized, with immature parasitoid present, adult parasitoid present (alive or dead), or dead but with a parasite exit hole. Live parasitized females were placed in petri dishes to allow the emergence of adult parasitoids. After emergence, the parasitoids were identified.

Results and discussion

***Acanthomytilus sacchari* (Hall)** *(*Fig. 1)

In life, each adult female *A. sacchari* lives beneath an elongate, mussel-shaped, light to mid-brown scale cover made of the exuviae of two previous instars and felted secretions. The scale cover is 2-3 mm long, with the exuviae located at the narrow end. Beneath the scale cover, the live adult female and eggs of *A. sacchari* are slightly translucent, creamy white. The scale cover of the immature male is similar in colour and shape to that of the adult female, but is shorter and narrower, with a single exuviae situated at the narrow end.

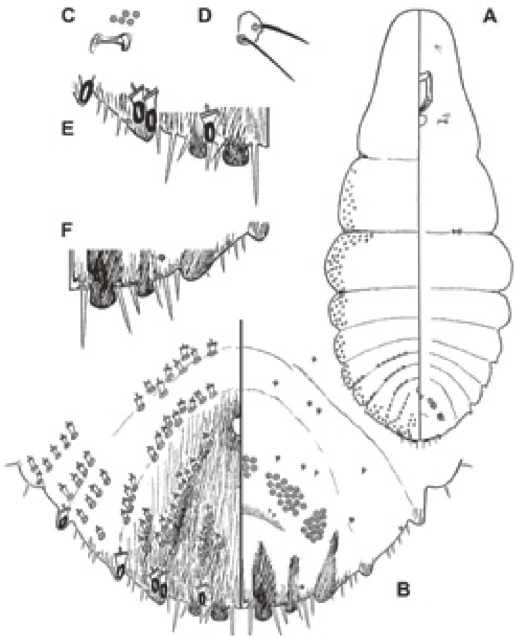

Figure 1. Adult female of *Acanthomytilus sacchari* (Hall), partly based on the figure by Hall (1923). A = body, B = pygidium, C = right anterior spiracle, D = right antenna, E = pygidial margin, dorsal detail, F = pygidial margin, ventral detail.

Diagnosis

Body of slide-mounted adult female 0.95–1.77 mm long, widest at abdominal segment II, membranous apart from fused segments of pygidium; in older specimens, head and thorax may become lightly sclerotized. Antennae each bearing 2 or 3 setae. Pygidial margin bearing two pairs of well developed lobes; third lobes often indicated only by a prominence of the margin, sometimes serrated, and some ventral sclerotization. Median lobes not linked by any sclerosis, separated by at least width of one lobe; each median lobe almost symmetrical, slightly shorter than wide, often without any lateral notches, and lacking any basal sclerosis. Second lobes each smaller than a median lobe, usually bilobed but outer lobe often very small or sometimes absent. Anal opening situated near anterior margin of pygidial shield. Vulva situated approximately half way between anal opening and posterior margin of pygidium. Pygidial margin with four or five marginal macroducts on each side, each macroduct fairly short, with two sclerotized bars at the inner end, and the orifice oriented with the long axis perpendicular to the margin. Abdominal segments IV and V each with a pore prominence on each margin. Dorsal macroducts largest on pygidial shield, becoming smaller anteriorly. Macroducts on pygidium with sclerotized orifices; anterior to pygidium, macroduct orifices becoming less sclerotized anteriorly. Macroducts present on thoracic margins and forming submarginal and submedian segmental series on abdominal segments III–VI and occasionally on segment II (see Fig. 1). Gland spines well developed, with 2 present between median lobes, each about 3x as long as a median lobe; 2 between median and second lobes; 3 between second and third lobes; 3 between third lobe and first pore prominence; and 4 between first and second pore prominences.

Abdominal segments III and II each with 3 small gland spines on each margin. Duct tubercles absent. Anterior spiracles each associated with 3-6 pores; posterior spiracles without any associated pores. Perivulvar pores present in five groups.

Host range

Acanthomytilus sacchari has been recorded only on large members of the plant family Poaceae (=Gramineae), e.g. *Anadelphia arrecta, Arundo donax, Chesmopodium caudatum, Imperata cylindrica, Miscanthus* sp., *Neyraudia arundinacea, Phragmites communis, Saccharum biflorum* and *S. officinalis* (Miller & Gimpel, 2001).

Incidence, density and distribution of infestation

Infestation of the selected field of sugarcane with *A. sacchari* was detected by early May 2000. In the third week of July, 72% of sugarcane leaves were infested (at 32°C and 49.4% R.H.); four weeks later, the infestation level had increased to 96% (at 31.8°C and 52% R.H.); it reached 100% by late August (at 32.1°C and 46.4% R.H.) and continued at the same level until late September (Table 1).

Population density was generally about 19 scales per leaf (Table 1). *A. sacchari* was found in low numbers (about 5 scales per leaf) on the third week of July and numbers fluctuated over the next two months. Three population peaks were observed: in early and late August, and in the third week of September (at mean temperatures of 33.5°, 32.1° and 29.9°C and mean relative humidities (R.H.) of 42.9%, 46.4% and 49.1% respectively). Significantly more scales were found on the upper surface and on the middle third of the leaf, compared with the lower surface or on either end of the leaf (Table 2).

Fecundity

An adult female *A. sacchari* lays eggs under the protective scale cover, from which the crawlers later disperse. Oviposition was recorded between late July and late September 2000 (Table 1). In late July each female produced a high number of 39 eggs and first stage larvae but this figure decreased to 22 in late August (at average temperatures of 32.2°C and 32.1°C and relative humidities of 46.7% and 46.4% respectively). Overall, an average of about 27 eggs and first stage larvae per female were recorded at any one time. Two peaks of fecundity were recorded, in the first and third weeks of September.

Table 1. Field-collected data on sugarcane, late July to late September 2000.

Sampling date		**% leaves infested**	**Mean no. scales per leaf**			**Mean no. eggs and first stage larvae per ♀**	**Total no. of scales on 25 leaves**		**Sex ratio**
Month	Day		♀	♂	Total both sexes		♀	♂	♀:♂
July	20	72	1.9	3.2	5.1	0	22	32	1:1.4
	27	64	6.0	9.1	15.1	39	83	91	1:1
Aug	3	72	10.1	13.9	24.0	20	129	139	1:1
	11	68	8.4	11.9	20.3	17	127	119	1:1
	18	96	3.7	8.1	11.8	18	61	81	1:1.3
	25	100	8.4	17.0	25.4	22	110	170	1:1.5
Sept	1	100	7.6	13.3	20.9	48	93	133	1:1.4
	8	100	6.3	14.8	21.1	27	77	148	1:1.9
	15	100	4.4	7.8	12.2	38	55	78	1:1.4
	22	100	24.8	15.3	40.1	47	286	153	1.9:1
	29	100	4.8	8.2	13.0	25	64	82	1:1.3
General mean		88.4	7.8	11.1	18.9	27.4	1107	1226	1:1.1

Table 2. Mean number of *A. sacchari* on the basal, middle and apical thirds of a leaf, on upper and lower surfaces, late July to late September 2000. * and ** indicate significant differences between the general means of scale numbers on different thirds of the leaf, or between the upper and lower leaf surfaces, at the 0.05% and 0.01% levels, respectively.

Sex	**Mean no. of scales on leaf third**						**Total**	
	Basal third		Middle third		Apical third			
	Upper surface	Lower surface	Upper surface	Lower surface	Upper surface	Lower surface	Upper surface	Lower surface
Male	1.9	0.7	3.5	1.8	2.0	1.9	7.4	4.4
Female	0.9	0.4	2.7	1.6	1.5	1.1	5.1	3.1
Total	2.8	1.1	6.2	3.4	3.5	3.0	12.5	7.7
General mean	*1.0		2.4		1.6		**2.1	1.3

Sex ratios

The usual sex ratio was about 1:1 (Table 1); this was found between late July and the end of August, during which average temperature and relative humidity did not vary much. However, the sex ratio varied during September, the month in which temperature fluctuated more and relative humidity declined; almost twice as many males as females were found at the end of the first week, and almost twice as many females as males recorded at the end of the third week (Table 1). This range of sex ratios is commonly recorded in diaspidid scale insects (Nur, 1990).

Number of generations

Four generations were found during July 25-December 12, 2000 (Table 3). For comparison, the diaspidid species *Lepidosaphes pallidula* (Williams) and *Pseudaulacaspis pentagona* (Targioni Tozzetti) had 4 and 3 generations per year on *Mangifera indica* and *Prunus persica* var. *nectarina* in Egypt and Bulgaria (Elwan, 2004; Trencheva, 2004). Decreased temperature and increased relative humidity generally prolonged the generation period. The longest and the shortest generation periods lasted 48 and 27 days at means of 22.6° and 29°C with 67.4% and 62.2% R.H., respectively. The generation period shortened by increased temperature and decreased relative humidity. The multiple correlation coefficient (R^2) was 0.99 and the multiple regression equation was y = 148.1 – 3.5 X1 – 0.3 X2.

Table 3. Generation periods of *A. sacchari* during July to December, 2000.

Generation (egg to egg)	Period in days	Mean value	
		Temperature °C	% Relative humidity (R.H.)
July 25 – August 20	27	29.0	62.2
August 21 – September 17	28	28.6	65.3
September 18 – October 25	38	26.0	64.2
October 26 – December 12	48	22.6	67.4

Reproductive capacity and oviposition period

Most species of Diaspididae are ovoviviparous or oviparous and produce 50-150 eggs per female (but some produce as few as 10 or as many as 600), at a rate of 1-10 laid per day according to species and conditions (Watson, 2002). The reproductive capacity of *A. sacchari* ranged between 35-59 eggs per female with a general mean about 50; however, these figures obtained were from non-feeding females. Actively feeding females in the field may be more productive. The longest and shortest oviposition periods lasted 16 and 7 days respectively. The highest egg count occurred at 28°C and 66.6% R.H., and the lowest egg count occurred at 15.5°C and 68.3 % R.H. (Table 4). Decreasing temperature and increased relative humidity positively influenced the oviposition period and the number of deposited eggs. Multiple correlation coefficients (R^2) were 0.63 and 0.95, and the multiple regression equations were: y = 34.9 – 1.4 X1 – 0.77 X2 and y = 10 – 0.79 X1 + 0.28 X2 respectively. Temperature and humidity influenced fecundity of *Chrysomphalus aonidum* (L.) (Bonafonte, 1981).

Scale insect ecology in the sugarcane field

Other scale insect pests of sugarcane present in the same fields in Egypt were: Coccidae - *Pulvinaria tenuivalvata* (Newstead); Margarodidae - *Icerya seychellarum* (Westwood); and Pseudococcidae - *Ferrisia virgata* (Cockerell) and *Saccharococcus sacchari* (Cockerell). *P. tenuivalvata* and *A. saccharifolii* were often the most numerous coccoid species present. Heavy infestation by *P. tenuivalvata* resulted in fouling of the leaves with honeydew, giving rise to a thick layer of sooty mould growth and dust on both leaf surfaces. Thick sooty mould growth resulted in a sharp decline in the number of diaspidid scales in late September and the scales disappeared until the end of the growing season.

Parasitism

Before this study, 18 species of hymenopteran parasitoid had been recorded from 17 diaspidid species in Egypt (Abd-Rabou, 1999). This work found a hymenopteran parasitoid, *Metaphycus flavus* (Howard) (Encyrtidae), in female *A. sacchari*, but not in the males. The parasitoid has been recorded from Egypt before, but *A. sacchari* is a new scale host record for *M. flavus*. The parasitoid had been recorded previously as a primary endoparasite of *Chrysomphalus aonidum* (Linnaeus), *C. dictyospermi* (Morgan), *C. pinnulifer* (Maskell), *Lepidosaphes beckii* (Newman) and *L. gloverii* (Packard) (Diaspididae). *M. flavus* is also the dominant parasitoid of *P. tenuivalvata* on sugarcane in Egypt (Guerrieri & Noyes, 2000; El-Serwy & Guerrieri, 2005).

Table 4. Mean number of eggs per female of *A. sacchari*, August to December, 2000.

Oviposition period		**Mean no. of eggs per female**	**Mean value**	
Month	Mean oviposition time in days		Temperature °C	% R.H.
August	7	48	29	67.5
September	7	35	28	66.6
October – November	11	56	22.1	65.1
December	16	59	15.5	68.3
General mean	10.3	49.5	23.7	66.9

In the summer of 2000, parasitoid activity occurred between the third week of July and late September, with an average level of 22%. The parasitoid population peaked in late July, mid-August and late September (about 28%, 39% and 25% respectively). Polyparasitism occurred in about 17% of parasitized females (Table 5).

During the 2006-7 parasitoid emergence season, two species of specialized parasitoids (Hymenoptera: Chalcidoidea) of armored scale insects (Hemiptera: Diaspididae) were identified from sugarcane leaf samples: *Aphytis lingnanensis* Compere and *Encarsia sophia* (Girault & Dodd) [Aphelinidae]. Leaves infested by *P. tenuivalvata* and *Acanthomytilus sacchari* were collected from the newly grown sugar cane plants in the same fields at Atfieh (Giza govenorate, East of the River Nile and 80 km south of Cairo). In material collected on 20 August 2007, parasitism occurred in about 33% of *A. sacchari* females. *Aphytis lingnanensis* emerged from the leaf samples in low numbers from the third week of November to late January in 2006-7. This species has been recorded on diaspidid pests including *Aonidiella aurantii* (Maskell), *Aspidiotus hederae* (Vallot) and *Lindingaspis floridana* Ferris and is one of nine parasitoid species recorded on diaspidid scale insects in Egypt (Hafez, 1988; Abd-Rabou, 1999). This parasitoid was imported to California from south China as a biological control agent against California red scale (*A. aurantii*) on citrus and played a major role in successful biological control of citrus snow scale, *Unaspis citri* (Comstock) on citrus in Florida (DeBach, 1974; Rosen & DeBach, 1979). *Encarsia sophia* emerged from late November to the third week of December, and a parasitoid of *Encarsia* males – *E. lutea* group - emerged in late December 2006. *Encarsia* species are mostly primary parasitoids of whiteflies (Aleyrodidae) and armoured scale insects, whereas the fertilized and unfertilized (haploid) eggs develop into males which are very often hyperparasitoids of females (or males) of their own or other hymenopteran parasitoid species (Viggiani, 1990). *E. sophia*, placed in the *E. strenua*-group, is a cosmopolitan parasitoid of whitefly pests which is regarded as a potential biocontrol agent of the *Bemisia tabaci* species-complex (Viggiani, 1990).

Table 5. Incidence of parasitism on *A. sacchari* during July-September, 2000.

Sampling date		**No. females collected**		**% parasitism**	**No. females with parasite exit holes**		
Month	Day	Healthy	Parasitized		1 hole	2 holes	3 holes
July	20	19	3	13.6	2	1	0
	27	60	23	27.7	19	3	1
August	3	101	28	21.7	20	7	1
	11	84	43	33.9	35	8	0
	18	37	24	39.3	18	6	0
	25	84	26	23.6	21	5	0
September	1	76	17	18.3	15	1	1
	8	63	14	18.2	14	0	0
	15	44	11	20.0	8	3	0
	22	248	38	13.3	36	1	1
	29	48	16	25.0	14	2	0
Total		864	243		202	37	4
%				22.0	83.1	15.2	1.7

In conclusion, sugarcane in Egypt is attacked by *A. sacchari* and *P. tenuivalvata*, scale insects that are probably native to Africa. Both could present a quarantine threat to sugarcane-growing countries where they do not occur at present. *P. tenuivalvata* in Egypt was discussed by Watson & Foldi (2002); it has not been recorded from outside Africa. Both *A. sacchari* and *P. tenuivalvata* are parasitized by the same Encyrtid wasp, *M. flavus*, which may be suitable for biological control purposes if either of these scale species become serious pests in other countries.

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