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On the biology of *Lioadalia flavomaculata* (Deg.) (Col., Coccinellidae), a predator of the wheat aphid (*Schizaphis graminum* (Rond.)) in South Africa

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Introduction

Accurate information on the biology and life-cycle of a particular entomophagous insect is fundamental to planning effective biological control. The present paper is aimed at investigating the developmental biology and different life stages of *Lioadalia flavomaculata* (Deg.), an important predator of the wheat aphid, *Schizaphis graminum* (Rond.), in the Orange Free State province of South Africa. Apart from general observations by Moore (1913–14), no detailed information on the biology of this species was previously available. Smit (1964) has reviewed its bionomics.

Often referred to as *Adalia flavomaculata* in the literature, there has been some confusion regarding the identity of this Coccinellid. Crotch (1874) considered it sufficiently distinctive to establish the genus *Lioadalia* for its inclusion, but Korchefsky (1931) regarded *Lioadalia* as a synonym of *Adalia*. More recently Fürsch (1961), in his revision of the African species of *Adalia*, supported Crotch and upheld *Lioadalia*. In response to a query by the writer, R. D. Pope (1969 *in litt.*) has stated that *Lioadalia flavomaculata* is the valid name for the species. This combination is accordingly used in the present paper.

According to Pope (1957), the species is widely distributed in South Africa and South West Africa and in the former territory is recorded from the Cape Province, Natal, O.F.S. and the Transvaal. Fürsch (1961) records it from Lesotho.

Experimental procedure

Laboratory cultures were initiated with field-collected beetles maintained in glass vials plugged at one end with cotton wool. Eggs laid on these plugs were transferred to clean 10×3-cm vials ready for incubation. Larvae, owing to their cannibalistic disposition, were reared individually in 5×1-cm vials arranged upright in suitably drilled wooden racks. All experimental individuals were fed on wheat aphids settled on short lengths of leaves. Care was exercised to see that an excess of food was always available and was replenished every morning. Vials were checked during the mornings and afternoons to record hatching and/or moulting or to remove eggs. The majority of experiments were maintained at different constant temperatures, *viz.* 4, 13, 16, 18·5, 21, 24, 27 and 32°C, but as a check some were also kept under uncontrolled laboratory conditions. Humidity was only controlled in the case of the incubation experiments where it was kept constant at 75% r.h.

Field observations were carried out on the Agricultural Experiment Farm near Bethlehem, O.F.S. (28°13′S, 28°18′E).

Results

The egg

The pale lemon yellow eggs are laid in batches, standing upright, almost touching each other and lightly affixed to the substrate (Fig. 1). The shape of the egg is

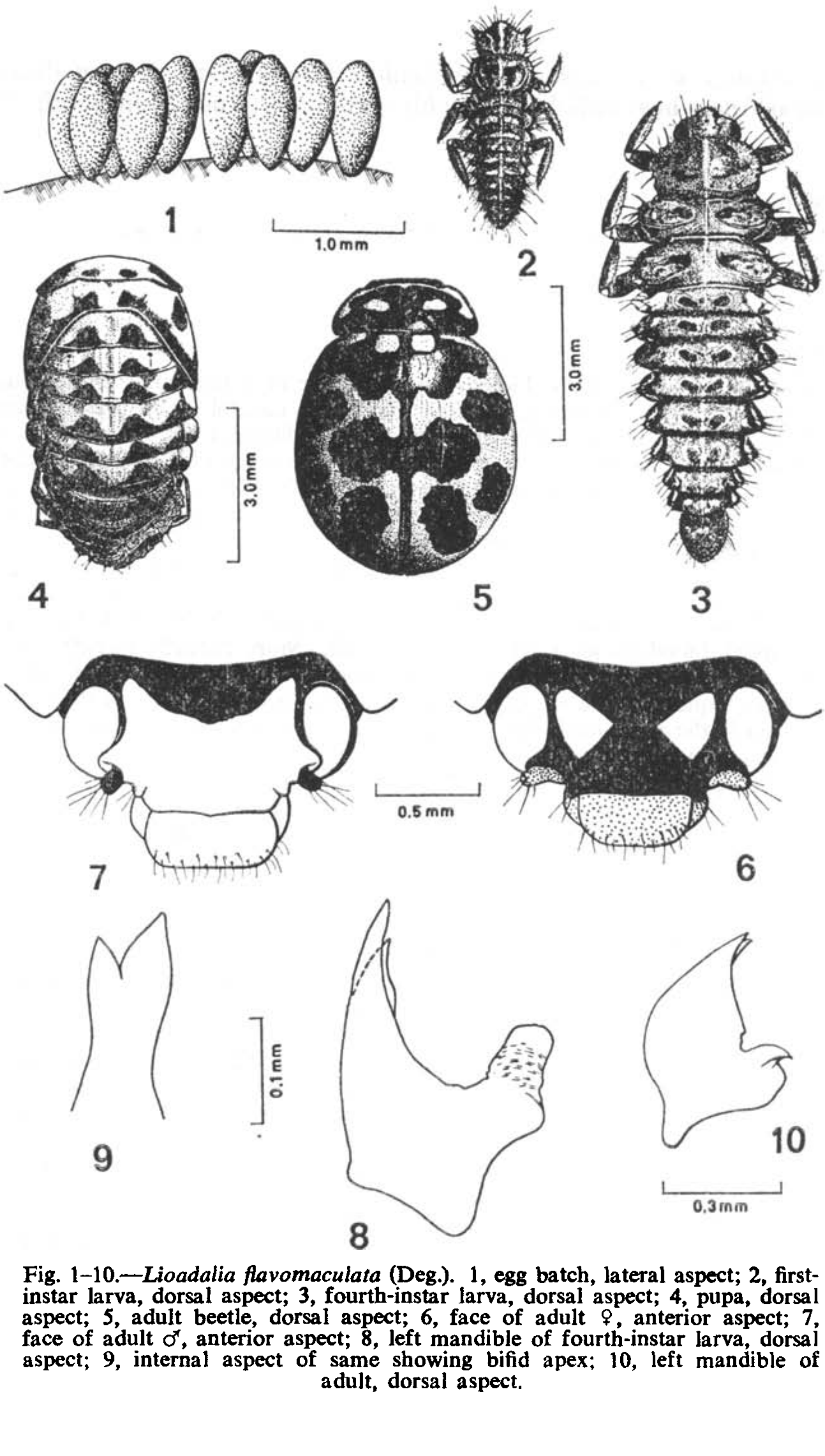

Fig. 1–10.—*Lioadalia flavomaculata* (Deg.). 1, egg batch, lateral aspect; 2, first-instar larva, dorsal aspect; 3, fourth-instar larva, dorsal aspect; 4, pupa, dorsal aspect; 5, adult beetle, dorsal aspect; 6, face of adult ♀, anterior aspect; 7, face of adult ♂, anterior aspect; 8, left mandible of fourth-instar larva, dorsal aspect; 9, internal aspect of same showing bifid apex; 10, left mandible of adult, dorsal aspect.

elliptical and the average length and breadth of 20 eggs was 1·0×0·5 mm. Under low magnification (40×), the chorion appears smooth and unsculptured. When newly laid, the eggs are yellow due to the colour of the yolk showing through the transparent chorion. A few hours before eclosion, however, the red eye-spots of the embryo become visible, differentiation of the yolk follows and the egg subsequently darkens. Just prior to hatching the fully segmented embryo can be clearly discerned inside the egg.

The average number of eggs per batch in 50 laboratory batches was 13·1 (range 6–23). Not all the eggs in the batches necessarily hatch and some remain undeveloped. In the field, eggs are generally laid on the undersides of clods and other crevices in the soil surface, but have also occasionally been encountered on leaves near the ground.

The incubation period of the egg was examined over a range of seven different temperatures (*i.e.*, 13, 16, 18·5, 21, 24, 27 and 32°C) and an inverse relationship with temperature observed; the period of incubation decreasing as temperature increased. This can be clearly seen in Fig. 11 where the incubation period was reduced to 2·1 days (range 2–3) at 32°C, whereas at 16°C it was increased to 9·1 days (8–11) and at 13°C to 13·1 days (10–16).

At temperatures of 13, 16, 18·5, 21, 24, 27 and 32°C the egg mortalities were 43, 18, 54, 23, 29, 37 and 37%, respectively.

The larva

After hatching, larvae remain on top of their empty egg shells for about a day before becoming active and dispersing from the oviposition site. A newly dispersed first-instar larva is shown in Fig. 2. There are four larval instars which closely resemble each other in morphology and differ only in size. The body of the larva is covered with numerous tubercles each bearing a bunch of setae; these tubercles have

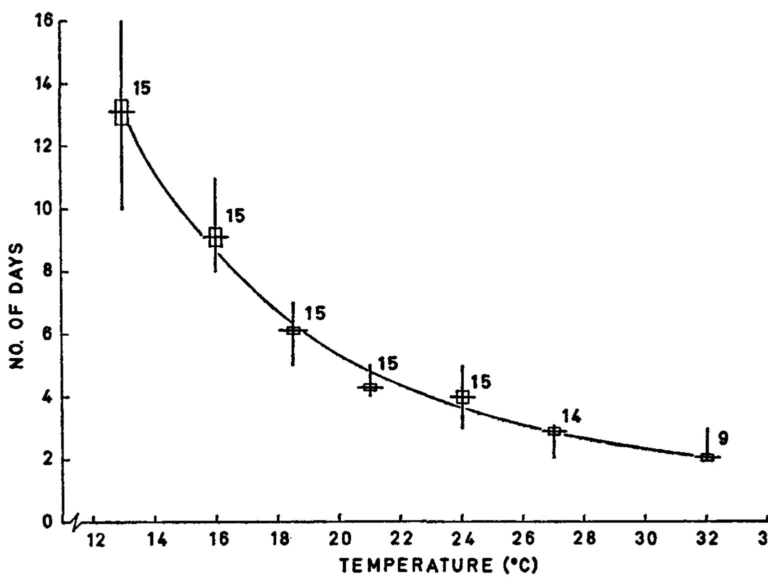

Fig. 11.—Effects of temperature on the incubation period of *L. flavomaculata* eggs. (Vertical lines = observed range; horizontal lines = mean value; blocks = s.e.; figures along curve denote numbers of replicates (curve fitted by eye).)

been termed strumae by Gage (1920). Larvae are slatey blue in colour with prominent yellow spots located on either side of the first abdominal segment. Such colour and morphological details can best be seen in the fourth instar (Fig. 3). The larvae are very active and travel extensively over both plants and soil in their search for aphids. Besides aphids, they feed avidly on their own unhatched eggs and also sometimes on other larvae, particularly when these are engaged in moulting. The mandible of the larva is bidentate at the apex (Fig. 8) and the mola broadly rounded (Fig. 10). The fourth-instar larva, which is at first very active, later becomes quiescent and then passes into a stationary prepupal phase. It attaches itself, as when moulting, by the tip of the abdomen to some convenient surface, usually the underside of a leaf or clod, and adopts a characteristic posture with the body arched and the head bent down. About a day is spent in this position and the larva then moults into a pupa.

The length of the body of the newly emerged larval instars measured: first instar, 1·3–1·8 mm; second instar, 2·8–3·5 mm; third instar, 4·1–4·9 mm; and fourth instar, 4·8–5·7 mm (n=10).

The pupa

The larval exuviae are slowly shed by alternate rocking movements of the body which pushes it back to the apex of the abdomen until the pupa is completely exposed. At first the pupa is entirely yellow, but shortly after the moult it begins to darken and is covered with scattered black patches (Fig. 4). Pupation in the field usually occurs in soil crevices, beneath clods or in other sheltered positions on the plant itself.

The duration of the larval and pupal stages was examined over a range of seven temperatures and is summarised in Table I, where an inverse relationship between development and temperature is evident. Total development was reduced to as little as

TABLE I. *The effects of temperature on the larval and pupal development of* L. flavomaculata

Temp. (°C)	No. individuals	Average duration of each instar (days)					Total development (days)	
		1st	2nd	3rd	4th	Pupa	Mean	Range
32	10	1·0	1·2	1·9	3·0	2·3	9·4	9–10
27	15	2·0	1·0	1·4	4·9	3·9	13·2	12–14
24	13	2·6	1·5	1·9	7·2	4·8	18·0	17–20
21	10	3·4	2·2	2·3	11·5	6·5	25·9	24–28
18·5	10	4·0	2·7	2·9	10·9	8·9	29·4	27–31
16	12	7·3	4·8	5·3	16·1	11·4	44·9	42–48
13	10	8·9	9·8	6·9	22·0	13·0	*60·6	—
4	15	29·6**	—	—	—	—	—	—

* Only one deformed beetle emerged.
** All individuals died before moulting, figure denotes survival period.

9·4 days (range 9–10) at 32°C while it averaged 44·9 days (42–48) at 16°C, and in the case of one survivor to about 61 days at 13°C. First-instar larvae survived for 29·6 days at a constant temperature of 4°C but died without moulting. Of the four larval instars, the fourth always took the longest to complete its development, irrespective of temperature. Mortality rates for these instars were 0, 20, 40, 40, 0, 25, 90 and 100% at 32, 27, 24, 21, 18·5, 16, 13 and 4°C, respectively. The total development of the immature stages (egg+larva+pupa) averaged 11·5, 16·1, 22·0, 30·2, 35·5 and 54·0 days at 32, 27, 24, 21, 18·5 and 16°C, respectively.

The adult

Throughout a two-year census (1964 and 1965) carried out at Bethlehem, O.F.S., there was always a preponderance of females present in monthly samples. Thus, the sex ratio of 763♂ and 2 482♀ collected throughout 1964 was 1♂ : 3·3♀ and for the 1 228♂ and 5 207♀ collected during 1965, 1♂ : 4·2♀. The average ratio for both years was 1♂ : 3·9♀. The average length and breadth of 15 beetles of both sexes from the field was 5·2×3·6 mm and their average weight 11·92 mg. Females were generally larger and heavier than males. The sexes may be easily distinguished by the markings on the frontoclypeal area of the head; in the female there are two triangular yellow spots on either side (Fig. 6) whereas in the male a broad continuous saddle-shaped patch extends right across this area (Fig. 7). As the adult has the head and pronotum fully pigmented at eclosion, immediate recognition of the sexes is possible. This is very convenient in experiments where sex differentiation of newly emerged beetles is desired. However, the elytra of the teneral adult remain yellow and unpigmented for several hours after eclosion. At first they are uniformly yellow but later become veined by broad dark areas which subsequently become a glossy black. The elytra then assume their characteristic marbled appearance (Fig. 5). The interspaces remain yellow for about a week at about 20°C after which they turn orange and then red. This change in colour is a useful age indicator and serves to distinguish teneral individuals from older ones in the field. The adults are very mobile insects and run swiftly about on the plants and on the ground in search of aphids. They readily fly to other fields when aphids become scarce but their individual flight performance is not known. The mandible of the adult has a bidentate apex and a sharp recurved basal tooth (Fig. 10).

Beetles copulate within a few days after emergence and union lasts 10–15 min in the laboratory. As pointed out by Balduf (1935), although they readily copulate throughout their lives, a single mating is apparently sufficient for successful fertilisation of eggs. The preoviposition period varies with temperature (Table II) taking about 3–5 days at the higher temperatures (27–32°C) and 5–10 days at the intermediate ones (18·5–24°C).

TABLE II. *The effects of temperature on the preoviposition period and fecundity of* L. flavomaculata

Temp. (°C)	*No. egg laying pairs	Preoviposition period (days)		Total fecundity (eggs/♀)	
		Mean	Range	Mean	Range
32	4	4·8	4– 5	431·1	177– 667
27	4	3·7	3– 4	631·5	367– 751
24	2	7·0	5–10	858·5	654–1063
18·5	3	8·0	—	408·3	89– 811
16	4	—**	—	255·5	92– 504
4	2	—	—	2	—
19–24†	3	—	—	775·0	362–1116

* Started with 5 pairs at each temperature; figures show surviving pairs.
** Record lost because pairs could not be placed together immediately following emergence.
† Room temperature.

Considerable variation in total fecundity took place at the different temperatures (Table II). Maximum fecundity occurred at 24°C where it averaged 858·5 eggs per female (range 654–1 063), but the highest record of 1 116 eggs was obtained from a female kept under uncontrolled conditions in the laboratory. However, the average of three pairs maintained at room temperature was 775 eggs.

The length of the oviposition period was also markedly influenced by temperature (Table III), being short at high temperatures and progressively increased at the lower ones. Comparison between columns 5 and 6 of Table III indicates that oviposition was almost continuous at the higher temperatures and intermittent at the lower temperatures, when the number of days on which eggs were laid declined as oviposition became increasingly erratic. Adult life span was prolonged by low temperatures; at

TABLE III. *The effects of temperature on the life span and oviposition period of* L. flavomaculata

Temp. (°C)	No. individuals	Life span of females (days)		Mean oviposition period (days)	Mean no. days on which eggs laid
		Mean	Range		
32	4	24·0	18– 31	17·5	17·5
27	4	39·3	25– 68	30·5	28·0
24	2	44·5	37– 52	37·5	37·0
18·5	3	52·3	24– 70	41·3	33·3
16	4	70·4	38–103	52·3	26·5
4	2	25·0	23– 27	—	—
19–24†	3	74·3	39–115	56·3	51·8

† Room temperature.

TABLE IV. *Daily rate of oviposition of* L. flavomaculata *at different temperatures*

Temp. (°C)	No. pairs	No. eggs/♀/day	
		Mean	Range
32	4	24·6	14·8–27·8
27	4	20·7	16·0–34·4
24	2	22·9	21·1–24·2
18·5	3	9·9	6·4–13·3
16	4	4·9	3·7– 5·5
19–24†	3	13·8	11·3–19·3

† Room temperature.

24°C, considered the optimum for oviposition, female beetles lived on average 44·5 days (range 37–52). Maximum life span appears to be approximately three months.

According to Table IV the daily rate of oviposition, calculated by dividing total fecundity by the oviposition period, declined with decreasing temperature. The maximum daily average was 24·6 eggs per female at 32°C with a range of 14·8–27·8 eggs.

The greatest number of eggs laid during a 24-h period was 64, secured from one pair kept at room temperatures which varied from 19° to 24°C.

A few incidental observations were also made on the daily periodicity of oviposition in eight females exposed to normal daylight conditions over a temperature range of 20–23°C. The insects were kept in darkness from 18.00 to 06.00 h and in light for the rest of the day. Every six hours the vials were inspected and the eggs recorded and removed. The experiment ran for a week. The results, summarised in Table V,

TABLE V. *Periodicity of oviposition by individual females of* L. flavomaculata *exposed to normal daylight conditions during the course of one week*

Female no.	Darkness 24·00–06·00h	Light 06·00–12·00h	Light 12·00–18·00h	Darkness 18·00–24·00h	Total eggs
1	13	32	21	5	71
2	29	17	18	9	73
3	20	37	35	0	92
4	0	11	38	12	61
5	20	12	7	0	39
6	11	1	7	0	19
7	2	2	5	0	9
8	0	9	0	0	9
Total eggs	95	121	131	26	373
%	25·5	32·4	35·1	7·0	100

indicate that of the 373 eggs laid, 252 (68%) were deposited during the daylight hours 06.00–18.00 h. Oviposition may have been influenced by the time of feeding, as it has been demonstrated that some species like *Diloponis inconspicuus* Pope and *Pharoscymnus sexguttatus* (Gylh.) feed mainly during the day (Bretell, 1964).

Under these conditions the reproductive capacity of *L. flavomaculata* was considerably higher than the figure of 100–150 eggs previously reported by Moore (1913–14). However, Balduf (1935) records *Coccinella novemnotata* Hbst., another member of the tribe Coccinellini, as laying an average of 731 eggs with a maximum of 1 047 eggs, which is more comparable with present findings.

Summary

An account is given of the biology and different life stages of *Lioadalia flavomaculata* (Deg.), an important predator of the wheat aphid, *Schizaphis graminum* (Rond.), in the Orange Free State, South Africa. Eggs are laid in batches of 6–23 eggs, generally on the soil, and incubation takes 2·1–2·8 days at 32°C and 8·6–9·1 days at 16°C. There are four larval instars, the last of which has the longest duration; total development of the immature stages averaged 11·5, 16·1, 22·0, 30·2, 35·5 and 54·0 days at 32, 27, 24, 21, 18·5 and 16°C, respectively. Beetles mate within a few days of emergence and oviposition commences 3–10 days later, depending on temperature. Maximum fecundity averaged 858·5 eggs at 24°C. From 20·7 to 24·6 eggs per day were laid at the higher range of temperatures studied (24–32°C). Oviposition took place mainly during the day. Adult life span was 24–74·3 days.

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