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A BIOLOGICAL AND ECOLOGICAL STUDY OF THE RICE PENTATOMID BUG, *SCOTINOPHARA LURIDA* (BURM.) IN CEYLON.

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(Plates XV & XVI.)

Until the year 1940, the black rice bug or rice Pentatomid bug, *Scotinophara lurida* (Burm.), was recorded as being an occasional insect found on the rice crop in a number of parts of Ceylon. In that year, however, this insect appeared in very large numbers in rice tracts extending over an area of about 10,000 acres of the Left and Right Bank Colonization Schemes of the Walawe River in the Southern Province. It has also been recorded in large numbers at Okkampitiya, in the Uva Province, and Polonnaruwa and Minneriya in the North Central Province. In all these areas rice is grown entirely under irrigation and not under rain-fed conditions. Since 1940, the insect has periodically assumed epidemic proportions in the Walawe Schemes and has also appeared in increasing numbers in the other areas mentioned.

About 12,000 acres of rice are cultivated under the Walawe Right and Left Bank Colonization Schemes. Two crops are grown a year of, chiefly, locally selected pure-line varieties of rice requiring 3½ to 4 months to mature. A seedling crop is in the field during the months of April–May and November–December and harvesting occurs in August–September and February–March. Fields in these areas lie fallow during the months of August–September and part of October and in February, March and April. Water is permitted by irrigation into the tracts during the months of April and October for preparatory tillage and sowing.

S. lurida is a major pest of rice in China and in Japan. The results of extensive studies on the biology and control of this pest in Japan have been reported by Katsumata (1929), Kawasi (1955) and Kawada & others (1954). De Alwis (1941) has provided an account of this insect in Ceylon. The increasing importance of the pest to rice cultivation in this country has necessitated more intensive studies on its biology, ecology and control. This paper presents the results of biological and ecological studies conducted during the past four years. The parallel studies conducted on the susceptibility of *S. lurida* to insecticides and its insecticidal control are published in a separate paper (Fernando, 1960).

S. lurida on seedling rice.

Invasion of seedling rice tracts.

Adults of *S. lurida* (Pl. XV, fig. 1) leave their aestivation sites to invade the earliest sown rice in nurseries or broadcast tracts when the crop is about two to three weeks old. This happens during the months of April and May for the first crop and the months of November and December for the second crop. At dusk and at night the bugs are very active and are found in flight in large numbers, and they are much attracted to lights. This migratory activity continues until the crop is 1 to 2 months old, when copulation and oviposition are completed.

Bugs congregate on the stems and leaves of rice seedlings and, during very heavy infestations, as many as five to eight have been found on a single 3- to 4-week-old seedling plant. Such infestations were, however, never uniformly distributed; they were heavier where the plants were closely packed and in those areas where the plants were greener and healthier. Even in infestations of low population densities the distribution of bugs followed the same pattern on the seedling rice. Another noticeable feature of the distribution of *S. lurida* on seedling rice is that plants on tracts having a few inches of water are preferred to those where no water is present at the base of the plants.

Diurnal activity.

During the early hours of the day, bugs are found feeding upon the upper parts of the rice seedlings and even upon the upper surface of the leaves. As the day advances and the intensity of the sunlight increases they migrate to the underside of the leaves and on to the stems. The bugs continue to feed during the day on parts of the plants shaded from direct sunlight and they have very rarely been observed to take wing during hours of daylight. During field evaluation of insecticides for the control of this pest it was found that all the bugs caged in field cages were not accounted for by those present upon the leaves and the stems of the rice seedlings or floating dead upon the surface of the water. Careful examination of the basal parts of the rice seedling stems below water-level showed that several bugs were adhering to those parts of the rice seedling which were under water. This observation was checked more carefully under natural field conditions. Bugs usually take cover rapidly or even drop into the water when disturbed. However, the possibility of disturbance being responsible for the bugs being found below water-level was eliminated by approaching observation points in the field with the greatest caution. The further possibility that bugs were found below water-level owing to sudden fluctuations in the water-level of race tracts could be eliminated because tracts where the water-level was stable for the previous 24 hours were selected for the observations. Data were taken of the number of bugs upon the leaves, on the stems near water-level and below it. In 20 separate counts at 8 a.m., the distribution on leaves and on the stems above water-level and below it was 52·22, 39·44 and 8·33 per cent., respectively. The corresponding figures for counts taken at 11 a.m. were, 48·2, 42·1 and 9·7, respectively. These data, it will be seen, indicate no relationship between the time of day or intensity of sunlight and migration of bugs below water-level on rice seedlings.

Experiments were conducted in the laboratory to assess the survival of *S. lurida* under water. The basal 4 inches of 6-week-old rice seedlings were planted in one inch of rice-field soil, in glass dishes 6 inches deep. Adult bugs were then placed on these planted rice stems and allowed to feed for about two hours. Water collected from a rice-field was then introduced into the glass dishes gradually until the stems of the rice seedlings were completely submerged. Bugs were removed from the water at hourly intervals and maintained on rice seedlings for observation of survival. The results in Table I show that some adults of *S. lurida* could survive up to 7 hours continuous immersion in rice-field water without showing any noticeable ill effects up to 24 hours later. The experimental conditions, however, were not an exact duplication of field conditions as the bugs were forced under water and their first response to the immersion was secretion from the stink glands.

Nocturnal migrations.

Whereas during hours of daylight *S. lurida* is very sluggish and rarely ever takes wing, at dusk, bugs on the seedling crop become very active. This marked difference between the diurnal and nocturnal activity of *S. lurida* is only apparent in the generation of bugs migrating from aestivation sites on to the seedling rice and lasts until oviposition. Feeding continues during the night.

S. lurida on maturing rice.

As the crop grows older, the bugs restrict their movements and feeding to the basal stem region of the plant. If no water is present on the rice tracts they will be found on the soil among the short weeds, grasses or débris surrounding the base of the rice plants or along the basal 3–4 inches of their stems. Bugs are rarely found feeding on the upper portions of the stems of maturing rice plants or on the leaves of such plants. During heavy rains, however, when the plants are wet and very moist conditions prevail, adults can be found in small numbers feeding upon the leaves of maturing and mature rice plants. When the ear-heads are freshly formed the bugs can be seen feeding upon the grains, but they are not particularly attracted to the young ear-heads as the bulk of the existing bug population can be found at the base of the plants. Nocturnal flight activity is negligible at this stage of the crop, when compared to that of bugs on the seedling crop.

TABLE I.

Survival of adults of *S. lurida* after submergence in rice-field water for varying periods of time.

Duration of submergence (hr.)	Number of bugs used in test	Survival of bugs 24 hr. after removal from water (%)
1	40	97·5
2	60	78·3
3	30	70·0
4	30	63·3
5	20	60
7	20	35

Distribution of adults of _S. lurida_ when crop is in the field.

The distribution of adults of *S. lurida* in the field depends to some extent upon the size of the population present at the time. Details of the distribution of the bugs at various seasons of the year and periods of different population densities of the pest are given in Table II. During preparatory tillage, when irrigation water has been introduced into the tracts, the bugs are found mainly on the bunds within rice tracts, patches of higher ground within and near rice tracts and on the edges of channels and other waterways near rice tracts during seasons of both high and low population densities of the insect. When the crop is on the field, however, the bugs concentrate within the rice tracts. The distribution of bugs outside the rice tracts depends to a large extent upon the size of the bug population existing at the time. During an epidemic of *S. lurida*, a relatively large number are to be found outside the rice tracts in locations such as on rice-field bunds, along irrigation channels, etc. During seasons of low population density, however, bugs are found almost entirely within the rice tracts when a crop is in the field.

Development of _S. lurida_.

Copulation.

After feeding for about one week upon the rice seedling crop, bugs are observed in copulation in the field. With the next generation copulation is observed about

TABLE II.

Distribution of populations of *S. lurida* in and around rice tracts in relation to time of year.

Site	Bug population per sq. yd.							
	During epidemic of pest				During low population density of pest			
	When fields are fallow	During preparatory tillage	When crop in seedling stage	When crop ready for harvest	When fields are fallow	During preparatory tillage	When crop in seedling stage	When crop ready for harvest
On rice tracts	14A*–25N** 13A–31N 25A–17N 11A–12N	2A– — 6A– — 1A– — 2A– —	125A–12N 63A–60N 57A–32N 67A–52N	40A–27N 26A–14N 13A–11N 51A–18N	3A–17N 1·5A– 2N 0·25A– 3N 0·5A–12N	9A– — 4A– — 2A– — 11A– —	20A–47N 11A–17N 40A–10N 27A–12N	3A– 7N 7A– 3N 2A–12N 4A– 5N
On bunds	75A–12N 37A– — 60A– — 18A– —	53A– — 18A– 1N 12A– — 21A– —	3A– 6N 2A– 3N 8A–14N — – 2N	12A– 3N 4A– 5N 11A– — 23A– 4N	7A– 2N 6A– 1N 18A– — 12A– —	10A– — 14A– — 5A– — 12A– —	2A– 4N 7A– — 1A– 2N — – —	— – — 2A– — 1A– — 1·5A– 1N
Up to 8 ft. of edge of higher ground surrounded by tracts	32A– 6N 17A– — 27A–12N 11A– —	17A– — 35A– 3N 37A– — 27A– —	1A– 3N 4A– 7N 2A– 2N 4A– 4N	3A– 2N 4A– 1N — – 2N 11A– —	3A– — 7A– — 3A– — 2A– —	10A– — 1A– 1N 5A– — 17A– —	1A– 7N 3A– 1N — – — — – —	— – — — – — 1A– — — – —
At centre of patches of higher ground surrounded by tracts	14A– — 3A– 1N 2A– — 2A– —	11A– — 3A– 1N 7A– — 11A– —	2A– 1N — – — 1A– 1N 2A– —	2A– 1N 1A– — — – — — – —	1A – — — – — — – — — – —	5A– — 19A– 1N 17A– — 7A– —	— – — 1A– — — – — 2A– —	— – — — – — — – — — – —
On other higher ground	1A– — — – — 7A– — 3A– —	2A– — 3A– — 1A– — 1A– —	— – — — – — 2A– 1N 2A– —	2A– — 3A– — — – — 1A– —	1A – — — – — 1A – — — – —	2A– — 11A– — — – — 4A– —	— – — — – — 2A– — — – —	— – — 1A – — — – — — – —
On edges of channels and other waterways	2A– 3N 4A– 2N 13A– — 1A– —	7A– — 17A– — 12A– — 9A– —	7A– 2N 4A– 3N 6A– — 11A– —	2A– 1N 3A– 1N — – — 7A– —	— – — — – — — – — — – —	27A– — 9A– — 14A– — 4A– —	3A– — 1A– 2N — – — 1A– —	— – — — – — — – — — – —

* A = Adult. ** N = Nymph. — — No insect.

the time the rice is entering the shooting stage. Copulation was observed at all hours of the day. Egg-laying commenced about 10 days after copulation was first seen.

Oviposition.

When the rice crop is in the seedling stage, oviposition is chiefly on the rice plants where the eggs are deposited upon the leaves or less frequently upon the stem. On the leaves of rice seedlings, oviposition is predominantly on the underside of the apical three inches of the leaves. Oviposition also occurs upon weeds, especially those within, and, to a lesser extent, those bordering rice tracts. Among the weeds, those belonging to the family Graminaceae, such as *Isachne globosa* and *Echinochloa crus-galli*, are preferred by *S. lurida* for oviposition. Other alternate oviposition sites are the leaves and stems of weeds belonging to the family Cyperaceae such as *Cyperus difformis*, *Cyperus flavidus*, *Cyperus iria*, *Cyperus rotundus*, *Fimbristylis miliacea* and *Fimbristylis dichotoma*, and also to the family Marsileaceae, such as *Marsilea quadrifolia*, and the family Pontederiaceae of which *Monochoria vaginalis* is frequently a host for oviposition. Under very windy conditions when the crop is in the seedling stage, egg-laying is mainly on the shorter, better protected grasses growing around rice seedlings, rather than on the rice seedlings themselves.

During the maturing of the rice crop, oviposition is mainly on leaf sheaths at the basal parts of the rice stems and to a lesser extent on the grasses and débris surrounding the bases of the rice plants.

The eggs.

Under natural conditions, eggs are laid in two to four rows but predominantly in two rows with two to eight eggs per row. The incidence of seven eggs to a row is most frequent. Eggs in the mass are contiguous. The eggs in a row are in a straight line and alternate with those in the next row (Pl. XV, fig. 2). The structure of the eggs has been described by de Alwis (1941). The number of eggs per mass collected in the field usually does not exceed 14 to 15. In 22 out of 25 egg-masses the eggs were laid in two rows and in 17 of these each row contained seven eggs. More than four rows were not recorded, and the number of eggs per mass varied from 8 to 15. However when egg-laying occurred under artificial conditions such as when bugs were held in any container, marked differences were noted. Under such conditions both the number of eggs in a row and the total number of eggs in each mass showed a considerable increase. The number of rows in 25 egg-masses varied between two and eight, and the number of eggs per mass from 6 to 31. Females of *S. lurida* usually lay two to three egg-masses in a period of about two weeks and die within about seven days of laying the last egg-mass.

Eggs when freshly laid show a marked variation in colour, ranging from yellow to pink, orange, grey, blue-grey and light brown. As the eggs develop they change to a deep orange-red colour when the compound eyes, egg-burster and other structures of the nymph could be observed through the chorion. At a relative humidity of 75 per cent. and a temperature of 25–28°C. the average duration of the incubation period of 25 egg-masses was 6 days (4–7).

Humidity and hatching.

Freshly laid eggs of *S. lurida* were maintained at a constant temperature of 25°C. and at a series of relative humidities ranging from 22 to 92 per cent. The results of this study are given in Table III. Development at the lower humidities (22%) was brief and ended with the eggs losing shape and becoming desiccated. At relative humidities between 43 and 64 per cent., embryonic development proceeded up to the point where fully formed nymphs could be seen through the chorion but hatching never took place. At relative humidities of 75 per cent. and above, embryonic development and hatching proceeded normally.

The immature stages.

The structural details of the immature stages of *S. lurida* have been described by de Alwis (1941). On the seedling crop, the first-instar nymphs remain gregariously near the egg-mass for about 24 to 48 hours (Pl. XV, fig. 2) and then gradually disperse towards the lower regions of the stem of the rice plants. When freshly hatched, the nymphs can be observed to be attempting to feed on the leaves or leaf sheaths. Nymphal life is spent almost entirely on the leaf sheaths at the lower regions of the rice plants if water is present in the tracts, or, on the soil, low grasses, débris around the rice plants and at the bases of rice plants if no water is present in the rice tracts. At a relative humidity of 75 per cent. and a temperature of 25–28°C., the average duration of the instars over 25 examples was first, 5 days; second, 9 (7–11); third, 7 (5–10); fourth, 9 (7–11) and fifth instar, 12 days (11–13).

TABLE III.

Effect of relative humidity on hatching of eggs of *S. lurida* at a constant temperature of 25°C.

No. of eggs	Relative humidity (%)	Number hatched	Other observations
33	22	0	Eggs lost shape, desiccated
42	43	0	Embryos developed within eggs
55	64	0	Embryos developed within eggs
94	75	72	Development and hatching normal
25	86	80	Development and hatching normal
52	92	86	Development and hatching normal

Number of generations per annum.

The relationship of the life-cycle and generations of *S. lurida* to the rice-growing seasons and off-seasons is fairly clear-cut. In the Southern Province the first sowing of the rice crop for the year is done in April and May. Bugs migrate on to the seedling crop from their aestivation sites when the crop is about two to three weeks old. Copulation and oviposition, which commence in mid-May on the rice seedlings, continue until the end of July, and the aestivating population that had originally invaded the crop dies during this period after egg-laying. The nymphs emerging from these eggs commence to mature in early July on the crop which is in the advanced shooting or flowering stage. A small number of bugs of this generation, which represents the first complete generation on the rice crop, reach sexual maturity and are responsible for a small amount of egg-laying commencing in mid-August and ending in mid-September when harvesting commences. The remainder that mature into adult bugs later, start migration to their aestivation sites from the crop during harvest. The nymphs hatched out from the small amount of egg-laying represent a partial second generation on the crop. These nymphs continue development on the scanty supply of wild grasses in the harvested rice tracts, which are in process of desiccation, and then migrate, in the fourth and fifth instars, to the aestivation sites where they gradually reach the adult stage with the advance of aestivation. These adults of the second generation, together with those from the first generation, proceed in due course to invade the second crop, in which the sequence of events follows a similar course to that described for the first crop.

There are, therefore, four overlapping generations in a full year. The first generation and part of the second is produced on the first crop and the remainder of the second, the third and part of a fourth on the second crop. Two overlapping generations are in aestivation at each period intervening between crops.

Aestivation of *S. lurida*

The commencement of migration of adults of *S. lurida* to aestivation sites is dependent upon the degree of moisture and shade obtaining within the rice tracts. If dry conditions prevail, the stubble will be short and erect and the soil at the base of the rice plants will have begun to dry and cake and the bugs will migrate to the bunds of the rice-fields and neighbouring higher ground, which form the chief aestivation sites. If, on the other hand, moisture in any quantity is present in the rice tracts, and the stubble is that of lodged rice plants providing damp and shaded conditions, bug populations in all stages of development remain in the rice tracts even after harvest and migrate to other sites when the tracts are completely dried. Once the migration has been completed, however, the bugs do not seek out areas of higher moisture content for aestivation.

Adult bugs are rarely noticed on the wing at the end of each rice crop. This fact when considered together with the pattern of distribution of the bugs in their aestivation sites strongly indicates that migration to these sites by the adults is mainly achieved by walking. Bunds in the rice tracts invariably harbour the largest populations of aestivating bugs. On the rice tracts as such, bugs are found under masses of rice stubble or within the cracks of caked and dried rice-field soil. On bunds, the bugs are located within cracks of the dried soil or merely at the bases of dried grasses among the débris. The other important aestivation sites are patches of higher ground surrounded by rice tracts, high ground bordering rice tracts and on the edges of channels or waterways containing water or otherwise. On the higher ground surrounded by rice tracts, bugs are especially concentrated on the area nearer the rice tracts (Table II), and on such ground the bugs are found chiefly in the débris at the base of grasses and other plants. In this situation the bugs are also frequently found, though in very small numbers, under the dried leaf-sheaths of banana plants or in the crowns of young coconut palms. The edges of waterways are not a particularly favoured aestivation site (Table II), and bug populations are present in these sites only at the ends of seasons of very heavy bug incidence. All aestivation sites mentioned are not necessarily situations having obvious moist conditions. On the contrary, most of the aestivation sites are usually completely desiccated but invariably they give protection against sunlight.

Tracts with a few inches of dried mud followed by a sandy soil below, which do not desiccate easily to produce deep cracks, only apparently harbour more aestivating bugs than those dried muddy tracts which desiccate rapidly at the end of the season and crack deeply at that stage. The results of a survey of bug populations easily accessible in two sites of the types mentioned are given in Table IV. It was impossible to assess bug populations within the deep cracks of the highly desiccated rice tracts. However, bugs have been traced up to a depth of 2 ft. within such cracks in caked up and desiccated fallow rice tracts. That such tracts actually harbour large bug populations can be seen from the data in Table IV, which also deals with bug incidence in the same tracts after the rains and when water was introduced preparatory to tillage.

Behaviour of S. lurida *in the aestivating and active stages.*

Bugs in the aestivation sites are predominantly in the adult stage. Some nymphs are also present (Table II) but this is only true at the commencement of aestivation and they are mainly in the fourth and fifth instars. Development of these nymphal stages into adult bugs was observed to proceed in the aestivation sites, so that, with the advance of aestivation, almost all the bugs observed were in the adult stage.

TABLE IV.

Bug populations in two areas of differing soil type assessed during the same two consecutive seasons.

Site	Bug population per sq. yd.*			
	Tract in fallow period moist On tract with about 6 in. dried mud below which sandy soil in fallow period		Tract in fallow period desiccated On tract with over 2·5 ft. dried mud deeply cracked in fallow period	
	When fields were fallow	When water introduced to tracts preparatory to tillage	When fields were fallow	When water introduced to tracts preparatory to tillage
Rice tracts	11	1·5	0	6·5
Bunds	27	2	0·5	9
Up to 8 ft. from edge of higher ground surrounded by rice tracts	16	6	1	12·5
At centre of patches of higher ground surrounded by rice tracts	1·5	2	0	15
On other higher ground ..	2	2	0	3·5
On edges of channels and other waterways	0·25	25·5	0	19
On irrigation reservations ..	3	4	0	7
Under shrubs, etc., on road edges	0	2	0	4

* Average of 4 readings in each case.

Aestivating bugs are gregarious in habit, being found at least in pairs close to each other in the aestivation sites; this is especially so in patches of higher ground. In the rice-field bunds or in other situations, such as near banana clumps, bugs are present in larger groupings (Table V).

The feeding activity of adults fluctuates widely according to the season. Bugs in the active phases, when the crop is in the field, feed almost continuously and are responsible for various lesions, and even more drastic effects on the crop, which will be described later. Furthermore, bugs in the active phase have an abundant supply of growing food-plants such as rice and wild grasses. Feeding during this stage takes place at all hours of the day and night.

TABLE V.

Numbers and sex of bugs in groups found in various sites during aestivation.

Site	Average no. bugs per group, and range	Average no. bugs of each sex per group, and range	
		Male	Female
At base of banana clumps on higher ground (5 groups of bugs)	9·8 (6–16)	5 (3–7)	4·8 (2–8)
At base of coconut palms on higher ground (2 groups)	2·5 (2–3)	1	1·5 (1–2)
At base of weeds on higher ground (21 groups)	2·9 (1–6)	1·6 (0–4)	1·3 (0–3)
On bunds (6 groups)	12 (5–21)	6 (2–12)	6 (3–11)

Aestivating bugs have not been observed feeding under natural conditions during the day-time but remain relatively motionless in the aestivation sites. At dusk a few bugs have been noted to insert their stylets into withering grasses in their environment and withdraw them after a short period, and some activity was apparent when bugs performed limited walking in their aestivation sites but they

TABLE VI.

Survival of adults of *S. lurida* under various conditions of food sources and relative humidity.

Environmental conditions	Duration of exposure to conditions	Percentage survival
On rice plants	30 days	96
	60 ,,	80
On cotton lint moistened with water	30 ,,	96
	60 ,,	70
No substratum—at room temperature and 60% R.H. ..	24 hr.	0
No substratum—at room temperature and 70% R.H. ..	24 ,,	12
No substratum—at room temperature and 78% R.H. ..	24 ,,	90
	48 ,,	62
	72 ,,	0
No substratum—at room temperature and 87% R.H. ..	24 ,,	100
	48 ,,	100
	72 ,,	80
	96 ,,	2

TABLE VII.

Effect of exposure of adults of *S. lurida* to a humidity gradient.

Time of observation (bugs introduced at 10.30 a.m. or 4.30 p.m.)	Distribution of 40 bugs introduced at lowest humidity chamber at 10.30 a.m. or 4.30 p.m.								Distribution of 40 bugs introduced at highest humidity chamber at 10.30 a.m. or 4.30 p.m.							
	Relative humidity (%)								Relative humidity (%)							
	7	19	25	43	47	74	87	92	7	19	25	43	47	74	87	92
10.30 a.m.	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40
11.30 a.m.	22	10	2	3	0	3	0	0	0	0	0	0	0	0	0	40
12.30 p.m.	21	9	1	3	3	3	0	0	0	0	0	0	0	0	0	40
1.30 p.m.	21	9	1	2	2	5	0	0	0	0	0	0	0	0	0	40
2.30 p.m.	21	8	2	0	5	3	0	1	0	0	0	0	0	0	0	40
3.30 p.m.	16	7	2	2	5	6	0	2	0	0	0	0	0	0	0	40
4.30 p.m.	14	11	4	0	2	5	0	4	0	0	0	0	0	0	0	40
5.30 p.m.	5	4	0	0	4	5	3	19	0	0	0	0	0	2	3	35
6.30 p.m.	7	1	2	1	7	4	3	15	2	1	3	0	3	2	2	27
7.30 p.m.	6	0	0	1	2	7	5	19	5	2	3	2	2	3	2	21
8.30 p.m.	5	0	3	3	2	5	4	18	5	3	0	1	2	5	7	17
9.30 p.m.	5	2	0	0	0	4	7	22	6	1	0	0	1	4	2	26
4.30 p.m.	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40
5.30 p.m.	10	4	2	2	5	1	5	11	1	0	0	0	0	0	10	29
6.30 p.m.	2	2	0	0	2	4	5	25	2	5	3	3	2	5	6	14
7.30 p.m.	1	1	0	3	2	5	7	21	5	4	2	2	1	1	7	18
8.30 p.m.	1	2	1	1	1	9	3	22	0	0	1	0	1	4	4	30
9.30 p.m.	5	0	1	1	1	3	3	26	1	0	1	0	1	2	4	31

rarely took wing. Feeding of aestivating bugs under field conditions, therefore, is very restricted.

The condition of the alimentary tract and the reproductive organs of aestivating adults was examined by dissection. Little or no food material was present in their guts when compared to those of bugs in the active condition when the crop is present; in the latter case, the alimentary tracts were consistently dilated with food material. The reproductory organs were underdeveloped and represented the condition apparent in sexually immature adults in the active stage. The relatively empty alimentary tracts and the retarded condition of the internal reproductive organs continued until the first rains and migration to the seedling rice crop began.

Laboratory tests have been conducted to evaluate the importance of food and moisture in the survival of freshly emerged adults under caged laboratory conditions. Bugs were either maintained on rice plants or on plugs of cotton lint moistened with water, or without any food or material from which moisture could be imbibed, kept under a series of relative humidities ranging from 60 to 90 per cent. The adult bugs used in these tests were about 3 days old, and the results are given in Table VI. Survival was best, as would be expected, where the rice plant was available, but good survival was also noted with water alone. Under moist conditions alone, without any food, survival was poor. Aestivating bugs gave similar results when subjected to the same test conditions.

The response of adults to moisture was studied by using a simplified apparatus, illustrated in Plate XV, fig. 3. This consisted of an elongated chamber 21 in. long, 4 in. wide and 0·75 in. deep, with a closely fitted lid. The chamber was divided into eight equal sections. The bottom of each section carried a fine-mesh (80 gauge) trough 1·5 in. square and 0·5 in. deep. There was a circular opening of 0·5 in. diameter at one end of the cover. This opening could be tightly closed with a cork. The chamber was prepared for use by placing it on top of a series of eight staining jars each carrying a saturated solution of a particular salt. Each of the eight mesh troughs rested within the top of one staining jar and the liquid surface in a jar was about 0·1 in. below the mesh. The solutions in the jars were selected to give a humidity range from 11 to 92 per cent. at 25°C., and the jars were so arranged as to give a humidity gradient from one compartment to the next. The results of these studies are given in Table VII. The pattern of response of both active and aestivating bugs to a moisture gradient was the same. The humidity reaction of bugs placed under conditions of very low humidity was sharper after dusk than during day-time. Bugs placed under high humidity conditions remained undisturbed until dusk, when small-scale wandering, apparently in search of food, began. There was no difference between the humidity reactions of aestivating and active adults.

Damage to rice plants caused by feeding of *S. lurida*.

Field observations.

Damage to the rice crop by *S. lurida* in the field can be classified into four categories, *viz.*, (a) highly localised and clearly demarcated light- to deep-brown lesions on leaves, (b) more extensive chlorotic markings on leaves, (c) death of central shoot or portions of central shoot, (d) death of entire plants.

Localised leaf lesions caused by direct feeding of *S. lurida* upon the leaves of rice plants result initially in the production of water-soaked areas around the point of insertion of the oral stylets. With time, these areas turn brown, usually darker brown at the margins, and wither and at this stage they strongly resemble those caused by the fungus disease, *Piricularia oryzae*. As these lesions age in the field they become bleached into a creamish to very light-brown colour. Lesions of this description (Pl. XVI, fig. 1, A & B) are found mainly on seedling rice and

TABLE VIII.

Effects of feeding of various numbers of adults of *S. lurida* for varying periods of time upon three-week-old rice seedlings.

Location of caged bugs	No. of bugs per plant	Duration of exposure (hr.) of plants to bugs	Observations on plants after infestation with bugs										
			1 day later	2 days later		4 days later	7 days later			14 days later			
			Original central shoot	Other leaves	Original central shoot	Original central shoot	Original central shoot	New shoot	Main stem	No. of tillers	Original plant	Original central shoot	New shoot
Parts of stem above 1·5 in. from growing point	1	24	Flaccid	1–1S* 2–N	Flaccid	Chlorotic	Tip dried	Chlorotic	Normal	2	Normal	Tip dried	Normal
	1	48	Flaccid	3N	Rolled	Chlorotic	Tip dried	Normal	Normal	1	Normal	Tip dried	Normal
	1	72	Rolled	1–1S 2N	Rolled	Chlorotic	Tip dried	Normal	Normal	1	Normal	Tip dried	Normal
	1	96	Rolled	2–2F 1N	Rolled	Dried	Dried	Chlorotic	Necrotic	2	Necrotic	Dried	Tip dried
	2	24	Rolled	2–2S 1N	Rolled	Chlorotic	Tip dried	Normal	Normal	2	Normal	Tip dried	Normal
	2	48	Rolled	1–1S 2N	Rolled	Chlorotic	Tip dried	Normal	Necrotic	2	Normal	Tip dried	Normal
	2	72	Flaccid	2–2S 1N	Dried	Chlorotic	Dried	None	Necrotic	2	Dried	Dried	None
	2	96	Rolled	3N	Dried	Dried	Dried	None	Necrotic	5	Dried	Dried	Chlorotic
	3	24	Rolled	3–4S	Dried	Dried	Dried	None	Necrotic	1	Dried	Dried	None
	3	48	Rolled	3–4S	Dried	Dried	Dried	None	Necrotic	3	Dried	Dried	None
	3	72	Rolled	3–8S	Dried	Dried	Dried	None	Necrotic	3	Dried	Dried	None
	3	96	Rolled	3–6D	Dried	Dried	Dried	Chlorotic	Necrotic	3	Necrotic	Dried	Tip dried
	4	24	Rolled	3–7D	Dried	Dried	Dried	None	Necrotic	4	Necrotic	Dried	None
	4	48	Rolled	3–10D	Dried	Dried	Dried	None	Necrotic	5	Dried	Dried	None
	4	72	Rolled	3–9D	Dried	Dried	Dried	None	Necrotic	4	Necrotic	Dried	Tip dried
	4	96	Rolled	3–7D	Dried	Dried	Dried	None	Necrotic	2	Necrotic	Dried	None
At and up to 1·5 in. from growing point	1, 2, 3 and 4 bugs, each for 24, 48, 72 and 96 hr.		Rolled	3–3 to 10D	Dried	Dried	Dried	None	Necrotic or dried	None	Dried	Dried	None
	Check		Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal

Three plants were used for test feeding.
N = normal, S = snapped, F = flaccid, D = dried.
* First figure = number of plants affected; second figure = number of leaves affected in the plants.

rarely on maturing rice plants and are strongly reminiscent of those caused by MIRIDAE of the genera *Helopeltis*, *Sahlbergella* and *Distantiella* on the cacao plant (J. Nicol, ?1947 (The insect pests of cacao trees.—Typescript report, W. Afr. Cacao Res. Inst., Tafo); Carter, 1952; Fernando & Manickavasagar, 1956).

Chlorotic lesions are chiefly observed on seedling rice in the pre-shooting stage. It is the commonest observable type of damage associated with attack in the field. The lesions are white in colour without clearly demarcated margins. The white areas gradually diffuse into the green of the healthy portions of the leaf. These lesions are extremely variable in size and location. When they first appear they are as turgid as the rest of the leaf but they soon lose their turgidity, wither, turn light brown and gradually dry up, resulting frequently also in death of portions of the leaf beyond the lesions (Pl. XVI, fig. 1, C).

Death of the central shoot is chiefly observed in rice plants in the pre-shooting stage in the field. The central shoot is either rolled up longitudinally and wilted, or completely dried.

Death of entire plants is noticed only in seedling rice up to about six weeks old in the field during seasons of heavy attack.

Laboratory observations.

Experiments under controlled laboratory conditions were next conducted with a view to elucidating the conditions under which the various responses of the rice plant to feeding, observed in the field, occurred. Feeding tests were carried out with adults in the active phase both on seedling and on maturing rice plants.

The first series of tests aimed at investigating the possibility that a toxin, which would eventually become systemic in its action, was involved in the feeding damage caused by this pest. Adults were enclosed on two of the well-developed leaves of each of three 4-week-old rice seedlings at the rate of two bugs per plant and four bugs per plant. Feeding was permitted for 48 hours, and observations were maintained on the development of lesions and on the effect of the feeding on the growth of the plants.

The first reaction was apparent within two hours of commencement of the test; parts of the leaves which had been fed upon lost their turgidity and the tissues appeared collapsed. In normal sunlight these areas turned brown and their margins were clearly demarcated from the rest of the green leaf by a fringe of deep brown. These lesions strongly resembled those caused by the fungus disease, *Piricularia oryzae*, on rice. Leaf tissues which had been fed upon usually reached this stage within 24 hours of commencement of feeding. These necrotic patches dried up completely within about two days and in about one week had become bleached into a very light-brown colour (Pl. XVI, fig. 1, A & B). Whilst these changes were taking place on the portions of the leaves exposed to direct feeding by the bugs the rest of the seedlings grew normally. No difference could be noted on the growth rates of the test seedlings over a period of two weeks, when compared with plants not exposed to feeding.

In the next series of tests, adults were caged on the stem either above 1·5 in. from the growing point (which is located at the base of the seedling) or at and up to 1·5 in. from the growing point of 3-week-old rice seedlings. The details of these tests, summarising the results obtained from plants for each infestation rate and test period of exposure of plants to bugs, are given in Table VIII. These data indicate that the first reaction of the seedling to feeding by the bugs, whether near the growing point or above 1·5 in. from it, is the wilting of the central shoot followed by a longitudinal rolling up of this shoot. The term central shoot is used here to connote the youngest leaf which was emerging at the time the feeding tests were started. The speed of this response was related to the number of bugs feeding on the stem and the location of the feeding. Feeding near the growing point evoked the wilting of the central shoot more rapidly than feeding on the upper regions of the stem.

Within two days of the test feeding by the bugs the older leaves showed a response to the attack. Leaves either lost their normal turgidity and snapped along the midribs, or had wilted completely and dried. This reaction of the rice seedlings was also proportional to the number of bugs feeding, the duration of the feeding and the location of the feeding. Here again the reaction was more drastic where feeding on the stem was allowed near the growing point.

The central shoot invariably wilted, rolled up and gradually dried within two days in all cases where two bugs were allowed to feed for 96 hours or three or more bugs were allowed to feed for 24 hours or more, regardless of the location of the feeding on the stem. In all those cases of one bug feeding for 24 to 96 hours or two bugs feeding for 24 to 48 hours on regions of the stem above 1·5 in. from the growing point, death of the central shoot was not complete. That portion of the growing shoot which had emerged at the time of feeding wilted and eventually dried up. The portion of the growing shoot which emerged subsequently appeared healthy on emergence but exhibited chlorosis in patches. When fully emerged, such leaves showed the typical leaf-tip death. The chlorotic patches varied in size and location. These patches were pure white in the centre but gradually diffused into the green of the rest of the leaf (Pl. XVI, fig. 1, C). Such chlorotic patches withered within about 48 hours after emergence and opening of the young leaf and if they extended over a transverse section of the leaf that portion of the leaf beyond the chlorotic patch also wilted and dried. The subsequent new shoot occasionally also showed chlorotic patches.

Another consequence of feeding by *S. lurida* on rice seedlings is the killing of the main axis of the plant unless only light feeding on the regions above 1·5 in. from the growing point was permitted. In those plants where feeding was allowed above 1·5 in. from the growing point, death of the main axis resulted where two bugs fed for 72 hours or three or more bugs fed for 24 hours or more. However, in all cases of such feeding, death of the plant was not complete because tillering was vigorous within 14 days. On the other hand, where bugs fed around the growing point, death of the plant, which occurred in all cases, was complete, and no tillering occurred.

In the next series of tests, adults were allowed to feed either at the base or at or around and above the growing point of rice plants 2½ months old, which had passed the shooting stage. In such plants the growing point was about 6 in. or more above the base of the plants. Bugs were enclosed at the rate of three per plant to feed upon one of the regions of the stem, *viz.*, at the base, at the growing point or 3 in. above the growing point. Each of the regions exposed to the bugs extended over about 3 in. of stem length. Feeding at the base had to be continuous for 21 days before the plant showed the first reaction of wilting and subsequent drying up. Sectioning of the base of the stems of such plants showed that concentrated mechanical injury caused by the penetrating stylets of the bugs during feeding had caused their death. Where feeding was permitted at the growing point, death of the central shoot occurred within three days of feeding and the entire plant had dried on the twelfth day after feeding. Where feeding occurred above the growing points, the effects were similar to that obtained with light feeding in the same region of seedling rice plants, in that chlorotic patches developed on the new leaves after the bugs were withdrawn.

Parasites and predators.

S. lurida has no recorded predators in Ceylon either in its immature or adult stages, but attack on the eggs by a Hymenopterous parasite is extensive. What appears to be a low mortality of the adults caused by entomogenous fungi, particularly during aestivation, has also been observed.

The egg-parasite is the minute Scelionid, *Telenomus triptus* Nixon. This parasite is extremely active in the field when the bugs are ovipositing and during parasitisation of egg-masses it is extremely tenacious and cannot be dislodged even by violent movement of the egg-mass (Pl. XVI, fig. 2). Parasitisation of eggs under field conditions fluctuated between 30 and 36 per cent. as assessed from recorded observations between the years 1953 and 1955.

Under laboratory conditions, the parasitisation of eggs by *T. triptus* was observed closely. One- to ten-day-old parasites were used, and the results of these studies are given in Table IX. The parasites, on being provided with a leaf carrying an egg-mass, rapidly located it and then proceeded to examine it closely with their antennae in rapid motion. Only those eggs which had not been previously parasitised were used by the parasite for oviposition. Oviposition in a fresh egg-mass was not effected in an orderly fashion but in no instance was a parasite observed to oviposit or even attempt oviposition more than once in a single host egg. The ovipositor is inserted either into the egg cap or into the side of the egg. The time taken for each oviposition was highly constant at 1 minute 45 seconds, and 3 to 5 seconds later the next commenced. Eggs that had been successfully parasitised turned deep purplish-black in colour on about the third day later. As can be seen from Table IX, parasites maintained on sugar solution, and 1 to 10 days old, can successfully parasitise host eggs under laboratory conditions. Host eggs, which normally hatch in six days, were susceptible to successful parasitisation by *T. triptus* under laboratory conditions even up to the fifth day of their development when the fully developed nymphs could be observed through the chorion. However, 5-day-old eggs more frequently produced nymphs than parasites if attacked by *T. triptus*. On an average, parasites emerged from the host egg from 12–15 days after oviposition. Parasitised eggs on emergence of the parasites had irregular apertures on the operculum and a blackish residue within. *T. triptus* lived from 8 to 22 days after emergence if maintained on sugar syrup.

During aestivation and in the following preoviposition period *S. lurida* is susceptible to attack by fungi (Pl. XVI, fig. 3). If diseased, the insects appear sluggish and die shortly afterwards, and 24–48 hours later fructifications of a fungus appear. Two fungi recovered from affected bugs are *Metarrhizium anisopliae* and *Penicillium citrinum*. The former is normally responsible for the green muscardine disease in insects but the latter has to date not been recorded as being entomogenous.

Discussion.

A study of the Japanese literature on *S. lurida*, especially the work of Katsumata (1929) and Kawasi (1955), shows many interesting similarities and also differences in behaviour between *S. lurida* in Japan and in Ceylon.

In Japan, *S. lurida* develops one generation per year and the first generation of bugs developed on the rice crop hibernates in the winter in the adult state, to invade the next year's crop in the seedling stage. In Ceylon, on the other hand, the pest develops 3 to 4 generations per year on the two rice crops and aestivates as an adult during the two fallow periods. These differences are, however, related to radical differences in the climates obtaining in the two countries.

In Japan, *S. lurida* feeds both as an adult and in the nymphal stages on all parts of the rice plant, whether seedling, maturing or mature. In Ceylon, this insect feeds as an adult on all parts of the seedling and only on the basal region of maturing or mature rice plants, while in the nymphs, feeding is limited to the basal parts of the rice plants whether seedlings or otherwise. The difference in the feeding habits of this insect in Japan and Ceylon results in differences in the incidence and distribution of their feeding lesions on the rice plants in the two countries.

TABLE IX.

Parasitisation of eggs of *S. lurida* by *Telenomus triptus*.

No. of egg-masses introduced	No. of eggs in masses	Age of eggs (days)	No. of parasites to which eggs exposed	Age of parasites (ays)	Period for parasites to emerge (days)	No. of parasites emerged	No. of nymphs emerged	Recent parasitisation (%)
3	70	1	1	1	11–13	67	—	95
4	16	1	1	3	15	15	—	93
1	10	1	1	9	12	10	—	100
9	100	1	1	10	—	—	100	—
1	14	1	2	2	12	14	—	100
1	14	1	2	2	15	14	—	100
1	25	1	2	2	12–15	24	—	96
1	28	1	2	2	13–15	28	—	100
1	22	2	2	2	12–13	20	—	99
1	27	2	2	2	13–15	27	—	100
2	40	3	2	2	13–15	34	—	85
1	27	4	2	2	13–15	27	—	100
1	29	5	2	2	12	12	—	42
1	8	5	1	1	—	—	8	—
1	31	5	2	2	14–16	31	—	100
1	15	5	1	9	—	—	15	—
1	24	5	1	9	—	—	24	—

It would appear that, when the bugs feed upon the stems of rice plants, a toxin which either diffuses upwards or a toxin with localised action but which affects the translocation of water is involved. The latter appears to be more likely as can be seen from the further effects of feeding by *S. lurida*. This type of damage is similar to that caused by the Pentatomid bug, *Chlorochroa sayi* (Stål), on potato plants in the U.S.A., where the first symptom is the wilting of the leaves (Daniels, 1939).

Very frequently the stylet tract of the feeding bug is noticeable in the centre of the extensive white lesions (see p. 571) that develop subsequent to feeding. The extent of these lesions most likely defines the limits of the diffusion of a toxic component in the salivary secretion which has as one of its properties the inhibition of the development of chlorophyll. The fact that only feeding near the growing point always leads to the complete death of the plant without subsequent tillering is a further indication that the salivary toxin is not one which becomes fully systemic in its action but diffuses only over a limited area from the point at which the stylets were inserted.

In addition to the various reactions in the rice plant to feeding by *S. lurida* noted in Ceylon, Kawasi (1955) has recorded the development of sterile branches from the higher nodes in attacked rice plants in Japan. This phenomenon of upper nodal branching is usually recorded in Japan as being a result of exposure to extreme physiological stress such as to frost. This type of branching never occurs in Ceylon and is more likely to be the consequence of physiological differences between the Japonica and Indica varieties of rice grown in the two countries rather than of physiological difference between the strains of *S. lurida* in Ceylon and Japan.

Summary.

The black rice bug, *Scotinophara lurida* (Burm.), is widely distributed in Ceylon in areas where rice is grown under irrigation. It first became a serious pest in 1940 and, periodically since, it has assumed epidemic proportions in the Southern Province where two crops of rice are grown annually. Each crop takes from 3½ to 4 months to mature, the fields lying fallow in the intervening periods. During these periods the insects aestivate, in the adult or late nymphal stages, in cracks in the bunds in the rice-fields or on neighbouring higher ground. They remain motionless for the most part during aestivation, are gregarious and occur as much as 2 ft. below ground-level.

The adults leave the aestivation sites in April and May and settle in the first crop when it is two to three weeks old, and a subsequent aestivating population behaves similarly in November and December for the second crop. There is at first considerable flight activity at dusk, and at night, and after feeding for about a week on the rice seedlings copulation takes place and oviposition commences about ten days later.

Egg-masses in the field usually consist of two rows, each containing seven eggs, but under artificial conditions the number of eggs and rows were considerably in excess of these figures. At a relative humidity of 75 per cent. and temperature of 25–28°C. in the laboratory, the average duration of the stages was: egg, 6 days; the five instars, 1st, 5; 2nd, 9; 3rd, 7; 4th, 9 and 5th, 12 days, respectively.

There are four overlapping generations during the year. The first generation, and part of the second, is produced on the first crop and the remainder of the second, the third and a part of a fourth generation on the second crop. The periods intervening between the two crops are passed in aestivation by the nymphal or adult stages of two overlapping generations.

Damage to the rice crop in the field consists of localised leaf lesions, chlorotic lesions, which gradually dry up and frequently result in the death of that portion of the leaf between the lesion and the leaf tip, death of the central shoot or death

of the entire plant. Laboratory experiments showed that feeding near the growing point of a seedling always leads to death of the plant without subsequent tillering but, when feeding took place more than 1·5 inches above the growing point, the leaves developed necrotic patches and dried off but the plant tillered and the rest of it grew normally. The nature of the chlorotic areas surrounding the initial lesions, it is suggested, may be due to the diffusion of a toxic compound in the salivary secretion of the insect.

No predators of *S. lurida* have been recorded in Ceylon but the eggs are parasitised by *Telenomus triptus* Nixon and parasitisation in the field was assessed as between 30 and 36 per cent. in the years 1953 to 1955. The parasite only lays one egg in a single host egg. Details are given of the course of parasitisation under laboratory conditions.

S. lurida is a major pest of rice in China and Japan and the behaviour of the pest in these countries is compared with that in Ceylon.

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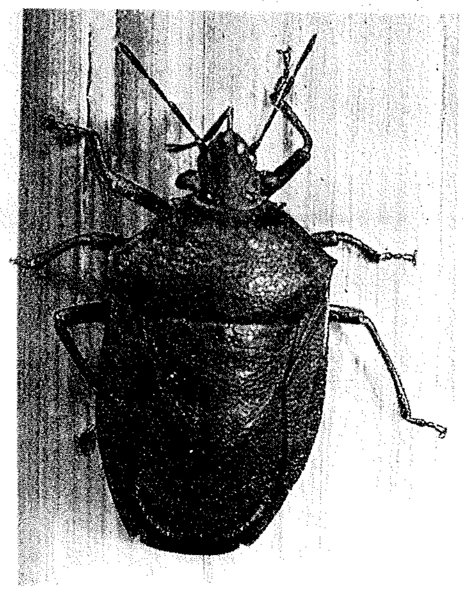

FIG. 1. Adult of *Scotinophara lurida* on rice leaf (× 6, approx.).

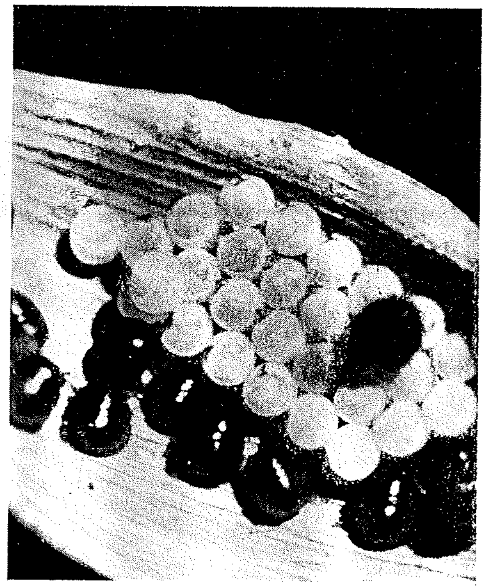

FIG. 2. Freshly hatched nymphs of *S. lurida* near egg-mass. The egg-bursters can be seen below the open opercula of the hatched eggs (× 10, approx.).

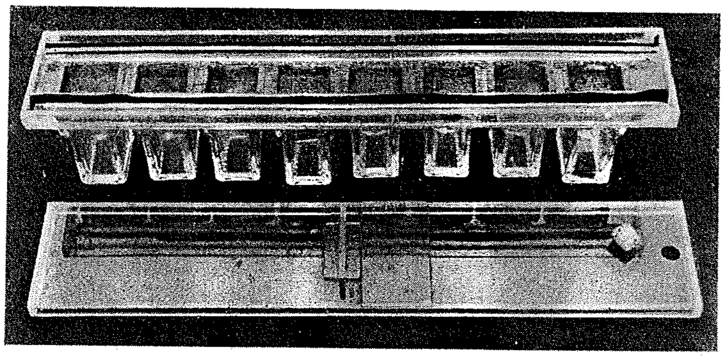

FIG. 3. Equipment used for the study of the reactions of adults of *S. lurida* to a humidity gradient.

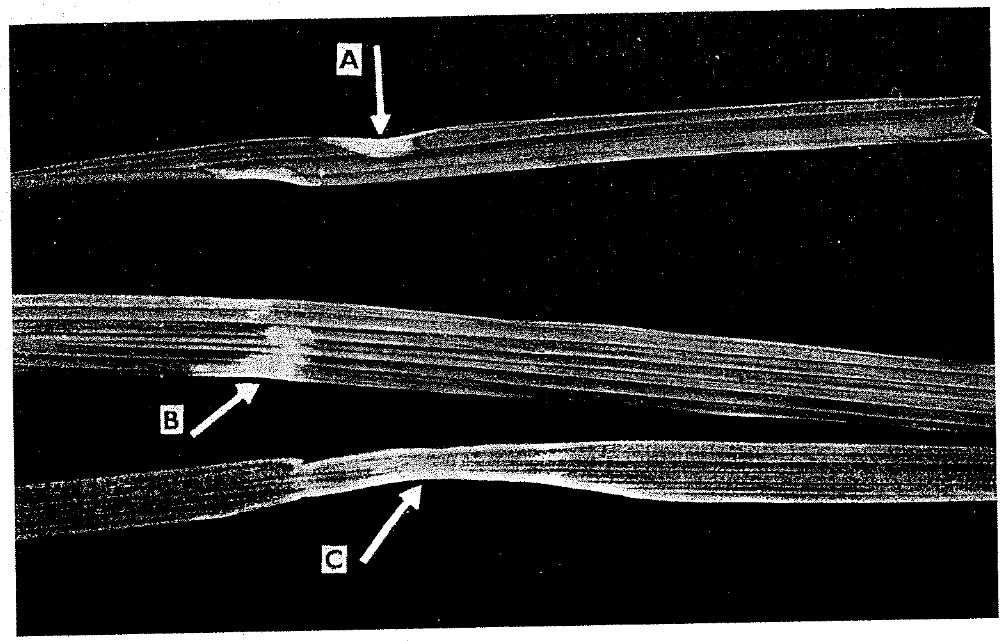

FIG. 1. Various types of lesions caused by feeding of *Scotinophara lurida* on rice plants. A, B, localised lesions caused directly by feeding; C, chlorotic lesion.

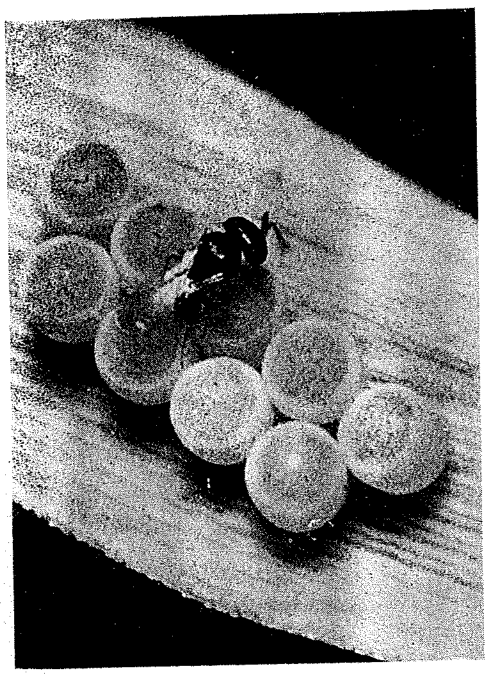

FIG. 2. *Telenomus triptus* ovipositing in eggs of *S. lurida* (× 20, approx.)

FIG. 3. Adult of *S. lurida* killed by the fungus, *Metarrhizium anisopliae*.