Effect of Some Ecological Factors on the Development and Maturity of Gonads OF Spathosternum prasiniferum Walker (Orthoptera : Acridoidea)

THESIS SUBMITTED FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN ZOOLOGY

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Under the Supervision of Dr. Syed Abdul Aziz Reader in Zoology

DEPARTMENT OF ZOOLOGY
ALIGARH MUSLIM UNIVERSITY, ALIGARH (Uttar Pradesh, India) 1972
I certify that "Effect of some ecological factors on the development and maturity of gonads of Sporothronum prasiniferum Walker", is the original work of Mr. Mohammad Iqbal and is suitable for submission for the award of the degree of Doctor of Philosophy in Zoology of the Aligarh Muslim University, Aligarh. This work has been done by the candidate under my supervision.

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I. INTRODUCTION

Orthopteroid insects are a source of considerable damage to agriculture as they voraciously feed on the green vegetation rendering large tracts almost barren. With the phenomenal increase in human population and limited food resources, man cannot afford to incur such heavy losses. Although a good number of these pests have been brought under control yet there still remain many destructive insects against which little progress has been made. *Spalthosternum prasiniferum* Walker 1871 is one of them.

The grasshopper, *S. prasiniferum* Walk., has been reported from India, Ceylon and China (Uvarow, 1953). In India this grasshopper has been reported from Maharashtra, Bengal and Bihar by Kirby (1914). In the course of present investigation, it has been observed feeding on a great variety of food-plants in Uttar Pradesh and Punjab. It is primarily a pest of *Zea mays*, *Pennisetum typhoides* and *Oryza sativa* but also causes damage to many other field crops like *Sorghum vulgare*, *Saccharum officinarum*, *Triticum aestivum* and *Hordeum vulgare*. Among the garden plants, viz., *Solanum melongena*, *Solanum nigrum* and *Abelmoschus esculentus* and weeds like *Echinochola colona*, *Hemarthria compressa*, *Setaria verticillata*, *Cynodon dactylon* and *Sorghum halopense*
are also seriously damaged by this insect. In recent years the extent of damage has increased so enormously that it has become a pest of considerable economic importance.

Considerable work has been done on the effect of ecological factors influencing the development of acridoid pests at different stages of their lives. Notable contributions in this field during the last decade have been made by Dudley (1961) on locusts, Singh (1961) and Grewal and Atwal (1968) on *Chrotonomus trachyterus* Blanchard, Misra (1962) on *Campula pallucida* Scudder, Barnes (1963, 1965) on *Melanoplus differentialis* Uhler and *Melanoplus sanquisipes* Fabricius respectively, Pradhan and Peswani (1961) and Rizvi (1967) on *Hieracium micoreeiatus* Bolivar, and Antoniou and Hunter-Jones (1968) on *Sympochroa pteron ematina* Walker. No information concerning *S. prasiniifera* Walk. is available in this regard. It was, therefore, considered necessary to work out the aspect mentioned above in great detail. However, some information is available on allied species of *Spathostinae* Krauss. Golding (1948) published field observations on *Spathostinae nigrotaeniata* Stål and *Spathostinae pygmaea* Karsch. Joyce (1952) observed the soil condition preferable for the oviposition of *S. nigrotaeniata*.

In order to investigate the effects of ecological factors influencing the development especially the maturation of gonads of *S. prasiniifera* Walk., the present author studied first the development of this grasshopper under constant ecological factors. Subsequently they
were reared under different levels of ecological factors such as food-plant, temperature, humidity and density. Field observations were made during the period of two years, from August 1969 to July 1971, and were compared with the findings under laboratory conditions. The present author has also tried to make necessary comparisons with other orthopterous insects.

For the sake of convenience the present work has been divided into three parts. The first part deals with the development of various stages under constant ecological factors; the second part includes the observations on the development of various stages under different levels of ecological factors; the third part includes the records of the development of various stages in relation to different ecological factors during the different months of the year.
II. MATERIAL AND BREEDING TECHNIQUE

In order to maintain stock, adult males and females of *S. prasiniformis* Walk. were collected in August, 1969, from *Oryza sativa*, Zee meva, *Saccharum officinarum* and *Eysdena decylona* fields in and around the Acridians Experimental Field Station, Scindia Fort, Aligarh (Plate I), and kept in wooden cages, each measuring 63 x 40 x 30 cm. (Plate II). All sides of the cage were wooden while the front one was divided into two parts, the upper and the lower. The upper part was fixed and made of glass measuring 31 x 31 cm. and the lower portion measuring 31 x 12 cm. formed a wooden window for cleaning the faecal matter. A false-floor of wire-gauze was provided at the level of glass plate inside the cage. Three perforations, each measuring 3.3 cm. in diameter, were provided in the false-floor for the insertion of metallic tubes, each measuring 11 cm. in length and 3 cm. in diameter. The metallic tubes, filled with sterilized sand moistened uniformly with distilled water (6 ml. distilled water for every 100 gm. of sand) were inserted into the perforations for oviposition. A socket with an electric bulb was provided on the left side of the cage for maintaining temperature. A maximum and minimum thermometer was placed in the cage on the right side. A window, measuring 13 x 13 cm. fitted with wire-gauze was provided on the back side of the cage for ventilation. On the right side of the back window a hair hygrometer was suspended
Map of Acridians Experimental Field Station, Scindia Fort, Aligarh.
EXPLANATION OF PLATE II

In the cage the light bulb is seen giving a temperature of 33°C. The maximum and minimum thermometer and hair hygrometer, indicating the temperature and humidity, are seen on the right and back sides respectively. In order to obtain the eggs, three metallic tubes filled with slightly moistened sand are inserted into the perforations in the false-floor of the cage. The bundle of cut leaves, *Cynodon dactylon* is also seen in the beaker kept on the false-floor.
Wooden cage used for rearing *S. prasiniferum* Walk.
inside the cage. The bottom and the roof of the cage were made of wood. The cage was provided with a wooden lid, measuring 13 x 13 cm. for transferring the insects and food etc.

The temperature inside the cage was maintained at about 33°C by using the electric bulbs of different watts (15 W., 25 W., 40 W., 60 W. and 100 W.).

The relative humidity was maintained at approximately 70% by caustic potash solution in a beaker placed below the false-floor of the cage.

Bundles of cut wood, Cynodon dactylon, were placed in water in a beaker measuring 5.6 x 3.6 cm. The food was changed after every 24 hours.

In order to obtain eggs, adult males and females of this grasshopper were also placed in small glass jars, each measuring 16 x 11 cm (Plate III, Fig. 2). A circular piece of card-board, measuring 10.3 cm. in diameter with a hole (3.7 cm. in diameter) in the centre, was placed in each small glass jar at a distance of 5.8 cm. from the bottom. A beaker, measuring 5.6 x 3.6 cm., filled with moist sterilized sand (8 ml. distilled water for every 100 gm. sand) was inserted into the opening of the card-board. In this way the card-board provided / false-floor and the beaker with sand as pseudo-earth for egg-laying while the insects and food (Cynodon dactylon) remained on the false-floor. The open end of each jar was covered with muslin cloth. These glass jars were placed in the constant temperature room at 33°C ± 1°C and 70% ± 5% R.H. where 12 hours' light
EXPLANATION OF PLATE III

Figure 1  Glass tube used for rearing the individual hopper. The food-plant, Cynodon dactylon is seen in the tube.

Figure 2  Small glass jar used for rearing the adults. In order to obtain the eggs, the beaker filled with sand is seen into the perforation in the card-board present inside the jar. The bundle of cut leaves, Cynodon dactylon is also seen on the false-floor of card-board.
Small glass apparatus used for rearing *S. prasiniferum* Walk.
altered with 12 hours' darkness.

The egg-pods were obtained in the metallic tubes and the beakers. These pods were placed in large glass jars, each measuring 21 x 19 cm. (Plate IV). These glass jars were then covered with muslin cloth and placed either in the refrigerator at 16° ± 1°C for storage or in the constant temperature room at 33° ± 1°C and 70% ± 5% R.H. for hatching. The egg-pods placed in the constant temperature room were slightly moistened with distilled water according to needs. The newly hatched hoppers were also confined in large glass jars and they were allowed to feed on the bundles of cut weed, Cynodon dactylon. These glass jars were then covered with muslin cloth and placed in the same constant temperature room. The adults were transferred into the cage for egg-laying.

The newly hatched hoppers were also reared in glass tubes, each measuring 10 x 3.0 cm. (Plate III, Fig. 1). The plant leaves were placed inside the tubes. The open ends of glass tubes were then covered with muslin cloth. These glass tubes were also placed in the same constant temperature room. The adults were transferred into the cages for egg-laying.

When there was no egg-laying, the egg-pods stored in the refrigerator were taken out and placed in the constant temperature room where a stock of eggs, hoppers and adults was maintained.

The experimental methods and results are included in different sections of the thesis.
EXPLANATION OF PLATE IV

Figure 1  In the jar the beakers are seen. The beakers are filled with slightly moistened sand. The apical ends of the deposited egg-pods are also seen.

Figure 2  The jar used for mass rearing. *Cynodon dactylon* leaves are seen inside the jar.

Figure 3  In the jar the metallic tubes are seen, filled with slightly moistened sand. The apical ends of the deposited egg-pods are also seen.
Large glass apparatus used for rearing *S. prasiniferum* Walk.
PART I

III. DEVELOPMENT OF VARIOUS STAGES UNDER CONSTANT ECOLOGICAL FACTORS

(1) REVIEW OF LITERATURE

Considerable work has been done on the development of various stages of acridoid pests. Increase in fat-body during the sexual maturation of *Melanoplus differentialis* and *Locusta migratoria migratoroides* has been studied by Weed Pfeiffer (1945b) and Phipps (1950) respectively. The differences in the relative growth of the oldest egg and the second one have been studied by Phipps (1949, 1950, 1959), Viado (1950) and Maloff (1954). Later Phipps (1962) found that the egg 2 grows relatively more to egg 1 in small grasshoppers than in the larger ones.

Beldyrev (1929) and Rooswal (1949) have studied the number of ovarioles in *Locusta migratoria* and *Schistocerca gregaria* respectively. According to them the number of ovarioles varies in different individuals and even in the right and left ovaries of the same individual.

Phipps (1949) found that the new egg-rudiments are produced throughout life of the females of *Ommatius viridulus*, *Sporobothen lineatus*, *Chorthippus parallelus*, *Chorthippus bicolor* and *Hypheslotettix amiculus*. Richards and Maloff (1954) found a very
high number of egg-rudiments in heavily ovipositing females of *Chorthippus brunneus*.

Phipps (1950) in *Locusta*, Norris (1954, 1959a) in *Schistocerca gregaria* and Nomadacris septemfasciata and Richards and Walöff (1954) in *Omocestus viridulus* observed that the weight increases during the sexual maturation and subsequently fluctuates throughout life.

Pruthi and Nigam (1939) observed in *Poecilocerus pictus* that the male does not start copulation immediately after it becomes an adult, but the female is copulated just after its emergence. During copulation the male sits on the back of the female. The penis is then introduced between the ventral ovipositor valves of the female into the vagina and its tip reaches the spermathecal duct (Fedorov, 1927; *Anacridium aegyptium*; Boldyrev, 1929, *Locusta migratoria*; Kyl, 1938, *Melanoplus differentialis*). This type of copulating posture is found in the species where male is smaller than the female. The copulating posture may differ in other species. In addition to the above types, Katiyar (1952, 1956b) distinguished two other types of copulating postures - (i) 'riding' which occurs in the species with both sexes of similar size and (ii) 'lateral' which occurs in species where the ratio of the female length to that of the male is very high.

Hebard (1937) observed in *Sphaniacris* that during the copulation process the female takes to wings along with the male. In some species, e.g., *Schistocerca gregaria* (Popov, 1958) the copulating female may continue to feed, crawl and jump.
Ivanova (1926, 1926) and Gregory (1965a, 1966b) in Locusta.
Fedorov (1927) in Anacridium aegyptium and Norris (1954) in Schistocerca gregaria demonstrated that the presence of more than one spermatophore in each female of these species indicates the necessity of repeated copulation. Hunter-Jones (1960) observed in Schistocerca that the latest copulation is the effective one.

The process of oviposition has been described by Fedorov (1927) in Anacridium aegyptium, Pruthi and Nigam (1959) in Poecilocares pictus, Agrawal (1965) in Atractomorpha gregaria, Katyar (1955) in Aularches punctatus, and Rafe and Ibrahim (1966) in Acrida pallidae and it is claimed that these insects lay their eggs in holes made in the moist soil with the help of their abdomen. In addition to this, Rao (1921) observed that the females of Oxya velox may lay their eggs on the foliage of the plants in the watery fields.

During the embryonic development, the eggs of Locusta migratoria gradually increase in size (Rooswal, 1936a). Similar increases have been recorded for other species with the exception of the highly xerophilous Tribilia, the eggs of which do not change in size (Shulov, 1952d).

Extensive descriptions on the hatching have been given by Krummel d’Hercules (1890a, 1890b, 1893 to 1905) for various acridoids, Vosseler (1905) and Bernays (1971) for Schistocerca and Mikkel'son (1922) for Locusta.
The vermiform larva emerges on the surface of the soil and casts off its outer covering membrane known as the intermediate moult (Uvarov, 1928). The individual now resembles in its general appearance to the adult and called the first instar hopper.

In acridoids the number of instars may vary from species to species and even in the individuals of the same species. Nevertheless, few suggestions have been made by Uvarov (1966). According to him the majority of the most advanced group (Gomphocerinae) pass through only four instars, while the most primitive groups (e.g., Catantopinae, Pamphagidae, Pygromorphidae) the number is five or more. This suggests an evolutionary trend towards a reduction in the number of instars.
(2) DEVELOPMENT OF VARIOUS STAGES OF SPATHOSTERNUM PRASINIFERUM WALKER UNDER CONSTANT ECOLOGICAL FACTORS

The following three sets of experiments were conducted to study the development of various stages of this grasshopper.

(1) Ten male and ten female adults were obtained from the stock in a large glass jar (Plate IV, Fig. 2). The general body colour of these insects was recorded before killing in 70% alcohol and studies were undertaken to find out morphological differences, if any, with its hoppers and other acridoids. These results are presented under the sub-heading 'distinguishing characters'.

(2) Two hundred and fifty pairs of newly emerged adults were taken from the stock. Each pair was kept in a small glass jar (Plate III, Fig. 2) and placed in the constant temperature room at $33^\circ \pm 1^\circ C$, $70\% \pm 5\%$ R.H. where 12 hours' light altered with 12 hours' darkness. The insects were fed on Cynodon dactylon. Ten pairs were dissected daily and continuously over a period of 25 days to study the changes during the maturation of gonads, variation in the number of egg-rudiments per ovariole. These data are included under the sub-headings 'maturation of reproductive organs', 'variation in the number of ovarioles' and 'number of egg-rudiments'.

(3) Ten pairs of newly emerged adults of this grasshopper were obtained from the stock. Each pair was kept in a small glass jar (Plate III, Fig. 2) and placed in the constant temperature room at
33° ± 1°C, 70% ± 5% R.H. where 12 hours' light altered with 12 hours' darkness. The insects were fed on Cynodon dactylon. The weight after emergence was recorded daily to study relation between the weight and the maturation, and also the fluctuations during the reproductive period. Graphs were drawn from the weight of single male and single female adult grasshopper to study the weight and maturity. The number of egg-pods were counted throughout the life of each pair. Egg-counts were recorded from each egg-pod and observations were also made alongside on the copulation, oviposition and longevity of each pair of the grasshopper. Ten newly laid healthy eggs were taken and incubated at 33° ± 1°C, 70% ± 5% R.H., 12 hours' light altered with 12 hours' darkness and 8% sand moisture. The incubation period of these eggs was noted. Observations on the vermiform larvae soon after hatching were made. For detailed and extensive observations on the duration and morphology of different instars, some of the newly hatched first instar hoppers were kept individually in glass tubes. The type of glass tube used for individual hopper rearing is seen in Plate III, Fig. 1. These glass tubes were placed in the constant temperature room at 33° ± 1°C, 75% ± 5% R.H. where 12 hours' light altered with 12 hours' darkness. The insects were fed on Cynodon dactylon. The results are presented under the sub-headings 'weight and maturity', 'copulation', 'oviposition', 'longevity of adults', 'egg-pods', 'vermiform larva' and 'hopper instars'.

The development of this grasshopper is described as given below:-
(A) Adult

(i) Distinguishing characters

The following observations were made from the first set of experiments.

The general body colour of the female grasshopper is green while it is brown in male. Both the male and female grasshoppers are with broad blackish or dark green stripes on the thorax running behind the lower part of the eyes. It is banded above and below by yellow lines. The upper line is narrow and the lower one is broad. A dusky band is present below the broad lower line and is bordered below with yellow colour. The tegmina is light brown towards the base, and subhyaline beyond. Its central part has a longitudinal black streak which may or may not be present in the male but remains well marked in the female. It is, however, quite variable, since sometimes it appears entire, more frequently it has white transverse markings. Occasionally it is seen broken up into spots. The inner margin of this line is not well marked. In the male this part is brownish while it is generally green in the female. The wings are hyaline often clouded towards the tip. The legs are rufo-testaceous; hind femora are more or less green, especially in the female and frequently with a dark longitudinal band on the outer area; hind tibiae have 10 to 11 spines and sometimes green in colour.

In general the male is smaller than the female, but the antennae of the male are slightly longer than those of the female. The average
values of various structures are as follows:

<table>
<thead>
<tr>
<th></th>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body</td>
<td>2.1 cm. long.</td>
<td>1.6 cm. long</td>
</tr>
<tr>
<td>Antennae</td>
<td>0.417 cm. long.</td>
<td>0.455 cm. long,</td>
</tr>
<tr>
<td></td>
<td>23-segmented</td>
<td>22-segmented</td>
</tr>
<tr>
<td>Hind femur</td>
<td>0.95 cm. long</td>
<td>0.90 cm. long.</td>
</tr>
</tbody>
</table>

(ii) Sexual maturity

(a) Maturation of reproductive organs:- The following observations were obtained from the dissections of adult grasshoppers in the second set of experiments.

An orange or yellow coloured sheath is developed around the testes and the seminal vesicles with some increase in the length of the tubules of the accessory glands during the maturation of the male reproductive organs.

The ovaries of newly emerged adult grasshopper are small and white. They show little change in appearance for two or three days. The fat-body shows considerable increase in size during the maturation. The accessory glands, which are straight and generally shorter than the ovarioles in the newly emerged females, increase in size until in the mature females they are as long as, or longer than the ovarioles. Several eggs of an ovariole may undergo simultaneous growth. The measurements of the egg 1 and egg 2 (Table 1) show that the growth occurs during this period. Thus the females with ripe egg 1 in the oviduct may have an almost fully formed egg 2. The egg 1 is nearest to the oviduct and first to be
Relative growth of egg 1 and egg 2 in the adult females of *S. prasinifera*um Walk. from their emergence up to the end of second oviposition, reared at 33° ± 1°C, 70% ± 5% R.H., 12 hours' light altered with 12 hours' darkness and fed on *C. dactylon*.

10 replicates (one female in each replicate)

On the 9th day only those 10 females were dissected which had deposited the first egg-pod in the morning of the same day and on the 11th day only those 10 females were dissected which had deposited the first egg-pod in the morning of the 9th day and second egg-pod in the morning of the 11th day.

<table>
<thead>
<tr>
<th>Age in days</th>
<th>Egg 1</th>
<th>Egg 2</th>
<th>Egg 1</th>
<th>Egg 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.312</td>
<td>0.131</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.332</td>
<td>0.154</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.402</td>
<td>0.223</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.561</td>
<td>0.334</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.674</td>
<td>0.435</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.792</td>
<td>0.562</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.812</td>
<td>0.623</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.820</td>
<td>0.632</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 laid</td>
<td>0.813</td>
<td></td>
<td>0.611</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>nearest to the oviduct so called the egg 1 and the succeeding egg is known as the egg 2.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.821</td>
<td>0.735</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 laid</td>
<td>0.746</td>
<td>0.612</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>nearest to the oviduct so called the egg 1 and the succeeding egg is known as the egg 2.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ovulated and that above it lies egg 2. It is also evident from Table 1 that the egg 2 grows relatively faster than the egg 1, that is why the grasshoppers deposit eggs frequently. All the ovarioles do not function simultaneously as some of them remain thread-like. These thread-like ovarioles may, however, be intermittently functional and some can be seen with corpora lutea, indicating the recent ovulation. The ovaries of this grasshopper are of panoistic type and the number of egg-rudiments increase throughout life.

The young and old females can be distinguished from the mature ones by the presence of thread-like ovarioles. In addition to these the old females show the presence of accessory glands, distended oviduct and yellow corpora lutea which are not present in young females and this is how one can distinguish between young and old females.

(b) Variation in the number of ovarioles: The following observations were obtained from the dissections of the adult grasshoppers in the second set of experiments.

The number of ovarioles in the right and left ovaries of the adult of S. prasiniferum Walk. is either 3+5 or 4+3 or 3+4 or 4+4 or 4+5 or 5+3 or 5+4 or 5+5 (Table 2). It is apparent from these observations that the number of ovarioles varies in different individuals and even in the right and left ovaries of the same individual. The dissections of newly emerged females in this set of experiments revealed that no ovariole is developed at this stage, their average number, however, increases with age. In one, two, three, four, five, six, seven, eight and twenty-five days old females the average increase in the number of
Table 2

Variation in the number of ovarioles of the adult females of *S. prasiniferum* Walk., reared at 33° ± 1°C, 70% ± 5% R.H., 12 hours' light altered with 12 hours' darkness and fed on *C. dactylon*.

250 females were dissected (10 females daily)

<table>
<thead>
<tr>
<th>Age (in days)</th>
<th>Variation in the number of ovarioles (number of ovarioles in the left ovary + number of ovarioles in the right ovary)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4 + 3, 3 + 4, 4 + 5 (2) (4) (4)</td>
</tr>
<tr>
<td>2</td>
<td>4 + 4, 3 + 5, 3 + 4 (2) (4) (4)</td>
</tr>
<tr>
<td>3</td>
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</tr>
<tr>
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</tr>
<tr>
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</tr>
<tr>
<td>6</td>
<td>3 + 5, 5 + 5, 5 + 4 (5) (4) (1)</td>
</tr>
<tr>
<td>7</td>
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</tr>
<tr>
<td>8</td>
<td>3 + 5, 4 + 5, 5 + 4 (3) (2) (5)</td>
</tr>
<tr>
<td>9</td>
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</tr>
<tr>
<td>10</td>
<td>5 + 5 (10)</td>
</tr>
<tr>
<td>11</td>
<td>5 + 5, 4 + 5, 5 + 4 (6) (2) (2)</td>
</tr>
<tr>
<td>12</td>
<td>3 + 5, 5 + 4 (5) (5)</td>
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<tr>
<td>13</td>
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<tr>
<td>15</td>
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<tr>
<td>16</td>
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(Contd.)
Table 2 (Contd.)

<table>
<thead>
<tr>
<th></th>
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<tr>
<td>17</td>
<td>(2)</td>
</tr>
<tr>
<td>18</td>
<td>(7)</td>
</tr>
<tr>
<td>19</td>
<td>(1)</td>
</tr>
<tr>
<td>20</td>
<td>3 + 5, 5 + 4</td>
</tr>
<tr>
<td>21</td>
<td>(5)</td>
</tr>
<tr>
<td>22</td>
<td>(5)</td>
</tr>
<tr>
<td>23</td>
<td>5 + 5, 4 + 5</td>
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<td>24</td>
<td>(6)</td>
</tr>
<tr>
<td>25</td>
<td>(4)</td>
</tr>
</tbody>
</table>

Figures in paranthesis indicate the number of females.
ovariols is found to be 0.5, 0.8, 1.2, 6.4, 9.8, 10.1, 10.3, 13.0 and 20.0 respectively (Table 3).

(c) Number of egg-rudiments: - The following observations were obtained from the dissections of the adult grasshopper in the second set of experiments.

The average number of egg-rudiments is 9.12 for newly emerged females, 9.20 for one to two days' old females, 9.25 for three to four days' old females, 9.31 for five days' old females, 9.13 for six days' old females, 9.32 for seven days' old females and 9.21 for eight days' old females (Table 3). It indicates that no significant difference occurred in the number of egg-rudiments found during this period. But there is a marked increase in the number of egg-rudiments in the females after eight days (Table 3). It may, therefore, be concluded that new egg-rudiments are produced at such a rate as to compensate for the next oviposition.

(d) Weight and maturity: - The following observations were obtained from the dissections of adult grasshoppers in the third set of experiments.

The weight increase in females is 94.4 per cent (Table 4) during the maturation period (pre-oviposition period) which on an average is 8.7 ± 0.366 days (Table 5). This may be due to the maturation of the eggs as the average weight of females fluctuates before and after the successive ovipositions, rarely exceeding 125 per cent.
Table 3

Number of small ovarioles and number of egg-rudiments per ovariole in adult females of *S. prasiniferum* Walk., reared at 35° ± 1°C, 70% ± 5% R.H., 12 hours' light altered with 12 hours' darkness and fed on *C. daetvlon*.

250 females were dissected (10 females daily)

<table>
<thead>
<tr>
<th>Age (in days)</th>
<th>Average number of small ovarioles</th>
<th>Average number of egg-rudiments per ovariole</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newly Moulted</td>
<td>0.5</td>
<td>9.20</td>
</tr>
<tr>
<td>1</td>
<td>0.5</td>
<td>9.20</td>
</tr>
<tr>
<td>2</td>
<td>0.8</td>
<td>9.25</td>
</tr>
<tr>
<td>3</td>
<td>1.2</td>
<td>9.25</td>
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<tr>
<td>4</td>
<td>6.4</td>
<td>9.31</td>
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<tr>
<td>5</td>
<td>9.8</td>
<td>9.13</td>
</tr>
<tr>
<td>6</td>
<td>10.1</td>
<td>9.32</td>
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<td>7</td>
<td>10.3</td>
<td>9.21</td>
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<td>13.0</td>
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<td>14.5</td>
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<td>14.8</td>
<td>16.25</td>
</tr>
<tr>
<td>11</td>
<td>15.0</td>
<td>16.21</td>
</tr>
<tr>
<td>12</td>
<td>15.3</td>
<td>16.42</td>
</tr>
<tr>
<td>13</td>
<td>16.1</td>
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<td>16.12</td>
</tr>
<tr>
<td>21</td>
<td>19.1</td>
<td>15.82</td>
</tr>
<tr>
<td>22</td>
<td>19.3</td>
<td>16.21</td>
</tr>
<tr>
<td>23</td>
<td>19.3</td>
<td>15.20</td>
</tr>
<tr>
<td>24</td>
<td>20.0</td>
<td>14.94</td>
</tr>
</tbody>
</table>
### Table 4

Weight of adults of *C. praegniferum* Walk., reared at 33° ± 1°C, 70% ± 5% R.H., 12 hours' light alternated with 12 hours' darkness and fed on *C. daetlina*.

The results are based on 10 replicates (one pair in each replicate)

<table>
<thead>
<tr>
<th></th>
<th>Average weight (in mg.) of adults just after emergence</th>
<th>Average weight (in mg.) of mature adults</th>
<th>Percentage increase from emergence to maturity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Female</td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td></td>
<td>67.4</td>
<td>63.2</td>
<td>169.91</td>
</tr>
</tbody>
</table>
Table 6

Pre-copulation, pre-oviposition, oviposition and post-oviposition periods of *S. presistiferum* Walk., reared at 33°C ± 1°C, 70% ± 5% R.H., 12 hours' light altered with 12 hours' darkness and fed on *C. peptrion*.

Ten experiments (one pair in each experiment)

<table>
<thead>
<tr>
<th>Exp. No.</th>
<th>Pre-copulation period (in days)</th>
<th>Maturation period or Pre-oviposition period (in days)</th>
<th>Oviposition period (in days)</th>
<th>Post-oviposition period (in days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>6</td>
<td>13</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
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<td>2</td>
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<tr>
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<td>3</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>10</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>Average</td>
<td>3.5</td>
<td>6.7</td>
<td>16.9</td>
<td>2.8</td>
</tr>
<tr>
<td>S.E.</td>
<td>± 0.223</td>
<td>± 0.366</td>
<td>± 1.441</td>
<td>± 0.270</td>
</tr>
</tbody>
</table>

S.E. = Standard Error
During maturation period (pre-copulation period) which on an average is $3.5 \pm 0.223$ days (Table 5) the male grasshoppers increase their weight by about 56.8 per cent (Table 4). This may be due to the elaboration of the reproductive organs. The weight after maturation period fluctuates from day to day. The maximum weight during adult life never exceeds 61 per cent.

From the graph (Plate V) for a single female, it is evident that the increase in weight is rapid in the beginning, then decreases for about two days and afterwards again start increasing. The weight of individual female is 164.80 mg. at the time of first oviposition. Fluctuation of weight is well marked and irregular in the females over eight days old. From the same graph it is also evident that the weight of a female frequently rises to higher value between successive ovipositions than any value attained before the first oviposition and that there is a rather sudden fall just before the death.

From the graph (Plate V) for a single male, it is apparent that the weight increases during the maturation. The weight for single male is 99.92 mg. at the time of first copulation. Then the weight fluctuates from day to day. There is also sudden fall in weight of a male just before its death.

(iii) Copulation

The following observations were obtained from the third set of experiments.
S. prasiniferum Walk., weight changes during adult life.
The male does not start copulation immediately after it becomes adult. The pre-copulation period in male grasshopper varies from three to five days (Table 5). However, the female is ready for copulation soon after it undergoes the final moul. When the newly emerged females are provided with sexually mature males, the copulation starts immediately. During copulation the male mounts over the back of the female (Plate VI, Fig. 1) clasping her firmly by the first two pairs of legs, while the third pair plays no direct part during the whole process. The pairing can take place even if the hind pair of legs is removed (Plate VI, Fig. 2). Their tibiae are pressed close under the femora and the tarsi under the tibiae. The forelegs of the male clasp the pronotum of the female, their claws grasp the lower margin of the lateral pronotal lobes. The middle-legs clasp the female under its wings near the base of the hind-legs. After holding the female firmly, the abdomen of male is curved down, its tip is brought under that of the female abdomen, the aedeagus is protruded and is inserted between the valves of the female sub-genital plate. Ultimately, it enters the opening of spermathecal duct of female. Afterwards the sub-genital plate of the male is pressed tightly against the valves of the ovipositor of the female. The ovipositor valves fit with the marginal excision of the sub-genital plate, while the male cerci clasp all the more tightly the sub-genital plate of the female near its base, so that their ends nearly reach the corresponding tergite of the female. In case the upper valves of the ovipositor are raised four to five hours after the beginning of the actual copulation, one may observe between the lower valves the formation of the milky-white

2. *S. prasiniferum* Walk., copulating pair. Showing that the copulation is possible even when the hind legs are removed.
jelly-like mass.

Female with male *in copula* may continue to feed, crawl and even hop.

When the process of copulation is over, the female begins to jerk the hind legs and repeats it frequently. This disturbs the male which leaves the copulating female soon after. The time taken for copulation varies from eight to forty nine hours.

The jelly-like mass between the lower valves of the ovipositor now turns yellow in colour, it becomes harder and more brittle and the female loses it bit by bit. Soon only a few flakes remain, and four to six hours after all of it is lost and there remains no external trace of copulation.

The copulation is repeated several times. The females are copulated before or after every oviposition. But it does not mean that the copulation is necessary for each oviposition. The first copulation is sufficient to fertilize the eggs in all succeeding ovipositions. It has been observed that if the male is separated from the female after the first copulation, the fecundity is less than when the female is kept with the male throughout life. If there is any disturbance during the copulation, it may start again. Both polyandry and polygamy are observed as far as the choice of male or female is concerned. The copulation is very frequent both before and after the oviposition.

The average pre-copulation period is $3.5 \pm 0.223$ days (Table 5).
(iv) **Oviposition**

The following results were obtained from the third set of experiments.

Three to eight days after copulation, the female begins to oviposit in the moist sand, and occasionally on the leaves of the food-plant. The egg-batch in the sand is known as the egg-pod (Plate VIII, Fig. 1) whereas the egg-batch on the plant leaf is called as the egg-clutch (Plate VIII, Fig. 2).

The female of *S. prasinifera* Walk., before oviposition makes a selection of the site by crawling over the surface of the sand or the leaves provided in order to feel suitable moisture with her antennae and palpi (Plate VII). If suitable moisture is available in the sand its abdomen bends slightly and taps the surface of the sand gently with the valves of the ovipositor closed. The whole process of oviposition can be observed if the female bores holes in close proximity of the glass. During the course of boring, the female raises its body on the first two pairs of legs, slightly supporting itself by the hind pair as well, while the abdomen rotates through an angle of 180°. The loose sand of the burrow is compacted by moving the abdomen up and down frequently. The chambers are generally 1.8 to 2.7 cm. deep. Although the abdomen in normal position is only 1 to 1.5 cm. long yet it can be extended to reach the depth of chamber with the help of elastic intersegmental membranes.
S. prasiniferum Walk. female in the act of oviposition.
1. Egg-pod of *S. prasiniferum* Walk.

2. Egg-clutch of *S. prasiniferum* Walk.
In many cases the female makes several chambers and discards them without laying any egg therein, probably due to unsuitable texture or moisture content of the sand. When the hole is completed, the female retracts its abdomen slightly and the frothy secretion of the accessory gland is poured out. This is partly absorbed by the sand which hardens to form the walls of the egg-pod and a part of it about 1 cm. in thickness is also deposited at the bottom of egg-chamber. It is on this hardened fluid bed the eggs are laid one by one in four rows to form a compact mass. The female gradually retracts its abdomen as the chamber gets filled up with the eggs. When all the eggs have been laid, the vacant space in the chamber is filled with froth up to the top. The whole process takes about two to four hours. After oviposition, the female appears to be exhausted and starts feeding voraciously.

The average of pre-oviposition, oviposition and post-oviposition periods are $8.7 \pm 0.366$, $16.9 \pm 1.441$ and $2.8 \pm 0.270$ days respectively (Table 5).

(v) **Longevity of the adult**

The following observations were obtained from the third set of experiments.

The males generally live longer than the females; the average longevity being $39.2 \pm 1.612$ days for males and $28.4 \pm 1.310$ days for females (Table 6.)
Table 6

Longevity of adults of *S. prasiniferum* Walk., reared at 33° ± 1°C, 70% ± 5% R.H., 12 hours' light altered with 12 hours' darkness and fed on *C. dactylon*.

Ten experiments (One pair in each experiment)

<table>
<thead>
<tr>
<th>Exp. No.</th>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
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<td>25</td>
<td>41</td>
</tr>
<tr>
<td>2</td>
<td>27</td>
<td>43</td>
</tr>
<tr>
<td>3</td>
<td>27</td>
<td>47</td>
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<tr>
<td>4</td>
<td>32</td>
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<td>5</td>
<td>34</td>
<td>31</td>
</tr>
<tr>
<td>6</td>
<td>26</td>
<td>39</td>
</tr>
<tr>
<td>7</td>
<td>25</td>
<td>46</td>
</tr>
<tr>
<td>8</td>
<td>32</td>
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<td>9</td>
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<td>40</td>
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<tr>
<td>10</td>
<td>28</td>
<td>35</td>
</tr>
<tr>
<td>Average</td>
<td>28.4</td>
<td>39.2</td>
</tr>
<tr>
<td>S.E.</td>
<td>± 1.310</td>
<td>± 1.812</td>
</tr>
</tbody>
</table>

S.E. = Standard Error
(B) **Egg-pod**

The following results were obtained from the third set of experiments.

The female of *S. pretiniformis* Wulk. lays six to eleven eggs per pod. There is an increase in the number of eggs from first to few ovipositions and then the number dwindles (Table 7).

The average number of the egg-pod per female is $6.40 \pm 0.393$. The average number of eggs per pod is $7.69 \pm 0.491$ and the average number of eggs laid by a female is $51.00 \pm 2.704$ (Table 7).

The term egg-pod (Plate VIII, Fig. 1 and Plate X, Fig. 1) is applied to the mass of eggs, enclosed in a case formed by hardening of the secretion of the accessory glands exuded at the time of oviposition. It is dark brown in colour and is more or less cylindrical in shape varying from 1.2 to 2.2 cm. long and 0.25 to 0.3 cm. in diameter. It is almost straight, short and usually broad in the middle, the basal end is round while the apical end is flat. The apex of the pod is that part through which the hoppers emerge. While the base is the opposite end toward which the micropylar ends of the eggs are usually directed. Internally the secreted material is greyish brown, soft and spongy. It lines the walls and forms lamellae between the eggs. The interior of the pod is one chambered. The eggs do not fill the whole chamber, but there is a space above them filled with porous and spongy mass formed of dried secretion. The pod with encrusted sand particles has small and easily detachable lid.
Table 7

Fecundity, fertility and incubation period of eggs of *S. prasiniferum* Walk., reared at 33° ± 1°C, 70% ± 5% R.H., 12 hours' light altered with 12 hours' darkness and fed on *C. dactylon*.

Ten experiments (one pair in each experiment)

<table>
<thead>
<tr>
<th>Exp. No</th>
<th>Egg-pods</th>
<th>Total No. of eggs laid (fecundity)</th>
<th>Total No. of hoppers hatched</th>
<th>Percentage of hatching</th>
<th>Incubation period in days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I II III IV V VI VII VIII</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>8 9 10 9 (8) (12) (14) (17)</td>
<td>36</td>
<td>34</td>
<td>94.44</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>9 9 10 9 7 6 6 (8) (10) (12) (19) (22) (25) (29)</td>
<td>57</td>
<td>53</td>
<td>92.88</td>
<td>21</td>
</tr>
<tr>
<td>3</td>
<td>8 9 9 10 7 7 7 (8) (12) (14) (16) (19) (19) (24)</td>
<td>57</td>
<td>51</td>
<td>89.47</td>
<td>21</td>
</tr>
<tr>
<td>4</td>
<td>9 10 10 8 7 6 (11) (14) (17) (21) (25) (29)</td>
<td>42</td>
<td>41</td>
<td>97.62</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>8 8 10 9 6 7 6 6 (8) (11) (15) (17) (20) (23) (25) (31)</td>
<td>60</td>
<td>52</td>
<td>86.67</td>
<td>22</td>
</tr>
<tr>
<td>6</td>
<td>8 8 10 11 6 6 (10) (15) (17) (22) (25)</td>
<td>49</td>
<td>43</td>
<td>87.76</td>
<td>20</td>
</tr>
<tr>
<td>7</td>
<td>8 9 10 9 7 (8) (12) (14) (17) (20)</td>
<td>43</td>
<td>39</td>
<td>90.70</td>
<td>20</td>
</tr>
<tr>
<td>8</td>
<td>8 9 10 9 7 7 6 6 (8) (10) (12) (19) (22) (25) (29) (31)</td>
<td>62</td>
<td>58</td>
<td>93.55</td>
<td>21</td>
</tr>
<tr>
<td>9</td>
<td>8 8 10 9 6 7 6 (8) (10) (14) (17) (19) (22) (25)</td>
<td>54</td>
<td>51</td>
<td>94.44</td>
<td>21</td>
</tr>
<tr>
<td>10</td>
<td>8 9 10 11 6 6 (10) (14) (17) (19) (22) (25)</td>
<td>50</td>
<td>46</td>
<td>92.00</td>
<td>20</td>
</tr>
</tbody>
</table>

Average 8.20 8.80 9.90 9.40 6.55 6.50 6.20 6.00 51.00 46.80 91.96 20.60

S.E. ±0.267 ±0.211 ±0.100 ±0.305 ±0.065 ±0.189 ±0.200 ±0.000 ± 2.704 ± 2.355 ± 1.062 ± 0.065

Figures in parenthesis denote the age in days of the females at the time of oviposition.
Averages ± S.E.: 6.40 ± 0.393, egg-pods per female and 7.69 ± 0.491 eggs per pod.

S.E. = Standard Error.
(i) Egg

The eggs in the pod (Plate X, Fig. 1b) are glued together by the secretion and placed in four rows. In each case, the micropylar pole of the egg points toward the base of the pod.

The sub-cylindrical elongated and curved egg is thick in the middle and tapers toward the ends which are bluntly rounded (Plate IX, Fig. 1). It is 0.4 x 0.846 cm. in size. When freshly laid, the egg is light yellowish brown which changes to dark yellowish brown after about ten days. There are two egg-coverings, the chorion and the vitelline membrane. The former is sculptured and in a mature egg can be peeled off easily by scratching. The vitelline membrane is yellow and smooth but tough and cannot be easily pierced by an ordinary needle. The micropyle is dark coloured and can be easily distinguished as development progresses within the egg. The egg gradually increases in size and reaches up to 0.456 x 1.406 cm. The embryonic eyes are distinct just before the hatching.

(ii) Hatching

The eggs of *S. prasiniforme* Walk. hatch in 20 to 22 days and the average incubation period being 20.60 ± 0.065 days (Table 7).

When the eggs are about to hatch, the young ones inside may be seen moving their abdomen and hind-femora through the egg-coverings. Just prior to hatching some black spots make their appearance on the surface of chorion near the operculum. From these spots some transparent liquid oozes out, and it is at these spots that the membrane ruptures and
EXPLANATION OF PLATE IX

Figure 1  Freshly laid egg.
Figure 2  Vermiform larvae.
Egg and vermiform larva of *S. prasiniferum* Walk.
EXPLANATION OF PLATE X

Figure 1a  External appearance of egg-pod.
Figure 1b  Egg-pod showing the arrangement of eggs.
Figure 2   First instar hopper (female)
Figure 3   Second instar hopper (female)
Figure 4   Third instar hopper (male)
Figure 5   Fourth instar hopper (female)
Figure 6   Fifth instar hopper (male)
Figure 7   Sixth instar hopper (female)
Figure 8   Adult (female)
The egg-pods, eggs, hoppers and adult of *S. prasiniferum* Walk.
the vermiform larva hatches out.

(C) Vermiform larva

The following observations and results were obtained from the third set of experiments.

The vermiform larva (Plate IX, Fig. 2) is enclosed in a thick membrane. Its head is bent downwards and legs lie close to the body. The larvae make their way up through the dry froth by wriggling movement of their bodies and all of them emerge forming a cluster over the mouth of the burrow. The emergence of all the larvae from a single egg-pod takes about twelve minutes. After reaching the surface of the sand the larva sheds away its cuticle. This is termed as the intermediate moult. Just before this moulting the cervical ampulla gets inflated and presents a double-knobbed swelling. Due to the alternate swelling and contraction of this ampulla, the thin white skin ruptures dorsally in the thoracic region and eventually the young hopper crawls out. The process of intermediate moult is completed within two to four minutes.

The orange coloured vermiform larva measures on an average 0.55 cm. in length. Its fore- and middle-legs have traces of blackish spots at the base of setae; hind-tibiae are long with five rows of spinules. The antenna is 1.1 cm. long and 13-segmented; spicis of mandibular teeth are much acute; wing pads are not distinct; female has rudimentary buds of ovipositor on the eighth abdominal sternum, while the male external genitalia is round, in some cases it has a notch on the supra-anal plate.
(D) **Hopper instars.**

The following observations and results were obtained from the third set of experiments.

The newly emerged hoppers are negatively geotropic as they move upwards and ascend any piece of stick or twig. The hoppers begin to feed about fourteen hours after their emergence.

The hoppers undergo six moults before they reach the adult stage. The intermediate moult is not included in this count. A day before moulting, the hoppers stop feeding and become sluggish. The duration of the instars varies as shown in Table 8. It is also evident from Table 8 that the average duration of hopper instars in male is $6.33 \pm 0.141$ days for first instar, 7 days for second instar, $6.67 \pm 0.141$ days for third instar, $6.33 \pm 0.141$ days for fourth instar, $5.58 \pm 0.141$ days for fifth instar and $5.58 \pm 0.515$ days for sixth instar; while in female $6.17 \pm 0.117$ days for first instar, $6.42 \pm 0.148$ days for second instar, $6.42 \pm 0.148$ days for third instar, $7.42 \pm 0.198$ days for fourth instar, $8.56 \pm 0.515$ days for fifth instar and $9.33 \pm 0.141$ days for sixth instar. The average duration of hopper stage in male is $37.58 \pm 0.280$ days while in female it is $44.25 \pm 0.883$ days. So the males become adults 6.67 days earlier than the females.

(1) **Description of hopper instars**

The different instars are described as below:

**First instar hopper:** (Plate X, Fig. 2). The first instar hopper, immediately after the intermediate moult is called a hatchling. Its colour
Table 6

Duration (in days) taken by the different hopper instars of *S. prasiniferum* Walk., reared at 33° ± 1°C, 70% ± 5% R.H., 12 hours' light altered with 12 hours' darkness and fed on *C. dactylon*.

(12 experiments (one hopper in each experiment)

<table>
<thead>
<tr>
<th>Exp. No.</th>
<th>1st instar</th>
<th>2nd instar</th>
<th>3rd instar</th>
<th>4th instar</th>
<th>5th instar</th>
<th>6th instar</th>
<th>Total duration</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Female Male</td>
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<td>7</td>
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<td>10</td>
<td>6</td>
</tr>
</tbody>
</table>

Average 6.17 6.33 6.42 7.00 6.42 6.67 7.42 6.33 8.56 5.56 9.33 5.58 44.26 37.68

± S.E. ±0.117 ±0.141 ±0.148 ±0.000 ±0.148 ±0.141 ±0.198 ±0.141 ±0.515 ±0.141 ±0.515 ±0.803 ±0.280

S.E. = Standard Error
is orange. After the lapse of a day the hoppers appear yellowish-
orange in general appearance and on an average measures 0.6 cm. in length.

The head is slightly reddish brown in colour. It is conical and
stout in the front view. The antenna comprises 13 segments and measures
about 0.11 cm. in length. The first or the basal joint is cylindrical
and the second is small and globular whereas the thirteenth segment is
as long as any three segments taken together. The spines of the mandibular
tooth are acute (Plate XI, Fig. 1).

The fore- and middle-legs are small with numerous blackish
spots at the base of each seta. The hind pair of legs is stout. The
hind-femur is 0.2 cm. long. The hind tibia is long with 10 pairs of
spinules. The hind tarsi are three-jointed, the terminal joint is
provided with a pair of claws and a median pad, the aroliaum.

The wing-pads are not distinct (Plate XII, Fig. 1). The abdomen
is almost cylindrical. The eleventh tergum and the supra-anal plate
are fused into one piece, at the sides of which and slightly lower in
level are the two small cerci. These are the appendages of the eleventh
abdominal segment. The females are provided with rudimentary buds of
ovipositor on the eighth abdominal sternum (Plate XIII, Fig. 8), while the
external genitalia in males are round, in some cases having a notch
on the supra-anal plate (Plate XIII, Fig. 1).

Second instar hopper: (Plate X, Fig. 3). The second instar hopper
resembles in general appearance and colour with the first instar hopper,
but larger in size measuring 0.65 cm. long with traces of white markings
EXPLANATION OF PLATE XI

Figure 1  Mandibular teeth of first instar hopper.
Figure 2  Mandibular teeth of second instar hopper.
Figure 3  Mandibular teeth of third instar hopper.
Figure 4  Mandibular teeth of fourth instar hopper.
Figure 5  Mandibular teeth of fifth instar hopper.
Figure 6  Mandibular teeth of sixth instar hopper.
Figure 7  Mandibular teeth of adult.

ABBREVIATIONS OF PLATE XI

O  -  Incisor area of mandible
P  -  Molar area of mandible
Mandibular teeth of various stages of *S. prasiniferum* Walk.
EXPLANATION OF PLATE XII

Figure 1  Growth of wing-pads in first instar hopper (female); dorsal view.

Figure 2  Growth of wing-pads in second instar hopper (female); dorsal view.

Figure 3  Growth of wing-pads in third instar hopper (female); dorsal view.

Figure 4  Growth of wing-pads in fourth instar hopper (female); dorsal view.

Figure 5  Growth of wing-pads in fourth instar hopper (male); dorsal view.

Figure 6  Growth of wing-pads in fifth instar hopper (female); dorsal view.

Figure 7  Growth of wing-pads in fifth instar hopper (male); dorsal view.

Figure 8  Growth of wing-pads in sixth instar hopper (female); dorsal view.

Figure 9  Growth of wing-pads in sixth instar hopper (male); dorsal view.
Growth of wing-pads in *S. prasiniferum* Walk.
EXPLANATION OF PLATE XIII

Figures 1 to 6  Ventral view of posterior abdominal region of the male hoppers of first, second, third, fourth, fifth and sixth instars respectively; showing phallic complex.

Figure 7  Ventral view of posterior abdominal region of the male adult grasshopper; showing phallic complex.

Figures 8 to 13  Ventral view of posterior abdominal region of the female hoppers of first, second, third, fourth, fifth and sixth instars respectively; showing ovipositor.

Figure 14  Ventral view of posterior abdominal region of the female adult; showing ovipositor.

ABBREVIATIONS OF PLATE XIII

P - Podical plate
SG - Sub-genital plate
UV - Upper ovipositor valve
LV - Lower ovipositor valve
Growth of external genitalia in *S. prasiniferum* Walk.
on its body. The antenna comprises 13 segments and measures about 0.138 cm. in length. The hind femur is 0.37 cm. long. The apices of mandibular teeth are truncate or round (Plate XI, Fig. 2). Rudimentary wings are somewhat distinct (Plate XII, Fig. 2). Sub-genital plate of the female shows the valves of ovipositor (Plate XIII, Fig. 9), while the male external genital organs on the supra-anal plate protrude and are more or less round (Plate XIII, Fig. 2).

**Third instar hopper**: (Plate X, Fig. 4). The hopper usually measures about 0.75 cm. in length. Its body generally appears brownish with white and dark patches all around but the head bears reddish-brown and white markings. The antenna comprises 13 segments and measures about 0.139 cm. in length. The hind femur is 0.4 cm. long. The apices of mandibular teeth are strongly acute (Plate XI, Fig. 3). Wing-pads become more distinct (Plate XII, Fig. 3). Sub-genital plates of males become V-shaped and protrude a little beyond the last abdominal segment (Plate XIII, Fig. 3), while in females the two pairs of valves become more distinct (Plate XIII, Fig. 10).

**Fourth instar hopper**: (Plate X, Fig. 5). The males of the first, second, and third instars can only be differentiated from the females of the same instar by their genitalia. But in addition, the male of fourth instar and the instars onwards can also be differentiated by the colour and length of the body, length of the hind femur, and number of segments and length of the antennae. The distinguishing characters of fourth instar male and female hoppers are as follows:
The apices of mandibular teeth are round (Plate XI, Fig. 4).

Wing-pads are well developed and point downwards (Plate XII, Figs. 4 and 5). Tympanal organs are indistinct. The ovipositor extends much beyond the apex of supra-anal plate in the female (Plate XIII, Fig. 11), while the male external genitalia also extend much beyond the supra-anal plate (Plate XIII, Fig. 4).

**Fifth instar hopper:** (Plate X, Fig. 6). The male and female hoppers of this instar can be distinguished by the following characteristics:

<table>
<thead>
<tr>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body 1.4 cm. long, greenish in colour.</td>
<td>1.0 cm. long, brownish in colour.</td>
</tr>
<tr>
<td>Antenna 0.275 cm. long, 21-segmented.</td>
<td>0.24 cm. long, 20-segmented.</td>
</tr>
<tr>
<td>Hind femur 0.75 cm. long.</td>
<td>0.55 cm. long.</td>
</tr>
</tbody>
</table>

The apices of mandibular teeth are truncate (Plate XI, Fig. 5).

Wing-pads are well developed with distinct veins turned upward and extend to the posterior margin of first abdominal segment (Plate XII, Figs. 6 and 7). Tympanal organs are more or less distinct. The external genitalia of the male possess a postero-terminal extension (Plate XIII, Fig. 5). In females, however, the tips of valves of the ovipositor are
usually acute and straight (Plate XIII, Fig. 12).

**Sixth instar hopper** : (Plate X, Fig. 7). The distinguishing characteristics of male and female hoppers of this instar are as follows:

<table>
<thead>
<tr>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Body</strong></td>
<td>1.8 cm. long, greenish in colour.</td>
</tr>
<tr>
<td><strong>Antenna</strong></td>
<td>0.356 cm. long, 22-segmented.</td>
</tr>
<tr>
<td><strong>Hind femur</strong></td>
<td>0.9 cm. long.</td>
</tr>
</tbody>
</table>

The mandibles are without acute or truncate teeth (Plate XI, Fig. 6). Wing-pads are well developed with distinct veins and extend posteriorly just beyond the second abdominal segment (Plate XII, Figs. 8 and 9). Tympanal organs are more distinct. In female, the external genitalia develop further and extend farther backwards. The tips of dorsal valves of ovipositor are chitinised and curved upwards while those of the ventral valves are also chitinised but curved downwards (Plate XIII, Fig. 13). In male the external genitalia also developed further and are more protruded (Plate XIII, Fig. 6).

These hoppers just before the last moult, stop feeding and rest on the twig. They begin to contract and expand the anterior region of the body. The head is moved forwards and backwards and the pronotum is moved up and down by contraction of the cervical ampulla, causing the rupture of the skin along the medial line above the pronotum. This fissure gradually increases extending from the festigium upto the wing-pads. The head and thorax begin to emerge gradually through the slit in the skin.
The upturned wing-pads become horizontal in position and are drawn out of their sacs. The first and second pairs of legs are then gradually drawn out. The third pair of legs is the last to come out. The cast skin is discarded as the adult grasshopper emerges. The newly emerged adult is called the fledling. During the whole process of moulting, the hopper breathes hard and keeps on expanding and contracting its body. Just after the moult, the fore-wings partially expand and the hind pair of wings is folded like a fan. Gradually the wings are fluttered, raised vertically and within twenty to twenty five minutes the elytra (fore-wings) become fully expanded. The hind-wings are hyaline. The insect now rests on the twig and starts feeding after a few minutes.

(11) Key to the hopper instars

The following key is applicable to distinguish the different hopper instars.

1. (8) Wing-pads if developed point ventrad, antenna 13- to 18-segmented, tympanal organs indistinct.

2. (7) Antenna 13-segmented

3. (4) Wing-pads indistinct, apices of mandibles with acute teeth, body orange yellow with slightly reddish brown head ... first instar

4. (3) Wing-pads distinct, body reddish brown, traces of white markings on the head present.

5. (6) Apices of mandibular teeth rounded, Wing-pads distinct ... second instar
6. (5) Wing-pads distinct, apices of mandibular teeth more acute ...
   third instar

7. (2) Antennae 17- or 18-segmented wing-pads well developed ...
   fourth instar

8. (1) Wing-pads well developed and point dorsad, antennae more than 18-segmented, tympanic organs well developed.

9. (10) Wing-pads extend posteriorly up to posterior margin of first abdominal segment, tips of valves of ovipositor neither chitinised nor curved ...
   fifth instar

10. (9) Wing-pads extend posteriorly beyond the second abdominal segment, valves of ovipositor chitinised and curved.

11. (12) Wing-pads do not extend posteriorly up to the apex of abdomen, male with 21-segmented antennae while female with 22-segmented antennae ...
   sixth instar

12. (11) Wings fully developed with fore-wings modified to form thickened tegmina, hind wings membranous and reach up to the apex of abdomen, male with 22-segmented antennae while female with 23-segmented antennae ...
   Adult
(3) DISCUSSION

The adults of *Spathostemma prasiniferum* Walker have shown the gradual development of reproductive organs during the sexual maturation. An orange or yellow coloured sheath is developed around the testis and the accessory glands increase in size in males. In females also, the accessory glands as well as the fat-body increase in their size. The increase in size of the fat-body has also been observed in various acridoids, e.g., *Melanoplus differentialis* (Weed; Pfeiffer, 1945b) and *Locusta migratoria migratorioides* (Phipps, 1950). Growth takes place simultaneously in several eggs of the different ovarioles of *S. prasiniferum* Walk. and in the eggs of the same ovariole. In an ovariole egg 2 grows relatively faster than egg 1. Phipps (1962) also came to similar conclusion. The number of ovarioles varies in different individuals and even in the right and left ovaries of the same individual and Boldyrev (1929) and Roomwal (1949) noted the same in *Locusta migratoria* and *Schistocerca gregaria* respectively. The new egg-rudiments are produced after the first oviposition in *S. prasiniferum* Walk. but Phipps (1949) found that the new egg-rudiments are produced throughout life of *Omocestus viridulus*, *Stenobothrus lineatus*, *Chorthippus parallelus*, *Chorthippus bicolor* and *Myrmeleotettix maculatus*. Richards and Waloff (1954) found that the ovarioles of female of *Chorthippus brunneus*, which had oviposited heavily, had a high number of egg-rudiments.

The weight of an adult grasshopper of *S. prasiniferum* Walk. increases with age till maturation. This increase in average weight of the female is 94.4 per cent and in males 56.8 per cent. After maturation
period this weight fluctuates. Similar weight change has been noted in *Locusta migratoria migratoria* (Phipps, 1950), *Nemadactylus septemfasciatus* (Norris, 1959a), *Amelesus viridulus* (Richards and Waloff, 1954) and *Schistocerca gregaria* (Norris, 1954). Such correlation between weight and maturation may be of value in determining the readiness of a female in a wild population to oviposit without actual dissections.

The pre-copulation period in male *S. prasiniforum* Walk. varies from three to five days. However, the female is ready for copulation soon after it undergoes the final moult. Pruthi and Nigam (1939) also observed the same in *Pescilocorus pictus*. The process of copulation in *S. prasiniforum* Walk. as already described is very similar to what has been demonstrated in a large number of other acridoids, e.g., *Anoseridium egyptium* (Fedorov, 1927), *Schistocerca gregaria* (Uvarov, 1928), *Locusta migratoria* (Boldyrev, 1929) and *Melanoplus differentialis* (Kyl, 1938). Katiyar (1952, 1956b), however, observed 'riding' and 'lateral' copulating postures in some acridoids as well. In *S. prasiniforum* Walk. a female with a male in copula may continue to feed, crawl and even hop. Popov (1958) has also observed the same in *Schistocerca gregaria*. Some species, e.g., *Sporodactylus* (Hebard, 1937), female may even fly with the male attached. The first copulation is sufficient to fertilise the eggs in all succeeding ovipositions of *S. prasiniforum* Walk. Similar observation has been made in the case of *Schistocerca gregaria* (Norris, 1954). Besides this, it has been observed in *S. prasiniforum* Walk. that the number of copulation affects the fecundity. Ivanova (1925, 1926) and Gregory (1965a, 1965b) in *Locusta*, Fedorov (1927) in *Anoseridium* and
Norris (1964) in *Schistocerca gregaria* observed that the presence of more than one spermatophores in each female of these species indicates the necessity of more than one copulation. But they have not mentioned the importance of repeated copulation. Hunter-Jones (1960) has demonstrated that the latest copulation is effective.

*S. prasinaform* Walk. females either deposit their eggs in the moist sand or at the base of tufts of plants. Rao (1921) found the same in *Onya velox*. During oviposition the female of *S. prasinaform* Walk. bores holes, each measuring 1.8 to 2.7 cm. deep. Though the abdomen is only 1 to 1.5 cm. long in the normal position, it can be extended to reach the depth of chamber with the help of intersegmental membranes. The female abdomen is also extended in other acridoids like in *Anacridina savignyi* from 3.5 to 9-10 cms. (Fedorov, 1927) and *Acris pellucida* from 4.5 to 15-17 cms. (Hafez and Ibrahim, 1950). From the above it may be concluded that the depth of the hole for oviposition may vary from species to species and it depends upon the extension of the abdomen of the species concerned.

The eggs of *S. prasinaform* Walk. increase in size during embryonic development as has been reported in *Locusta migratoria* (Roomwal, 1936). While the eggs of *Tettix* do not undergo any change in size (Shulev, 1952d).

The vermiform larva of *S. prasinaform* Walk. is enclosed in a thick membrane. The larva casts its outer covering and may be termed as the intermediate moult. Some authors have not considered this intermediate moult to be a true one but since the present author has not
found any important difference between this and the subsequent moults, he is, therefore, inclined to agree with the findings of Uvarov (1928).

The hoppers pass through six instars to reach the adult stage. In other acridoids, the number of instars may vary from species to species and even in the individuals of the same species (Uvarov, 1966). Most of the acridologists have distinguished one instar from the other on the basis of the length of the body, number of segments and length of the antenna, length of the hind femur, wing-pads and external genitalia. In addition to these hopper instars of the present grasshopper, may also be distinguished from the succeeding instar on the basis of the apices of the mandibular teeth.
(4) CONCLUSIONS

The development of various stages of *Spathosternum prasiniferum* Walker was studied in the constant temperature room at $33^\circ \pm 1^\circ$C, 70% ± 5% R.H. where 12 hours' light altered with 12 hours' darkness. The insects were fed on the bundles of cut weed, *Cynodon dactylon*. The results are as given below:

(1) The number of ovarioles varies in the adult females, even, in the right and left ovaries of the same female.

(2) The number of small ovarioles increases with age.

(3) The number of new egg-rudiments are produced after the first oviposition at such a rate as to compensate for the next oviposition.

(4) The weight of male and female increases with the sexual maturation.

(5) The grasshoppers copulate freely under experimental conditions. The pre-copulation period varies from 3 to 5 days.

(6) The average pre-oviposition, oviposition and post-oviposition periods are $8.7 \pm 0.396$ and $16.9 \pm 1.441$ and $2.8 \pm 0.270$ days respectively.

(7) The average fecundity is $51 \pm 2.704$ eggs.

(8) The average incubation period is $20.6 \pm 0.065$ days.

(9) The average fertility of the eggs is $91.96 \pm 1.062$ per cent.

(10) The number of instars is found to be 6.

(11) The directional reversal of elytron wing-complex takes place in fifth instar.
(12) The adult males generally live longer than the adult females and survive on an average of $39.2 \pm 1.812$ days as against the females which live for $28.4 \pm 1.310$ days.

(13) The female hoppers take 6.67 days more to become adult than the male hoppers. The average stands at $44.25 \pm 0.883$ days for females as against $37.58 \pm 0.280$ days for males.

(14) The different instars may be distinguished from each other and also the male and female hoppers of the same instar. The presence of fully formed wings in the adults distinguish them from hoppers.
PART - II

IV. DEVELOPMENT OF VARIOUS STAGES UNDER DIFFERENT ECOLOGICAL FACTORS

(1) REVIEW OF LITERATURE

Investigations dealing with the distribution of the grasshoppers in North America in relation to the vegetation have been made by Vestal (1913), Hubbell (1922a, 1922b), Strohecker (1937), Urquhart (1941) and Castrell (1943). In general, the conclusion drawn from most of these studies has been that the distribution of the grasshoppers is correlated with different types of vegetation and further that the controlling factors are entirely physical. Misra (1962) found that the physical factors are unimportant if the composition of the plant is nutritionally unfavourable to the grasshopper.

Tewber et al. (1945), from their experiments on feeding of *Melanoplus bivittatus* Say. on dry feed, observed that dry alfalfa is unable to support life for long, whereas if excess of water is provided, the grasshoppers can live on dry feed. Hussain et al. (1946) and Roomwal (1953) found that locusts prefer succulent food over the papery one. Williams (1954) also studied the food-preference of some British acridoids and reported succulence of food to be of prime importance and
not the toughness of the blades. Therefore the grasshoppers bite off
the tough grass in smaller bits than the tender grass.

It is generally thought that the grasshoppers are oligophagous
rather than polyphagous or omnivorous. Some of them are grass-feeders,
others prefer forbs, while still others are mixed feeders. Rubtsov
(1932a, 1932b) found that every plant community has a characteristic
grasshopper population and vice versa. The relation between the two
is so close that "indicator" plants could be found to indicate grasshoppers
populations, i.e., one of the two major grasshopper pests,
*Gomphocerus albigunus* L., is closely connected with the localities
having *Agropyron cristatum*; another grasshopper pest *Chorthippus
alboargentatus* DeG., is associated with *Poa pratensis*. These indicators
serve as indices to the microclimatic conditions most favourable to
the grasshoppers.

*Melanoplus mexicanus* Sauss. prefers, flourishes and produces
the largest number of eggs on wheat, sunflower (*Helianthus petiolaris*
Nutt.), barley, dandelion (*Taraxacum officinale* Web.), alfalfa, Kentucky
bluegrass (*Poa pratensis* L.), brome (*Bromus inermis* Leyss.), Russian
thistle (*Salsola psiloter A. Nels.*, as small sprouts) and flaxweed
(*Descurainia sophia* L.), and it is generally a forbs-feeder or perhaps a
general feeder preferring forbs (Washburn, 1912; Reberd, 1938; Skeog,
1941; Urquhart, 1941; Brett, 1947; Pfadt, 1949a; Smith, 1950,
Smith et al., 1952; Scharff, 1954; Barnes, 1955). Isely (1938, 1946)
gave a comprehensive account of the feeding habits of grasshoppers in
Texas, indicating how the grass-feeders soon starve on forbs and
forb-feeders starve in the absence of their food-plants. He (1946) found that the graminivorous species, in nature, thrive best in the mesophytic habitats, select the succulent grasses for food in cages, and those species which are more and more tolerant of xeric environment in nature refuse the succulent grasses and feed on the more mature native grasses typical of the drier situations. Isely (1944) even correlated the mandibular morphology of the grasshoppers with the food specificity.

Some of the grasshoppers are restricted to single host species, e.g., Dioryctria tibialis, is specific to Anabasis aphylla (Uvarov, 1928). M. bowditchi ovatus to Artemisia cana, and Hypochlora alba to Artemisia ludoviciana (Criddle, 1933b). Criddle (1933b) gave several examples of other grasshoppers which are able to discriminate between the families of the plant kingdom; e.g., Acrolophus hirtipes Say subsists exclusively upon the members of Boraginaceae. An Oedipodine grasshopper, Schistocerca gregaria Say especially in the immature stages, shows a marked preference for the members of the family cruciferae, while several species of Trimerotropis are partial to Astragalus Sp. (Fabaceae). Criddle (1933a) observed that Camnula has a strong preference for Accrostemma smithii, Pan pratensis, Hordeum jubatum and Bromus inermis and that the green oats are not favourable food for reproduction purposes. Singh (1961) studied that Trifolium alexandrinum, Lycopersicum esculentum, Solanum tuberosum, Solanum melongena and Cucumis melo utilisima are highly preferred among the cultivated plants by Chortenoma trachypterum but Saccharum spontaneum and Asparagus indicus
are totally rejected while leaves of *Calotropis procera* and *Carthamus oxycantha* are not attacked, it is only the flower that are readily eaten.

In some grasshopper species it has been found that the food-preference changes with the growth stages of the food along with the growth stages of the grasshopper. Moore (1936) observed that *Camphula* does not feed upon *Agronivron smithii* in the spring or fall, but in the next season it appeared to be a favourite plant. Jacobson and Farstad (1941), Jones (1943), and McBean and Platt (1951) noted the varietal resistance of wheat and barley to *W. mexicanus*. Prescott (1951) observed that the declining succulence of range grasses normal to late summer conditions in the south-eastern Montana caused a separation of practically all grasshopper species on the short-grass range area into two major groups: (1) the primary range grass-feeders and (ii) forb-feeders. Newton and Esselbaugh (1952) showed the occurrence of a regular sequence of 63 species of adult grasshoppers in the eastern Wyoming and divided the over-all grasshopper complex into early, intermediate and late developing species. Anderson and Wright (1952) found that the distribution of the grasshopper species in Montana is not at random, but is dependent on the vegetation and the grasshoppers are selective feeders.

About the change of food-preference with the growth stages of the grasshoppers, Rubtozov (1932a) observed that the range of preference of the food-plants generally increases with the development of the grasshoppers. Some plants are eaten by nymphs and not by the adults;
this may be due to the hardening of the plant tissues. He (1932b) observed that most grasshoppers in Siberia change their habitats during the life-cycle. The adults live in one habitat and migrate to another for oviposition. The difference in the microclimate between the two habitats may be considerable, and the species with the greatest difference in the habitats exhibit the greatest fluctuation in numbers, leading to outbreaks. In North American grasshoppers, Pfadt (1949b) noted that the first and second instar nymphs of Aulecara elliotti Thos. feed chiefly on Sandberg's grass (Poa secunda Presl.), while the older nymphs and adults feed almost exclusively on western couch-grass (A. smithii), although both the grasses are available in green conditions early in the season. Similarly, Scharff (1954) found that all nymphal instars of *M. mexicanus mexicanus* prefer downy chess (Bromus tectorum L.) while the adults feed on some other grasses and forbs. Perhaps this change may be due to the grass ripening very early and having little foliage left when the grasshopper becomes adult. He even contended that *M. mexicanus mexicanus* when the habitats permit, generally selects favourable to its growth and viability. Misra (1962) also observed that *Campanula pellucida* Scudder is able to discriminate nutritionally favourable plants from unfavourable ones. But he did not adduce sufficient evidence in support of this contention.

Various workers have studied the effect of food-plants on the development of grasshoppers. Davis (1949) showed that the nymphs, adults and egg-pods of *M. mexicanus* and *M. differentialis* are 40 per cent less
abundant in the grassy field margins than in the weedy ones. In the choice of egg-laying sites, the grasshoppers in the grassy margins are only 58 per cent as abundant as those in the weedy margins. Earlier, Criddle (1933b) also laid stress on the accessibility of suitable food as an important consideration to oviposition in any given locality.

Pfadt (1949a) from his cage experiments in field collected late instar nymphs of *M. magicatus*, and found that a very high percentage of mortality (upto 90 per cent) occurs at the end of four weeks on the native grasses, viz., sandgrass (*Calamovilfa longifolia* Scribn.), blue grama (*Bouteloua gracilis* Lag.), fescue (*Festuca rubra* L.) and the speargrasses (*Stipa comata* and *S. viridula* Trin.). On some broad-leaved plants, viz., lamb's-quarters (*Chenopodium album* L.) and Russian thistle (*Salsola pestifer* A. Neis.) the mortality is also high (75 per cent). On the other hand certain other grasses, viz., downy chess (*Bromus tectorum* L.), crested wheat-grass (*A. cristatum* L.), the peas (*P. pratensis* L. and *P. arida* V.), wheat and certain broad-leaved plants, viz., sunflower (*Helianthus petiolaris* Nutt.), alfalfa, corn and dandelion (*Taraxacum erythrospermum* Andr.) gave very low mortality. On wheat and the broad-leaved plants mentioned above it was even lower (10-18 per cent). He found that the plants favourable from the point of view of egg-production are in descending order of suitability: dandelion, thistle, Kentucky bluegrass and western couch-grass. There is a high positive correlation of 0.9 between plants which are preferred and plants which afford high survival. Similarly a high correlation of 0.76 exists between survival and production of egg-pods. On rearing *M. mexicanus* from the
egg to the adult stage on eight different plants, Pfadt (1949a) found significant differences in the size of tenenal adults and in their length of nympbal periods, this being shortest on the most favourable diet. The plants (in descending order of favourableness) are: flaxweed, dandelion, wheat, downy chess, Kentucky bluegrass, western couch-grass, thistle and alfalfa.

Criddle (1924) found that the food-plant, wandering-jew, is particularly suitable for rearing N. _mexicanus_. Parker (1930) used wheat seedlings, corn seedlings, wandering-jew and dried alfalfa leaves in various experiments but he made no comparison of the value of each plant. Faure (1933a) in a study of the phases of N. _mexicanus_ used mainly young wheat and maize leaves. Drake et al. (1945) fed _N. mexicanus_ on a mixed diet of corn, legumes and several other plants. The oviposition rate on this diet was about 117 eggs per female, although comparison was not made for individual diet.

Food affects the course of development in _Schistocerca gregaria_ (Telenga, 1930) and _Melanoplus sanguinipes_ (Brett, 1947) when fed on lucerne because it retards the development of these insects. Brett (1947) also observed that _M. sanguinipes_ when reared on oat exhibit high mortality as compared with other food-plants.

Sanderson (1939) reported that _N. differentialis_ Thos. develops faster and shows a higher survival rate. It lays more eggs when reared on soyabean plants than reared on cotton. He also found that this grasshopper, when fed on Bermuda grass, _not develop beyond the first_
instar. Brett (1947), Smith et al. (1952) and Barnes (1955) studied the effect of food on survival, fecundity and growth of *M. mexicanus* under laboratory conditions. They agreed with Pfadt (1949a) that alfalfa alone is unsuitable food for this grasshopper, as compared with a mixed diet or an exclusive diet of weeds. Barnes (1955) also found normal to above normal development of *M. mexicanus* occurs when fed on alfalfa diet in the field with weeds. Barnes (1963) also found exclusive diet of alfalfa to be inadequate for the complete nymphal development of *M. differentialis*. No nymphs survived from the egg to the adult stage on that diet. Only 18 per cent of second instar nymphs collected from field reached the adult stage and these averaged much below the normal size. Of these 82 to 92 per cent survived up to the adult stage when fed on a favourable mixed diet. Increasing the density of one food-plant in the laboratory cages increased the amount of feeding on that plant in relation to another food-plant present.

Barnes (1965) studied nineteen single-plant and four two-plant diets to study the effect on the nymphal development of *M. sanquiniipes* F. and found that alternating a poor food-plant with a good food-plant gave results almost as good as those obtained with the good food-plant exclusively. A diet of two poor food-plants gave much better results than did either of the plants alone. Weedy alfalfa fields probably provide adequate diets for the nymphal development of the migratory grasshopper.

The wild lettuce and alfalfa feed leads to highest egg production in *M. bivittatus*; the other high producers being red clover, garden leaf
lettuce, onion plants, soybean and sweet clover. On the other hand, castor oil plant and ripe tomato gave the lowest egg record (Tauber et al., 1945).

Bodenheimer (1932) observed in the desert locust, *Schistocerca gregaria* Forsk. that the fresh succulent vegetation growing after rainfall may exert a powerful influence in quickening the sex maturation of locusts. Kozhanchikov (1950) found that more primitive groups of Acrididae feed mainly on the lower Dicotyledons, while the more advanced Oedopodinae feed mainly on Monocotyledons.

It has been pointed out in the reports of the United States Entomological Commission (1876) that temperature influences the development of the egg. But no precise work has been done since Church and Salt (1952), observed that the normal development of *Melanoplus bivittatus* occurs at about 12°C. Hunter-Jones (1964) found sudden reductions in the percentage of hatching at the extreme temperatures.

An egg in contact with water during the first few days of incubation absorbs enough of it for the embryo to undergo katatrepsis and to complete the development and that high or low relatively humidity apparently has no effect on the development. This has been amply demonstrated in *S. gregaria*. Eggs of this locust were incubated for three days in wet sand and then transferred to saturated air, where they could neither gain nor lose any amount of water, low percentage of eggs hatched if returned to wet sand after ninety days. This experiment shows a possibility of an extension in the incubation period due to deficiency
of water (Husain et al., 1941; Shulov and Pener, 1961, 1963). The eggs of *Anacridium aegyptium* normally develop in about thirty days, the incubation period may be extended for more than two months due to water deficiency (Shulov, 1956). Harjai and Sikka (1970) found that the soils with far lower or far higher levels of moisture had the common effect in prolonging the incubation period. They also stated that low moisture gave rise to solitary type hatchlings while higher moisture gave rise to black hatchlings characteristic of gregarious breeding.

Grewal and Atwal (1966) incubated the eggs of *Chroogomus trachypтерus* at different temperature and humidity conditions and found that the incubation period was inversely proportional to the temperature but the moisture level within the range of 4, 8 and 12 per cent of the soil did not affect the incubation period of the eggs although the viability of eggs was influenced by moisture. If, at a given high temperature, the moisture was also increased, the viability of the eggs was adversely affected. Parker (1929) found the percentage of hatching of the eggs of *Camnula pellucida* to be higher in moderately damp soil than in the wet or dry soil. Hunter-Jones (1964) observed that the eggs of *S. gregaria* did not hatch either in water logged (25 cc water per 100 gm of sand) or almost dry sand (0.6 cc of water per 100 gm of sand). Water content of the sand in the range between these two extremes made no difference.

One day old eggs of *S. gregaria* exposed to air with forty to eighty per cent relative humidity died within six days. Those placed in contact with water for a few days and later removed from contact, water were able to continue the development. (Shulov, 1952b). The development, however, was
noticed to be retarded in the eggs which were placed in arid condition, i.e., 0% R.H. (Shulov and Pener, 1963). Eggs in dry sand die within two days (Hunter-Jones, 1964).

Excessive water may also be a cause of egg mortality, particularly in species laying eggs in dry soil, e.g., *Dociostarum* and *Tetetix*. Their eggs are killed if moistened soon after egg-laying and up to the end of anatrepesis (Shulov and Pener, 1961). Eggs of *Locusta migratoria migratorioides* are killed if submerged in water when the embryo is ready to hatch (Shumakov and Yakhimovich, 1950).

Bodine (1925a) observed that exposure to low temperature for short time interrupted the development of grasshopper embryo for the same period but later on it is considered to act as a stimulus for development. Uvarov (1928) found that hatching of grasshopper eggs is greatly influenced by alternating low and high temperatures.

Effect of temperature and humidity on the development of hoppers has been studied by many workers. Parker (1930) found that temperature and humidity accelerate the rate of the development and shorten the nymphal duration of American grasshoppers. Hamilton (1936, 1950) studied the effects of different temperatures and relative humidities and concluded that the length of the hopper period decreased with the rising temperature. According to Hamilton the optimum conditions for the rate of the development and the survival do not coincide, e.g., *Locusta migratoria migratorioides* hoppers developed fast at 42.2°C while the lowest mortality occurred at 34.4°C. The respective optimum temperatures for *Schistocerca gregaria*
being 38.3°C and 32.2°C. According to Hamilton, *Schistocerca gregaria* hoppers complete their development at 32.2°C and 45% R.H. while at 26.7°C and 25% R.H. no development occurs. The same author observed that the rate of development is slowed down at low humidity than at higher which contradict the findings of Husain et al. (1946) and Chauvin (1941b) on *S. gregaria*.

Many workers have studied the effects of different levels of temperature and humidity on the development of adults. Grewal and Atwal (1968) found that the pre-oviposition and oviposition periods of *Chrotogonus trachypterus* decreased with the increase in temperature, whereas the temperature affect fecundity in a different way. Parker (1930) found that *Camnula pellucida* survived at 37°C for only 15.8 days, but laid 4.2 egg-pods per female during that time; whereas the span of life doubled (36.6 days) at 27°C, but laid only 1.0 egg-pod per female. Grewal and Atwal (1968) also reported that when *C. trachypterus* reared at 25°C, 30°C and 35°C the female lived longer at 25°C, but laid maximum number of eggs at 30°C. He observed that the relative humidity has a little effect on the reproductive potential.

Antonieu and Huáter-Jones (1956) found survival to be low in *Epip PROCNEMIS capitata* Miller when reared in crowding as well as in isolation, especially in the first instar. It was found to be lowest (10 to 30 per cent) under crowded conditions.

Schistocerca gregaria F., in crowded and isolated conditions. She could not detect any difference in the nymphal duration in these locusts when reared in isolated and crowded conditions. While Antoniou and Hunter-Jones (1956) stated that the nymphs of Evareenemisa capitata reared in crowded habitat took three or four days more to become adult than the isolated ones.

Antoniou and Hunter-Jones (1956, 1968) in E. capitata and E. plicata eratinae Walker, and, Hunter-Jones and Ward (1959) in Gastroderus anficanus Saussure found that the rearing density did not affect the adult morphometrics. Also the density during the adult life neither affects the rate of sexual maturation nor the number of eggs per ped. This result is in marked contrast to that obtained from the locusts (Paoli, 1932; Janone, 1938; Norris, 1950, 1952; Hunter-Jones, 1958).

Cannibalism is common in acridoids and has been reported by Uvarov (1931), Ballard (1932), Faure (1932), Husain and Mathur (1936), Smee (1936), Duarte (1938), Husain et al. (1946), Khan (1946), Nickerson (1956), and Bhatia and Singh (1959) in the hopper and the adult locusts but little is known in grasshoppers. Pradhan and Peswani (1960) have reported females of Hieraglyphus nigreropleptus Bolivar to feed occasionally on their freshly laid eggs. Rizvi (1967) has also reported this phenomenon in H. nigreropleptus but in the late hoppers and adults only.
(2) DEVELOPMENT OF VARIOUS STAGES OF *SPATHOSTERNUM PRASINIFERUM*
WALKER UNDER DIFFERENT ECOLOGICAL FACTORS

(A) Development of various stages of *Spathosternum prasiniferum*
Walker under different food-plants:

(1) *Food-preference*

The observations on food-preference of *S. prasiniferum* Walk. were
recorded from the field as well as in the laboratory. The data were
obtained from August 1969 to July 1971. The grasshopper used in the
experiments were obtained from the stock maintained in the laboratory.
The insect breeding cage (Plate XIV) was used for estimating the order
of preference of the various plants given below:

1. *Zea mays*
2. *Sorghum vulgare*
3. *Pennisetum typhoides*
4. *Saccharum officinarum*
5. *Oryza sativa*
6. *Triticum aestivum*
7. *Hordeum vulgare*
8. *Solanum melongena*
9. *Abelmoschus esculentus*
10. *Solanum nigrum*
11. *Echinochloa colona*
12. *Hemerthia compressa*
13. *Setaria verticillata*
14. *Cynodon dactylen*
15. *Cyperus retundus*
16. *Sorghum halopense*
EXPLANATION OF PLATE XIV

In the cage the light bulb is seen giving a temperature of 35°C. The maximum and minimum thermometer and hair hygrometer, indicating the temperature and humidity are seen on the right and back sides respectively. Two metallic tubes on the right and two on the left side are inserted into the perforations in the false-floor of the cage. Each metallic tube is containing the cut leaves of different plant species.
Wooden cage used for experiments on food-preference of *S. prasiniferum* Walk.
The false-floor of the cage was provided with four perforations, two on the left side and two on the right. The metallic tubes containing water with the bundles of cut leaves were inserted into the perforations. The experiments were performed at $35^\circ \pm 1^\circ$C and $75\% \pm 5\%$ R.H. The plants tested were in the early leaf stage. A common local weed, *Cynodon dactylon* served as the standard with which the remaining plant species were compared. Four plant species, one standard and three other plant leaves were placed in the cage and 100 grasshoppers starved for 24 hours were released in the cage. The grasshoppers, after a few exploratory bites, started to feed on the plants of their choice. The number of insects feeding on different plant species was noted after five minutes. Three such counts were taken at intervals of five minutes. The observations were not recorded after 15 minutes as the majority of the grasshoppers stopped feeding. Each experiment was repeated thrice with three different lots of grasshoppers and with the same four plant species, but each time the different plants were placed at different positions in the cage. The order of preference of each plant species for each instar and adult of this grasshopper was calculated by assuming that 100 grasshoppers fed on the standard plant and calculation was made for the corresponding number of grasshoppers feeding on other plants.

The preference value of *Solanum melongena*, *Salanum nigrum*, *Abelmoschus esculentus* and *Saccharum officinarum* was not calculated because the grasshoppers ignored these plant species in presence of other plant species used in the tests.
The results are summarized in Tables 9 and 10.

The following indications were obtained from this set of experiments:

A list of plants reported as having been damaged by *S. prasiniferum* Walk. is given in Table 9. This grasshopper is found feeding on *Zea mays*, *Sorghum vulgare*, *Pennisetum typhoides*, *Oryza sativa*, *Triticum aestivum*, *Hordeum vulgare*, *Echinochloa colonum*, *Hemarthria compressa*, *Setaria verticillata*, *Cynodon dactylon*, *Cyperus rotundus* and *Sorghum halepense* and affords evidence of preference for the above mentioned plants.

**Table 9**

Plants observed to be eaten or damaged by individuals of *S. prasiniferum* Walk.

Field observations (collection over a period of two years) from and near the A.E.F.S., S.F., Aligarh

<table>
<thead>
<tr>
<th>Field-crops</th>
<th>Grander-plants</th>
<th>Weeds</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Zea mays</em></td>
<td><em>Solanum melongena</em></td>
<td><em>Echinochloa colonum</em></td>
</tr>
<tr>
<td><em>Sorghum vulgare</em></td>
<td><em>Solanum nigrum</em></td>
<td><em>Hemarthria compressa</em></td>
</tr>
<tr>
<td><em>Pennisetum typhoides</em></td>
<td><em>Abelmoschus esculentus</em></td>
<td><em>Setaria verticillata</em></td>
</tr>
<tr>
<td><em>Oryza sativa</em></td>
<td></td>
<td><em>Cynodon dactylon</em></td>
</tr>
<tr>
<td><em>Triticum aestivum</em></td>
<td></td>
<td><em>Cyperus rotundus</em></td>
</tr>
<tr>
<td><em>Hordeum vulgare</em></td>
<td></td>
<td><em>Sorghum halepense</em></td>
</tr>
<tr>
<td><em>Saccharum officinarum</em></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Among the unpreferred plants are *Solanum melongena*, *Abelmoschus esculentus*, *Solanum nigrum* and *Saccharum officinarum* but these are eaten by this grasshopper after starvation.
Table 10
Food preference of different instar hoppers and adults of *S. prasinaferum* Walk., kept at 35\(^\circ\) ± 1\(^\circ\)C, and 75\% ± 5\% R.H. based on 3 replicates (100 insects were used in each replicate)

<table>
<thead>
<tr>
<th>Plant Species</th>
<th>Average preference value of plant eaten by different hopper instars ± S.E.</th>
<th>Average preference value of plant eaten by adult ± S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st</td>
<td>2nd</td>
</tr>
<tr>
<td><em>Zea mays</em></td>
<td>57 ± 0.423</td>
<td>59 ± 0.612</td>
</tr>
<tr>
<td><em>Sorghum vulgare</em></td>
<td>30 ± 0.312</td>
<td>31 ± 0.523</td>
</tr>
<tr>
<td><em>Pennisetum typhoides</em></td>
<td>56 ± 0.243</td>
<td>54 ± 0.412</td>
</tr>
<tr>
<td><em>Oryza sativa</em></td>
<td>75 ± 0.621</td>
<td>78 ± 0.242</td>
</tr>
<tr>
<td><em>Triticum aestivum</em></td>
<td>76 ± 0.341</td>
<td>75 ± 0.631</td>
</tr>
<tr>
<td><em>Hordeum vulgare</em></td>
<td>76 ± 0.648</td>
<td>76 ± 0.812</td>
</tr>
<tr>
<td><em>Echinochloa colonum</em></td>
<td>110 ± 0.412</td>
<td>112 ± 0.613</td>
</tr>
<tr>
<td><em>Hordeum compressus</em></td>
<td>92 ± 0.341</td>
<td>90 ± 0.242</td>
</tr>
<tr>
<td><em>Setaria verticillata</em></td>
<td>105 ± 0.712</td>
<td>105 ± 0.620</td>
</tr>
<tr>
<td><em>Cynodon dactylon</em></td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td><em>Cynodon rotundus</em></td>
<td>80 ± 0.347</td>
<td>81 ± 0.615</td>
</tr>
<tr>
<td><em>Sorghum halepense</em></td>
<td>82 ± 0.482</td>
<td>83 ± 0.450</td>
</tr>
</tbody>
</table>

S.E. = Standard Error
It is evident from Table 10 that the first, second, third and fourth instar hoppers prefer the food, *Echinochloa colenum*, *Setaria verticillata*, *Cynodon dactylon*, *Hemarthria compressa*, *Sorghum halepense* and *Cyperus rotundus*. The fifth and sixth instar hoppers and adult grasshoppers prefer *Zea mays*, *Sorghum vulgare*, *Pennisetum typhoides*, *Oryza sativa*, *Triticum aestivum* and *Hordeum vulgare* as food. It is also apparent that this grasshopper differentially select its food.

Having seen that early stages of *S. prasiniferum* Walk. mainly feed on weeds. On the basis of preference value the weeds are divided into two classes. Those which are highly preferred by the early stages of the grasshopper are *Echinochloa colenum*, *Setaria verticillata* and *Cynodon dactylon*, and those which are less preferred include *Hemarthria compressa*, *Cyperus rotundus* and *Sorghum halepense*. Among the weeds having high preference value for early stages, *Echinochloa colenum* tops the list. The early stages of this grasshopper feed very reluctantly on *Sorghum halepense*, therefore this weed has lowest preference value.

It has also been observed that late stages of the grasshopper primarily feed on field crops. On the basis of preference value, the field crops are also divided into two classes. (i) *Zea mays*, *Pennisetum typhoides* and *Oryza sativa* which have high preference value for the late stages while (ii) *Triticum aestivum*, *Hordeum vulgare* and *Sorghum vulgare* have low preference value.
(11) Development of hoppers and adults under different food-plants

The grasshoppers used in these experiments were obtained from the stock maintained in the laboratory. Tender leaves of the following plants were supplied individually as food:

1. *Zea mays*
2. *Sorghum vulgare*
3. *Pennisetum typhoides*
4. *Oryza sativa*
5. *Triticum aestivum*
6. *Hordeum vulgare*
7. *Echinochloa colenso*
8. *Hemarthria compressa*
9. *Setaria verticillata*
10. *Cynodon dactylon*
11. *Cyperus rotundus*
12. *Sorghum halepense*

Young leaves of mixed diet (*Oryza sativa* and *Echinochloa colenso*), (*Oryza sativa* and *Cynodon dactylon*), and (*Oryza sativa* and *Cyperus rotundus*) were also supplied to these grasshoppers.

One hundred and fifty newly hatched first instar hoppers were placed in each of the fifteen large glass jars (Plate IV, Fig. 2). The hoppers of different jars were supplied with different food-plants mentioned above till they reached the adult stage or died. The quality of food throughout remained the same in each jar. The number of hoppers reaching the adult stage and length of the hopper period was recorded as given in Table 11.
Effect of different food-plants on the survival and development of hoppers of *S. prasiniferi* Walk., reared at 35°±10°C, 75%±5% R.H. and 12 hours' light altered with 12 hours' darkness. 
150 newly hatched hoppers were reared on each diet.

<table>
<thead>
<tr>
<th>Food-plant</th>
<th>Sex</th>
<th>Number</th>
<th>Percent</th>
<th>Hopper reaching the adult stage</th>
<th>Average length of hoppers period (in days) ± S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Zea mays</em></td>
<td>Male</td>
<td>8</td>
<td>11</td>
<td>42.4 ± 0.304</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>8</td>
<td></td>
<td>52.1 ± 0.150</td>
<td></td>
</tr>
<tr>
<td><em>Sorghum vulgare</em></td>
<td>Male</td>
<td>4</td>
<td>6</td>
<td>46.3 ± 0.155</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>5</td>
<td></td>
<td>54.2 ± 0.087</td>
<td></td>
</tr>
<tr>
<td><em>Pennisetum typhoides</em></td>
<td>Male</td>
<td>7</td>
<td>11</td>
<td>42.2 ± 0.152</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>9</td>
<td></td>
<td>52.1 ± 0.150</td>
<td></td>
</tr>
<tr>
<td><em>Oryza sativa</em></td>
<td>Male</td>
<td>5</td>
<td>9</td>
<td>42.5 ± 0.079</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>8</td>
<td></td>
<td>52.4 ± 0.290</td>
<td></td>
</tr>
<tr>
<td><em>Triticum aestivum</em></td>
<td>Male</td>
<td>6</td>
<td>8</td>
<td>44.3 ± 0.236</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>6</td>
<td></td>
<td>53.2 ± 0.087</td>
<td></td>
</tr>
<tr>
<td><em>Hordeum vulgare</em></td>
<td>Male</td>
<td>5</td>
<td>8</td>
<td>44.1 ± 0.302</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>7</td>
<td></td>
<td>52.2 ± 0.191</td>
<td></td>
</tr>
<tr>
<td><em>Echinochloa colonum</em></td>
<td>Male</td>
<td>26</td>
<td>50</td>
<td>34.0 ± 0.236</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>49</td>
<td></td>
<td>38.0 ± 0.471</td>
<td></td>
</tr>
<tr>
<td><em>Hemarthria compressa</em></td>
<td>Male</td>
<td>18</td>
<td>27</td>
<td>39.0 ± 0.149</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>22</td>
<td></td>
<td>49.5 ± 0.167</td>
<td></td>
</tr>
<tr>
<td><em>Setaria verticillata</em></td>
<td>Male</td>
<td>27</td>
<td>40</td>
<td>34.5 ± 0.225</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>33</td>
<td></td>
<td>38.5 ± 0.225</td>
<td></td>
</tr>
<tr>
<td><em>Cynodon dactylon</em></td>
<td>Male</td>
<td>20</td>
<td>30</td>
<td>36.5 ± 0.307</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>25</td>
<td></td>
<td>42.5 ± 0.225</td>
<td></td>
</tr>
<tr>
<td><em>Cyperus rotundus</em></td>
<td>Male</td>
<td>18</td>
<td>27</td>
<td>42.0 ± 0.360</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>22</td>
<td></td>
<td>50.0 ± 0.149</td>
<td></td>
</tr>
<tr>
<td><em>Sorghum halepense</em></td>
<td>Male</td>
<td>19</td>
<td>29</td>
<td>40.5 ± 0.225</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>20</td>
<td></td>
<td>49.4 ± 0.311</td>
<td></td>
</tr>
<tr>
<td><em>Oryza sativa</em> and <em>Echinochloa colonum</em></td>
<td>Male</td>
<td>71</td>
<td>93</td>
<td>31.0 ± 0.149</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>68</td>
<td></td>
<td>34.0 ± 0.226</td>
<td></td>
</tr>
<tr>
<td><em>Oryza sativa</em> and <em>Cynodon dactylon</em></td>
<td>Male</td>
<td>62</td>
<td>65</td>
<td>33.1 ± 0.376</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>35</td>
<td></td>
<td>36.4 ± 0.407</td>
<td></td>
</tr>
<tr>
<td><em>Oryza sativa</em> and <em>Cyperus rotundus</em></td>
<td>Male</td>
<td>51</td>
<td>62</td>
<td>33.5 ± 0.307</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>42</td>
<td></td>
<td>37.1 ± 0.560</td>
<td></td>
</tr>
</tbody>
</table>

S.E. = Standard Error
From the above set of experiments, six male and six female adults were taken out from each of fifteen jars containing different feeds and released in pairs in small glass jars (Plate III, Fig. 2) containing the same food upon which they had fed during their hopper stage. Maturation period, oviposition period, egg-pods per female and the total number of eggs per female were recorded and tabulated (Table 12).

The following results were obtained from this set of experiments:

It is apparent from Table 11 that the food-plant has a well marked effect on the development of *S. prasiniferum* Walk. The best results are obtained by feeding them on mixed diet of *Oryza sativa* and *Echinochloa colenum*. Ninety three per cent of hoppers reach the adult stage when fed on this mixed diet and male and female hoppers take 31.0 and 34.0 days respectively to reach the adult stage. Poor results are obtained when the hoppers are fed on exclusive diet of *Sorghum vulgare*. Only six per cent of them reach the adult stage, and male and female hoppers take 46.3 and 54.2 days respectively to reach the adult stage.

The following plants have been arranged in descending order as regards their nutritive value in relation to the development of the hoppers:

*Oryza sativa* and *Echinochloa colenum*, *Oryza sativa* and *Cynodon dactyle*, *Oryza sativa* and *Cyperus rotundus*, *Echinochloa colenum*, *Setaria verticillata*, *Cynodon dactyle*, *Sorghum halepense*, *Cyperus rotundus*, *Hemerathria compressa*, *Zea mays*, *Pennisetum typhoides*, *Oryza sativa*, *Triticum aestivum*, *Hordeum vulgare* and *Sorghum vulgare*.

It is evident from Table 12 that there is a marked effect of
Table 12

Effect of different food-plants on the pre-oviposition period, oviposition period, eggs-pods per female and eggs per female of *S. prasiniferum* Walk., reared at 35° ± 1°C, 75% ± 5% R.H. and 12 hours' light altered with 12 hours' darkness. 6 replicates (one pair in each replicate)

<table>
<thead>
<tr>
<th>Food plants</th>
<th>Average maturation or maturation period (in days)</th>
<th>Average oviposition period (in days)</th>
<th>Average egg-pods per female (in number)</th>
<th>Average eggs per female (in number) ± S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Zea mays</em></td>
<td>7.3</td>
<td>23.0</td>
<td>6.0</td>
<td>86.4 ± 0.410</td>
</tr>
<tr>
<td><em>Sorghum vulgare</em></td>
<td>8.0</td>
<td>21.1</td>
<td>7.3</td>
<td>83.3 ± 0.308</td>
</tr>
<tr>
<td><em>Pennisetum typhoides</em></td>
<td>7.4</td>
<td>22.3</td>
<td>7.8</td>
<td>86.0 ± 0.402</td>
</tr>
<tr>
<td><em>Oryza sativa</em></td>
<td>7.6</td>
<td>22.3</td>
<td>7.6</td>
<td>86.1 ± 0.413</td>
</tr>
<tr>
<td><em>Triticum aestivum</em></td>
<td>7.8</td>
<td>21.6</td>
<td>7.5</td>
<td>86.0 ± 0.324</td>
</tr>
<tr>
<td><em>Hordeum vulgare</em></td>
<td>7.8</td>
<td>21.0</td>
<td>7.5</td>
<td>85.4 ± 0.370</td>
</tr>
<tr>
<td><em>Echinochloa colonum</em></td>
<td>8.1</td>
<td>17.3</td>
<td>7.1</td>
<td>75.1 ± 0.342</td>
</tr>
<tr>
<td><em>Hemarthria compressa</em></td>
<td>10.2</td>
<td>13.3</td>
<td>6.0</td>
<td>54.3 ± 0.271</td>
</tr>
<tr>
<td><em>Setaria verticillata</em></td>
<td>8.2</td>
<td>15.4</td>
<td>6.9</td>
<td>68.0 ± 0.232</td>
</tr>
<tr>
<td><em>Cynodon dactylon</em></td>
<td>8.4</td>
<td>13.7</td>
<td>6.7</td>
<td>55.6 ± 0.310</td>
</tr>
<tr>
<td><em>Cyperus rotundus</em></td>
<td>12.4</td>
<td>13.2</td>
<td>5.4</td>
<td>42.0 ± 0.326</td>
</tr>
<tr>
<td><em>Sorghum halepense</em></td>
<td>11.6</td>
<td>13.2</td>
<td>5.8</td>
<td>51.0 ± 0.345</td>
</tr>
<tr>
<td><em>Oryza sativa</em> and <em>Echinochloa colonum</em></td>
<td>5.2</td>
<td>35.0</td>
<td>10.2</td>
<td>120.3 ± 0.412</td>
</tr>
<tr>
<td><em>Oryza sativa</em> and <em>Cynodon dactylon</em></td>
<td>6.5</td>
<td>27.0</td>
<td>8.0</td>
<td>105.4 ± 0.381</td>
</tr>
<tr>
<td><em>Oryza sativa</em> and <em>Cyperus rotundus</em></td>
<td>7.0</td>
<td>25.2</td>
<td>8.0</td>
<td>98.1 ± 0.374</td>
</tr>
</tbody>
</table>

S.E. = Standard Error
food-plants on the development of adults. The gonads mature more quickly in the adults which are fed on the mixed diet of *Oryza sativa* and *Echinochloa colenum* than those fed on other plant species in the test. The mean maturation period of the adults when fed on different food-plants is as follows:

<table>
<thead>
<tr>
<th>Feed-plant</th>
<th>Maturation period</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>O. sativa</em> and <em>E. colenum</em></td>
<td>5.2 days</td>
</tr>
<tr>
<td><em>O. sativa</em> and <em>C. dactylon</em></td>
<td>6.5 days</td>
</tr>
<tr>
<td><em>O. sativa</em> and <em>C. retundus</em></td>
<td>7.0 days</td>
</tr>
<tr>
<td><em>Z. mays</em></td>
<td>7.3 days</td>
</tr>
<tr>
<td><em>P. typhoides</em></td>
<td>7.4 days</td>
</tr>
<tr>
<td><em>O. sativa</em></td>
<td>7.6 days</td>
</tr>
<tr>
<td><em>T. aestivum</em></td>
<td>7.8 days</td>
</tr>
<tr>
<td><em>H. vulgare</em></td>
<td>7.8 days</td>
</tr>
<tr>
<td><em>S. vulgare</em></td>
<td>8.0 days</td>
</tr>
<tr>
<td><em>E. colenum</em></td>
<td>8.1 days</td>
</tr>
<tr>
<td><em>S. verticillata</em></td>
<td>8.2 days</td>
</tr>
<tr>
<td><em>C. dactylon</em></td>
<td>8.4 days</td>
</tr>
<tr>
<td><em>H. compressa</em></td>
<td>10.2 days</td>
</tr>
<tr>
<td><em>S. halenpe</em></td>
<td>11.6 days</td>
</tr>
<tr>
<td><em>C. retundus</em></td>
<td>12.4 days</td>
</tr>
</tbody>
</table>

From the above it may be concluded that the nutritive value of the food-plant affects the maturation of gonads also.

It has also been observed that the type of food-plant also affects the fecundity of *S. parasiniferum* Walk. (Table 12). Their average are following:
The type of food-plants also affects the oviposition period of this grasshopper. Their average oviposition period increases in the following order:

<table>
<thead>
<tr>
<th>Feed-plant</th>
<th>Oviposition period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q. <em>sativa</em> and E. <em>celnum</em></td>
<td>35.0 days</td>
</tr>
<tr>
<td>Q. <em>sativa</em> and C. <em>dactylen</em></td>
<td>27.0 days</td>
</tr>
<tr>
<td>Q. <em>sativa</em> and C. <em>retundus</em></td>
<td>25.2 days</td>
</tr>
<tr>
<td>Z. <em>mays</em></td>
<td>23.0 days</td>
</tr>
<tr>
<td>P. <em>typhoides</em></td>
<td>22.3 days</td>
</tr>
<tr>
<td>Q. <em>sativa</em></td>
<td>22.3 days</td>
</tr>
<tr>
<td>T. <em>sestivum</em></td>
<td>21.6 days</td>
</tr>
<tr>
<td>Species</td>
<td>Days</td>
</tr>
<tr>
<td>-----------------</td>
<td>-------</td>
</tr>
<tr>
<td>S. vulgare</td>
<td>21.1</td>
</tr>
<tr>
<td>H. vulgare</td>
<td>21.0</td>
</tr>
<tr>
<td>E. colenum</td>
<td>17.3</td>
</tr>
<tr>
<td>S. verticillata</td>
<td>15.4</td>
</tr>
<tr>
<td>C. dactylen</td>
<td>13.7</td>
</tr>
<tr>
<td>H. compressa</td>
<td>13.3</td>
</tr>
<tr>
<td>C. retundus</td>
<td>13.2</td>
</tr>
<tr>
<td>S. halepense</td>
<td>13.2</td>
</tr>
</tbody>
</table>
(B) Development of various stages of Spathesternum prasiniferum
Walker under different levels of temperature and humidity

(i) Development of eggs in relation to different levels of
temperature and humidity

Freshly laid eggs obtained from the stock maintained in the
laboratory were kept in the sand having 4%, 8% and 12% moisture. Then
the eggs were incubated at 10°, 25°, 30°, 35°, 40° and 45°C to study
the effect of different temperature and moisture conditions on the
development of the eggs of S. prasiniferum Walk. The results are
summarised in Table 13.

It is apparent from Table 13 that the temperature has a pronounced
effect on the development of eggs. The eggs kept at 10° and 45°C fail to
hatch regardless of humidity condition. The incubation period is
prolonged with the decrease in temperature and conversely it is lowered
with the rise in temperature. Therefore, the development of egg is
accelerated with rise in temperature.

The incubation period is more or less the same at varying moisture
levels at the same temperature (Table 13). The influence of moisture is
pronounced on the viability of the eggs and the highest percentage of
eggs hatched at 8 per cent sand moisture and the lowest at 12 per cent
sand moisture.

Freshly laid eggs obtained from the stock maintained in the
laboratory were kept at 35°C and 8% sand moisture for 4, 8, 12 and 16
days. Then the eggs were transferred to 100% atmospheric humidity at
Table 13

Incubation period (days) and survival (per cent) of eggs of *S. prasiniferum* Walk., kept at different levels of temperature and humidity in the sand, based on 10 replicates (10 eggs in each replicate).

<table>
<thead>
<tr>
<th>Temperature °C</th>
<th>Incubation period (days ± S.E.)</th>
<th>Survival (per cent) ± S.E. of eggs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Moisture percentage in the sand</td>
<td>Moisture percentage in the sand</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>10</td>
<td>No. hatching</td>
<td>No. hatching</td>
</tr>
<tr>
<td>25</td>
<td>35.7 ± 0.132</td>
<td>36.4 ± 0.126</td>
</tr>
<tr>
<td>30</td>
<td>24.1 ± 0.164</td>
<td>23.6 ± 0.142</td>
</tr>
<tr>
<td>35</td>
<td>19.5 ± 0.165</td>
<td>19.1 ± 0.136</td>
</tr>
<tr>
<td>40</td>
<td>16.6 ± 0.125</td>
<td>15.4 ± 0.145</td>
</tr>
<tr>
<td>45</td>
<td>No hatching</td>
<td>No hatching</td>
</tr>
</tbody>
</table>

S.E. = Standard Error

The results are included in Table 14.

It is evident from Table 14 that the moisture absorbed by the eggs of *S. prasiniferum* Walk. in the initial stage is sufficient for the completion of the development at 35°C. The rate of development is rather slow in the eggs kept in contact with moisture for four days, which may be due to little quantity of water absorbed. A longer period (about 8 days) is needed.
for the satisfactory completion of the development. The incubation period is almost the same when the eggs are either kept at 8% sand moisture for 8, 12 and 16 days and then transferred to 100% atmospheric humidity or they are kept at 8% sand moisture throughout the experiment.

Table 14

Combined effect of contact moisture (8%) and atmospheric humidity (100%) on the development and viability of eggs of *S. prolixiferum* Walk., kept at 35°C, based on 10 replicates (10 eggs in each replicate)

<table>
<thead>
<tr>
<th>Period (in days) after which the eggs were transferred from 8% contact moisture to 100% atmospheric humidity</th>
<th>Throughout contact moisture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Incubation Period (days) ± S.E.</td>
<td>23.4 ± 0.221</td>
</tr>
<tr>
<td>Survival (per cent) ± S.E.</td>
<td>84.5 ± 0.123</td>
</tr>
</tbody>
</table>

S.E. = Standard Error
(11) **Development of eggs in relation to fluctuating temperature and humidity**

The following three sets of experiments were designed to study the effect of fluctuating temperature and humidity on the development of eggs of this grasshopper. The sand moisture was kept constant at 8% in each case. The eggs used in these experiments were obtained from the stock maintained in the laboratory.

(1) In the first set of experiments freshly laid eggs were exposed to 10°C for 4 and 72 days and were then incubated at 35°C. The incubation period and percentage of hatching were recorded in each case. The results are included in Table 15.

(2) In the second set of experiments the eggs which had already been incubated at 35°C for 5, 10 and 15 days were also exposed to 10°C for 4 days and then incubated at 35°C. The incubation period and percentage of hatching were recorded in each case. The results are given in Table 16.

(3) In the third set the experiments were repeated as in experiment (2) but the alternate temperatures used were 35°C and 50°C. Eight batches each containing 10 eggs were taken, out of which four batches which had already been incubated for 0, 5, 10 and 15 days at 35°C were exposed for one day at 50°C and then incubated at 35°C. The remaining four batches of eggs which had already been kept for 0, 5, 10 and 15 days at 35°C were exposed for three days at 50°C and finally incubated at 35°C. The incubation period and percentage of hatching were recorded in each case. The results are summarised in Tables 17 and 18.
**Table 15**

Effect of alternate temperatures of 10°C and 35°C on the hatching of eggs of *S. prasiniferum* Walk.

8% sand moisture was maintained. 10 replicates (10 eggs in each replicate) were exposed to 10°C for 4 or 72 days and then incubated at 35°C.

<table>
<thead>
<tr>
<th>Fresh egg kept at 10°C for days</th>
<th>Eggs then incubated at 35°C for days ± S.E.</th>
<th>Hatching (per cent) ± S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.0</td>
<td>22.1 ± 0.013</td>
<td>25.1 ± 0.121</td>
</tr>
<tr>
<td>72.0</td>
<td>84.1 ± 0.014</td>
<td>10.1 ± 0.234</td>
</tr>
</tbody>
</table>

S.E. = Standard Error

**Table 16**

Effect of alternate temperature of 10°C and 35°C on the hatching of eggs of *S. prasiniferum* Walk.

8% sand moisture was maintained. 10 replicates (10 eggs in each replicate) were kept at 35°C for 5 or 10 or 15 days, then exposed for 4 days to 10°C and incubated again at 35°C.

<table>
<thead>
<tr>
<th>Eggs kept at 35°C (days)</th>
<th>Eggs then kept at 10°C (days)</th>
<th>Eggs then incubated at 35°C ± S.E. (days)</th>
<th>Hatching (per cent) ± S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0</td>
<td>4.0</td>
<td>22.0 ± 0.041</td>
<td>58.1 ± 0.040</td>
</tr>
<tr>
<td>10.0</td>
<td>4.0</td>
<td>21.8 ± 0.035</td>
<td>78.4 ± 0.053</td>
</tr>
<tr>
<td>15.0</td>
<td>4.0</td>
<td>22.1 ± 0.043</td>
<td>88.2 ± 0.038</td>
</tr>
</tbody>
</table>

S.E. = Standard Error
Table 17

Effect of alternate temperatures of 35°C and 50°C on the hatching of eggs of *S. prasiniferum* Walk.

8% sand moisture was maintained. 10 replicates (10 eggs in each replicate) were kept at 35°C for 0 or 5 or 10 or 15 days, then exposed for 1 day to 50°C and again incubated at 35°C.

<table>
<thead>
<tr>
<th>Eggs kept at 35°C (days)</th>
<th>Eggs then kept at 50°C (days)</th>
<th>Eggs then incubated at 35°C ± S.E. (days)</th>
<th>Hatching (per cent) ± S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>1</td>
<td>19.1 ± 0.014</td>
<td>72.3 ± 0.043</td>
</tr>
<tr>
<td>5.0</td>
<td>1</td>
<td>18.8 ± 0.016</td>
<td>68.1 ± 0.042</td>
</tr>
<tr>
<td>10.0</td>
<td>1</td>
<td>18.0 ± 0.013</td>
<td>60.0 ± 0.046</td>
</tr>
<tr>
<td>15.0</td>
<td>1</td>
<td>No hatching</td>
<td>0.0</td>
</tr>
</tbody>
</table>

S.E. = Standard Error

Table 18

Effect of alternate temperatures of 35°C and 50°C on the hatching of eggs of *S. prasiniferum* Walk.

8% sand moisture was maintained. 10 replicates (10 eggs in each replicate) were kept at 35°C for 0 or 5 or 10 or 15 days, then kept at 50°C for 3 days and again incubated at 35°C.

<table>
<thead>
<tr>
<th>Eggs kept at 35°C (days)</th>
<th>Eggs then kept at 50°C (days)</th>
<th>Eggs then incubated at 35°C (days)</th>
<th>Hatching (per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>3</td>
<td>No hatching</td>
<td>0.0</td>
</tr>
<tr>
<td>5.0</td>
<td>3</td>
<td>No hatching</td>
<td>0.0</td>
</tr>
<tr>
<td>10.0</td>
<td>3</td>
<td>No hatching</td>
<td>0.0</td>
</tr>
<tr>
<td>15.0</td>
<td>3</td>
<td>No hatching</td>
<td>0.0</td>
</tr>
</tbody>
</table>
It is evident from Table 15 that increase in the duration of exposure to low temperature (10°C) of freshly laid eggs prolongs the incubation period by about as long as they are exposed to low temperature because no development occurs during this period and adversely affects the percentage of hatching. Therefore, it can be concluded that the development of freshly laid eggs is adversely affected by exposure to low temperature.

With reference to Table 16, it may further be concluded that the hatching of eggs in the advanced stages of development is not so adversely affected by exposure to low temperature (10°C for 4 days) as it is in the case of early stages.

From Table 17 it is apparent that in those eggs which are exposed to 35°C for 10 days, and then to a high temperature of 50°C for a day and again incubated at 35°C hatching occurs at the rate of about 60 per cent. On the other hand eggs which are exposed to 35°C for 15 days and then to a high temperature of 50°C for a day and again incubated at 35°C do not hatch at all. This goes to suggest that the percentage of hatching is less when the eggs in the advanced stage of development are exposed to a high temperature of 50°C for a day. It is also evident from Table 18 that eggs at 35°C fail to hatch when the exposure time at higher temperature (50°C) is increased to 3 days.
(iii) Development of hoppers under different levels of temperature and humidity:

Freshly hatched hoppers from the stock were placed in hundred small glass jars (Plate III, Fig.2). Hundred hoppers were reared at each level of temperatures 18°C, 27°C, 35°C, 40°C and 45°C and relative humidities 45% and 75% were maintained at each level of temperature. The hoppers were fed on *Cynodon dactylon*. The survival percentage and the duration (in days), indicating the development of the hoppers to the adult stage, was recorded. The results are summarised in Table 19.

None of the freshly hatched hoppers reached the adult stage when reared at 18°C and 45°C with R.H. 45% and 75%, all the hoppers died in the first instar. Only 32.2 per cent hoppers reached the adult stage at 40°C and 75% R.H., whereas the hoppers died in the first instar when reared at 40°C and 45% R.H. The survival percentage at 27°C and 35°C with 45% and 75% R.H. is 50.3% and 64.7%, 47.5% and 63.7% respectively. This indicates that the survival percentage is slightly more at higher R.H. as compared with the results at lower R.H. (Table 19).

It is also evident from Table 19 that the development of the hoppers is less at 45% R.H. than at 75% R.H. so that more time is required at low R.H. to complete the development. This clearly indicates that humidity affects the development of the hoppers.

Freshly hatched hoppers take less time to reach the adult stage at 35°C with 75% R.H. than other combinations of temperature and humidity.
### Table 19

Effect of temperature and humidity on the survival and development of the hoppers of *S. prasiniferum* Walk., reared at 18°C, 27°C, 35°C, 40°C and 45°C with relative humidities 45% and 75%, 12 hours' light altered with 12 hours' darkness and fed on *C. dactylon*.

10 replicates (10 hoppers in each replicate)

<table>
<thead>
<tr>
<th>Temperature °C</th>
<th>Survival (per cent) of hoppers ± S.E.</th>
<th>Duration (days) of hoppers ± S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>45% R.H.</td>
<td>75% R.H.</td>
</tr>
<tr>
<td>18</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>27</td>
<td>50.3 ± 0.038</td>
<td>64.7 ± 0.046</td>
</tr>
<tr>
<td>35</td>
<td>47.5 ± 0.042</td>
<td>63.7 ± 0.052</td>
</tr>
<tr>
<td>40</td>
<td>-</td>
<td>32.2 ± 0.036</td>
</tr>
<tr>
<td>45</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

S.E. = Standard Error
(iv) Development of adults under different levels of
temperature and humidity

Newly emerged adult grasshoppers, obtained from the stock were reared in pairs in small glass jars (Plate III, Fig. 2) at different levels of temperature and humidity. The temperatures used were $18^\circ$, $27^\circ$, $35^\circ$, $40^\circ$, $45^\circ$ and $50^\circ$C with $45\%$ and $75\%$ R.H. at each level. The grasshoppers were fed on *Cynodon dactylon*. The maturation period, oviposition period, egg-pods per female and eggs per female were recorded. Ten replicates were done in each experiment. The results are given in Table 20 and 21.

The maturation (pre-oviposition) period at $27^\circ$, $35^\circ$, $40^\circ$ and $45^\circ$C with $45\%$ R.H. is 13.2, 6.6, 5.3, and 4.3 days respectively, while it is 12.6, 8.4, 5.1 and 3.6 days respectively at the same temperatures with $75\%$ R.H. (Table 20). It is clear from these observations that temperature has a marked effect on the maturation of gonads. The maturation period increases as the temperature decreases. The females oviposit very quickly at $45^\circ$C while the maturation rate of the grasshoppers is very much slower when reared at $27^\circ$C. The humidity has no significant effect on the maturation period. Irrespective of the humidity conditions the females died at $18^\circ$ and $50^\circ$C before they attained maturity.

The oviposition period decreases as the temperature increases. The oviposition period at $27^\circ$, $35^\circ$, $40^\circ$ and $45^\circ$C with $45\%$ R.H. is 24.2, 14.8, 9.2 and 7.2 days respectively while at the same temperatures and higher humidity (R.H. 75%) it is 24.4, 13.7, 8.1 and 6.4 days respectively (Table 21). It is evident from these observations that
### Table 20

Effect of temperature and humidity on the pre-oviposition (maturation) and oviposition, periods (days) of females of *S. prasiniferum* Walk.

Rearing at 18°C, 27°C, 35°C, 40°C, 45°C and 50°C with relative humidities 45% and 75%. 12 hours' light altered with 12 hours' darkness and fed on *C. decylorum*.

10 replicates (one pair in each replicate)

<table>
<thead>
<tr>
<th>Temperature°C</th>
<th>Pre-oviposition (maturation) period</th>
<th>Oviposition period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>45% R.H. days ± S.E.</td>
<td>75% R.H. days ± S.E.</td>
</tr>
<tr>
<td>18</td>
<td>No oviposition</td>
<td>No oviposition</td>
</tr>
<tr>
<td>27</td>
<td>13.2 ± 0.028</td>
<td>12.8 ± 0.043</td>
</tr>
<tr>
<td>35</td>
<td>8.6 ± 0.031</td>
<td>8.4 ± 0.038</td>
</tr>
<tr>
<td>40</td>
<td>5.3 ± 0.026</td>
<td>5.1 ± 0.021</td>
</tr>
<tr>
<td>45</td>
<td>4.3 ± 0.034</td>
<td>3.8 ± 0.034</td>
</tr>
<tr>
<td>50</td>
<td>No oviposition</td>
<td>No oviposition</td>
</tr>
</tbody>
</table>

S.E. = Standard Error
Table 21

Effect of temperature and humidity on the fecundity of female of *S. prasiniferum* Walk. reared at 18°C, 27°C, 35°C, 40°C, 45°C and 50°C with relative humidities 45% and 75%, 12 hours' light altered with 12 hours' darkness and fed on *C. dactylen*. 10 replicates (one pair in each replicate)

<table>
<thead>
<tr>
<th>Temperature °C</th>
<th>Female grasshoppers oviposited (per cent)</th>
<th>Average egg-pods per female (number)</th>
<th>Average eggs per female (number) ± S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>45% R.H.</td>
<td>75% R.H.</td>
<td>45% R.H.</td>
</tr>
<tr>
<td>18</td>
<td>No oviposition</td>
<td>No oviposition</td>
<td>No oviposition</td>
</tr>
<tr>
<td>27</td>
<td>100.0</td>
<td>100.0</td>
<td>6.3</td>
</tr>
<tr>
<td>35</td>
<td>100.0</td>
<td>100.0</td>
<td>6.6</td>
</tr>
<tr>
<td>40</td>
<td>100.0</td>
<td>100.0</td>
<td>5.1</td>
</tr>
<tr>
<td>45</td>
<td>32.8</td>
<td>41.55</td>
<td>2.0</td>
</tr>
<tr>
<td>50</td>
<td>No oviposition</td>
<td>No oviposition</td>
<td>No oviposition</td>
</tr>
</tbody>
</table>

S.E. = Standard Error
the temperature has a pronounced effect on the oviposition period whereas relative humidity has no significant effect on the oviposition period.

It is apparent from Table 21 that 100% of the females lay eggs at 27°, 35° and 45°C with 45% and 75% R.H. while only 32.8% and 41.55% of the females lay eggs at 45°C with 45% and 75% R.H. respectively. Better results are obtained at 35°C which appears as optimum temperature for fecundity. There is a decline in the fecundity of this grasshopper with the decrease or increase of this optimum temperature.

It is also apparent from Table 21 that the fecundity of this insect is practically the same when reared at the same temperature with 45% and 75% R.H. and it may be concluded that fecundity is not affected by R.H.
(C) Development of *Spathasternum prasiniferum* Walker under different densities

(1) Development of hoppers under different densities

Two hundred freshly hatched hoppers were reared in crowded condition in each of the ten large glass jars (Plate IV, Fig. 2). One hundred hoppers were reared in isolated condition in 100 glass tubes (Plate III, Fig. 1). These grasshoppers were reared in the constant temperature room at 35° ± 1°C and 75% ± 5% R.H. The hoppers were fed on *Cynodon dactylon* leaves which were changed after every 24 hours. They were reared till they died or reached the adult stage. Survival percentage and time taken to reach the adult stage by both male and female hoppers were recorded in each experiment. The observations are presented in Table 22.

It is evident from Table 22 that the average total length of hopper life for the isolated males is 36.5 days and for the isolated

<table>
<thead>
<tr>
<th>Table 22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survival (per cent) and duration (days) of the hoppers of <em>S. prasiniferum</em> Walk., reared in single pair and mass at 35° ± 1°C, 75% ± 5% R.H. and fed on <em>C. dactylon</em>.</td>
</tr>
<tr>
<td>100 replicates (one hopper in each experiment when reared in isolation), 10 replicates (200 hoppers in each experiment when reared in mass).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rearing Conditions</th>
<th>Average Survival (per cent) of hoppers</th>
<th>Average duration (days) of hoppers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>Rearing in single pair</td>
<td>63.7</td>
<td>36.5</td>
</tr>
<tr>
<td>Mass rearing</td>
<td>50.2</td>
<td>38.7</td>
</tr>
</tbody>
</table>
females 42.5 days. Male hoppers reared under the crowded condition require 2.2 days more to become the adults than the isolated males, whereas the female hoppers reared in the crowded condition require 2.73 days more to become the adults than the isolated females. The average total length of hoppers life for the crowded males is 38.7 days, and for the crowded females 45.23 days. The mortality is high when this grasshopper is reared in the crowded condition than the grasshopper reared in the isolated condition (Table 22).

(ii) Development of adults under different densities

(a) Morphometrics and weight in relation to density

Experiments were performed to study the effect of crowding on the morphometrics and weight of the grasshopper. Twenty male and twenty female grasshoppers were taken from the above set of experiments(i). Ten males and ten females were taken from the isolated condition and ten males and ten females from the crowded condition. The weight of one day old adults was recorded, later they were killed in cyanide bottles and the measurement of the following parts were recorded: length of fore-wings, hind femur, pronotum, and width of head and pronotum. The results are presented in Table 23.

It is apparent from Table 23 that there is a little difference in the weight of one day old adults when reared in isolated and crowded conditions. The average weight of one day old male and female adults, when reared in isolated condition, is 65.0 and 83.21 mg. respectively. Whereas their average weight in crowded condition is 66.23 and 79.62 mg.
Table 23
Weight and morphometrics of one day old adults of *S. prasiniferum* Walk.
Freshly hatched hoppers reared in isolated and crowded conditions at $35^\circ \pm 1^\circ$C, 75% $\pm$ 5% R.H. and fed on *C. daetyn*log. They were reared till they reached the adult stage, then weighed and killed in cyanide bottle for measurements.

20 males and 20 females (ten males and ten females from isolated and crowded conditions were taken)

| Rearing conditions | Sex   | Weight (mg) | Length of forewings (cm) | Length of hind femur (cm) | Width of head (cm) | Pronotum
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Length (cm)</td>
</tr>
<tr>
<td>Isolated</td>
<td>Male</td>
<td>65.0</td>
<td>1.12</td>
<td>0.90</td>
<td>0.20</td>
<td>0.32</td>
</tr>
<tr>
<td>Isolated</td>
<td>Female</td>
<td>83.21</td>
<td>1.64</td>
<td>0.95</td>
<td>0.28</td>
<td>0.40</td>
</tr>
<tr>
<td>Crowded</td>
<td>Male</td>
<td>66.23</td>
<td>1.12</td>
<td>0.90</td>
<td>0.20</td>
<td>0.31</td>
</tr>
<tr>
<td>Crowded</td>
<td>Female</td>
<td>79.62</td>
<td>1.62</td>
<td>0.94</td>
<td>0.28</td>
<td>0.38</td>
</tr>
</tbody>
</table>
respectively.

There is no marked difference in the morphometrics of the grasshopper when reared under crowded and isolated conditions (Table 23).

(b) Reproduction in relation to density

The freshly emerged adults obtained from the experiments of section (i), were reared as single pairs and as under crowded conditions in the constant temperature room at $35^\circ \pm 1^\circ$C and $75\% \pm 5\%$ R.H. in large glass jars (Plate IV, Fig.2). Nine pairs of grasshoppers were placed in each glass jar when reared under crowded condition. The adults obtained from each group were reared under the same conditions in which they had been reared during the hoppers' life. The adults were daily fed on bundles of freshly cut weed, *Cynodon dactylon*, and any left-over food of the previous day swept off the jar. The maturation period, oviposition period, egg-pods per female, eggs per pod and eggs per female (fecundity) were recorded in the crowded and isolated conditions. The results are given in Table 24.

Table 24

<table>
<thead>
<tr>
<th>Rearing Conditions</th>
<th>Pre-oviposition period (days)</th>
<th>Oviposition period (days) per female per pod</th>
<th>Egg-pods</th>
<th>Eggs per pod</th>
<th>Eggs per female</th>
<th>Fecundity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reared in Single pair</td>
<td>8.4</td>
<td>13.7</td>
<td>6.7</td>
<td>8.3</td>
<td></td>
<td>55.61</td>
</tr>
<tr>
<td>Reared in mass</td>
<td>11.2</td>
<td>13.2</td>
<td>4.8</td>
<td>7.6</td>
<td></td>
<td>37.44</td>
</tr>
</tbody>
</table>

Reproduction in *S. prasiniferum* Walk., reared in crowded and isolated conditions at $35^\circ$C, 75% R.H. and fed on *C. dactylon*.

6 replicates (one pair in each experiment when reared in single pair and 9 pairs in each experiment when reared in crowded condition).
Table 24 shows that the females after emergence when kept as a single pair, started oviposition at an average of 8.4 days, while those reared collectively deposited the first egg-pod at an average of 11.2 days. It indicates that the maturation period is prolonged when the adults are reared under the crowded conditions. The oviposition period is more or less the same in both the conditions. The oviposition periods in isolated and crowded conditions are 13.7 and 13.2 days respectively. At an average of 6.7 and 4.8 egg-pods per female are laid by those reared in isolated and crowded conditions respectively (Table 24).

It is also evident from Table 24 that the average number of eggs per pod from isolated adults is 8.3 and from the crowded adults 7.8. The average fecundity is $8.3 \times 6.7 = 55.61$ eggs for the isolated females, $7.8 \times 4.8 = 37.44$ eggs for the crowded ones (Table 24). This suggests that crowding not only delays the oviposition but also decreases the fecundity.

(iii) Cannibalism

The present author made an attempt to study the phenomenon of cannibalism in *S. prasiniferum* Walk. under laboratory conditions.

Each one hundred and fifty hoppers of each instar and a similar number of adults were kept separately in small glass jars (Plate III, Fig. 2) and the same number of hoppers of each instar and adults in large glass jars (Plate IV, Fig. 2). One batch of grasshoppers of the same age
group was reared under starved condition while other was fed on Cynodon dactylon leaves and the food was changed daily. The results are presented in Table 25 and Plate XV.

The examination of Table 25 shows that the rate of cannibalism varies in different instars and is influenced by the availability of food and space conditions. It is at its highest level in the first instar hoppers when reared under crowded condition and starved for 72 hours. But in the fed condition the rate of cannibalism is reduced. Cannibalism, is therefore, high in limited space and unfed condition and low in large space and fed condition. Cannibalism is greatly reduced amongst the late instar hoppers and adults.

It can, therefore, be suggested that scarcity of food and crowded condition promote cannibalism.

Table 25

Effect of space and starvation on the rate of cannibalism in S. prasiniferum Walk., reared at 35° ± 1°C, 75% ± 5% R.H. and 12 hours' light altered with 12 hours' darkness. 150 insects were taken in each case.

<table>
<thead>
<tr>
<th>Hopper instars and adult</th>
<th>Feeding condition</th>
<th>Percentage of insects cannibalised</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Small glass jar</td>
<td>Big glass jar</td>
</tr>
<tr>
<td></td>
<td>48 hours</td>
<td>72 hours</td>
</tr>
<tr>
<td>I</td>
<td>20.2</td>
<td>0.0</td>
</tr>
<tr>
<td>II</td>
<td>12.4</td>
<td>0.0</td>
</tr>
<tr>
<td>III</td>
<td>7.6</td>
<td>0.0</td>
</tr>
<tr>
<td>IV</td>
<td>2.1</td>
<td>0.0</td>
</tr>
<tr>
<td>V</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>VI</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Adult</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>
S. prasiniferum Walk. effected by cannibalism.
Southestern proasiniferum Walker is found to feed on:

- *Oryza sativa*, *Zea mays*, *Sorghum vulgare*, *Pennisetum typhoides*, *Saccharum officinarum*, *Triticum aestivum*, *Hordeum vulgare*, *Solanum melongena*, *Solanum nigrum*, *Abelmoschus esculentus*, *Echinochloa colonum*, *Nemarthria compressa*, *Seteria verticillata*, *Cynodon dactylon*, *Cyperus rotundus* and *Sorghum halopense*. Extensive damage by this insect has been reported from Maharashstra, Bengal, Bihar, Uttar Pradesh and Punjab, where its distribution is correlated with the above mentioned plants which grow in abundance. Similar correlation between food-plants and distribution of grasshoppers has been observed by Vestal (1913), Hubbell (1922a, 1922b), Strohecker (1937), Urquhart (1941) and Cantrell (1943) in North America and Anderson and Wright (1952) in Montana.

The breeding places of this grasshopper are the turf areas in close proximity of the field crops where apart from *C. dactylon* equally succulent and palatable weeds like *E. colonum*, *H. compressa*, *S. verticillata*, *C. rotundus* and *S. halopense* also grow. The hoppers of the first, second, third and fourth instars prefer the above food-plants, while the fifth- and sixth instar hoppers and the adults prefer more succulent plants like *Z. mays*, *S. vulgare*, *P. typhoides*, *O. sativa*, *T. aestivum* and *H. vulgare*. This is the reason why later stages are generally found in fields having the above mentioned plants. So it may be concluded that this...
grasshopper selects only those plants which are favourable for its development, and food-preference changes with its age. Similar observations have been made by Rubtsov (1932a, 1932b) in Siberian Acridoidea, Pfeft (1949b) in A. elliottii, Scharff (1954) in E. mexicanus mexicanus and Misra (1962) in C. pellucida. It has also been found that S. preniniforme Wall. avoids to feed on S. officinarum, S. montanum, S. nigrum and A. esculentus in the presence of the above mentioned plants probably due to the hardness of the food material, less nutritive value and perhaps its distastefulness. Therefore, it may be suggested that preference value of a food depends largely upon (i) its succulence, (ii) its nutritive value and (iii) its palatability. If all these qualities are present in a certain food it is classed as a first preference as compared with any other which is short of either of the above. If other physical factors are favourable either singly or jointly they constitute an additional advantage. In case any of the physical factors tend to become hostile, the grasshoppers abstain from taking food, however, attractive it may be, this goest to suggest that physical factors in themselves play a key role in the food-preference of the grasshopper.

Interesting observations have been made by Misra (1962) in C. pellucida. This grasshopper has been found feeding on reed canary-grass as its food because of its succulence. Other grass like redtop, eastern couch-grass, oats, sloughgrass, brome, fescue, Kentucky blue grass, as well as many forbs, have preference values much lower than reed
canary-grass. The same author, therefore, suggests that the physical factors are unimportant if the composition of the plant is nutritionally unfavourable to the grasshopper. This contention is not entirely immune to criticism, for he has taken only one physical factor of succulence into consideration on the basis of which a generalization can scarcely be made.

In contradiction to Misra's observations Vestal (1913), Hubbell (1922a, 1922b), Strohecker (1937), Urquhart (1941) and Centrall (1943) also observed that the distribution of the grasshoppers in North America is correlated with the different type of vegetation and further that the controlling factors are entirely physical. Tauber et al. (1945) also laid stress that M. bivittatus is unable to live for long when fed on dry alfalfa, whereas, if excess of water is provided the grasshopper can live.

Observations on hopper duration and reproductive potential have shown that the hoppers take less time to reach the adult stage, gonads mature earlier and fecundity is higher when the grasshoppers are kept at constant temperature ($35^\circ \pm 1^\circ C$), constant humidity ($75\% \pm 5\%$ R.H.) and fed on mixed diet in comparison with the grasshoppers kept at the same temperature and same humidity but fed on the single component of the same mixed diet.

Food-plant tests show that the weeds are favourable for the development of hoppers upto the fourth instar. But the later stages develop better on field crops. The gonads mature earlier and the
Secundity is higher when the grasshoppers are fed on the field crops in comparison with the grasshoppers fed on the weeds. As the early stages of this grasshopper develop better when fed on weeds than on the field crops, therefore, removal of weeds from the breeding sites may check its population considerably. Similar observations have been made on Melanoplus by Brett (1947), Pfadt (1949a), Smith et al. (1952) and Barnes (1955, 1963, 1965).

Eggs of S. prasiniferum Walk. are laid in moist sand. The eggs do not hatch unless sufficient moisture is present in the sand. A good percentage of hatching occurs if moisture in the sand is 8% as compared with 4 or 12% sand moisture. Grewal and Atwal (1966) observed the same in C. trachvetera. The most favourable temperature for survival of eggs is 30°C with 8% sand moisture and for incubation period 40°C with 8% sand moisture. It indicates that the best results on the survival and development are not obtained at the same temperature. The optimum condition for over all development of the eggs is found to be 35°C temperature with 8% sand moisture. Similar observation have been made on Schistocerca gregaria (Hunter-Jones, 1964) and Chortoicetes terminifera (Grewal and Atwal, 1966).

Exposure of freshly laid eggs to low temperature (10°C) for a longer period of time adversely affects its development while such an exposure has no appreciable effect on advanced stages of development. High temperature (50°C), however, adversely affects the development in such advanced stages. Exposure of eggs to low temperature (10°C)
for some time interrupted the development for the same period but later
on it is considered to act as a stimulus for development as it is also
evident from the observations on the development of certain Orthoptera
(Bodine, 1925a).

The temperature and humidity accelerate the rate of development
of hoppers. Parker (1930) observed the same in *M. mexicanus* and *C. pellucida*
The hoppers of *S. presiniiform* Walk. develop faster when reared at 75% R.H.
with 35°C than at 45% R.H. with 35°C. It is clear from these observations
that the rate of development is slowed down at low humidity than at
higher. This is in conformity with the findings of Hamilton (1936, 1950)
on *L. m. migratoroides*, *Nonscadris septemfasciata* and *S. gregaria* which
contradict the findings of Husain et al. (1946) and Chauvin (1941b) on
*S. gregaria*.

Freshly hatched hoppers take less time to reach the adult stage
when reared at 35°C and 75% R.H. than other combinations of temperature and
humidity. This may be due to more food consumption at this combination
of temperature and humidity. This is in accordance with the findings of
Husain et al. (1946) who found that the daily food consumption increased
with the temperature up to 35°C, but beyond that there was no increase.
While Parker (1929, 1930) found that the amount of food consumed by
grasshopper larvae remained practically the same at constant temperature of
22°C to 37°C. According to him the increase in the daily amount of food
consumed at higher temperature is counterbalanced by the shorter period of
the larval development.
In *S. prasiniferum* Walk, the maturation period, oviposition period, and fecundity decreases as the temperature increases. Irrespective of the humidity conditions, the best results on the fecundity of this grasshopper are obtained at 35°C. The humidity has no marked effect on the maturation of gonads and fecundity. Somewhat similar results have also been obtained by Parker (1930) in *H. m. mexicanus* and *C. pellucida*, and Grewal and Atwal (1968) in *C. trachypterus*.

The survival of hoppers of *S. prasiniferum* Walk, is 13.5% per cent higher when reared under isolated condition than in crowded condition. Male hoppers reared under crowded condition require 2.2 days more to become adults than the isolated males, whereas the female hoppers reared under crowded condition require 2.73 days more to become adults than the isolated females. The maturation period is 11.2 days when this grasshopper is reared under crowded condition and 8.4 days when reared under isolated condition. This indicates that the rate of maturation of the grasshopper reared under crowded condition is slower than in those reared in isolated condition. The fecundity of isolated females is 55.61 eggs and that of crowded females is 37.44 eggs. Similar effects of crowding and isolation have been observed by Norris (1950) in *L. m. migratorioides* and Hunter-Jones (1969) in locusts. In contradiction to the above observations Paoli (1932) and Jannone (1938) in *D. mericanus* and Norris (1952) in *S. oregonia* found that isolation slowed the rate of development. Antoniou and Hunter-Jones (1956) in *E. capitata*, Hunter-Jones and Ward (1969) in *G. africana*, Antoniou and Hunter-Jones (1968) in *E. p. serratipes* observed that density during
the adult neither affects the rate of sexual maturation nor the number of eggs per pod.

Density has no marked effect on the morphometrics and weight of *S. prasiniferum* Walk. Similar observations in other grasshoppers have been recorded by Antoniou and Hunter-Jones (1956, 1968) and Hunter-Jones and Ward (1959). But this observation is in marked contrast to those obtained from the locusts (Norriss, 1950, 1952, and Hunter-Jones, 1958).

Cannibalism is quite common in *S. prasiniferum* Walk. Scarcity of food and crowded conditions promote this habit. This observation is in agreement with that of Duarte (1938) in *L. m. migratorioides*, Smeč (1936) in *N. gVentemfaciata*, Hussain et al. (1946) in *S. oregaria*, Uvarov (1931) considers shortage of water as a factor influencing cannibalism. Rizvi (1967) observed in *H. nigrolineatus* that high temperature coupled with overcrowding leads to cannibalism.
(4) CONCLUSIONS

The effect of ecological factors on the development of *Spathostema prasiniforme* Walker has been studied in the constant temperature room. The ecological factors - food-plant, temperature, humidity and density - were taken into consideration. The results are summarized as given below:

(1) This grasshopper selects only those plants which are favourable for its development, and food-preference changes with its age.

(2) This grasshopper prefers to lay its eggs in weedy fields as such places are quite favourable for the hoppers as they hatched out.

(3) The grasshopper is a selective feeder and not a general feeder.

(4) The food-plant has a well marked effect on the development of hoppers of this grasshopper. The best results are obtained when it is fed on mixed diet of *Oryza sativa* and *Echinochloa colona* in contrast with the results obtained when fed on exclusive diet of *Sorghum vulgare*.

(5) The best results on the development of the adults are obtained when fed on mixed diet of *Oryza sativa* and *Echinochloa colona* in contrast with the results obtained when fed on exclusive diet of *Cynarae rotundus*.

(6) The removal of weeds from the breeding beds may check the population of this grasshopper.
The incubation period and percentage of hatching of eggs are greatly influenced by alternate temperatures. Eggs kept at $10^\circ$ and $45^\circ$C fail to hatch regardless of humidity conditions. The best results of incubation period and viability are obtained at $40^\circ$ and $30^\circ$C respectively. The optimum temperature for survival and development is $35^\circ$C.

The incubation period increases as the temperature decreases and vice versa.

The viability of eggs decreases as the temperature increases or decreases from $30^\circ$C.

The incubation period is not much influenced by the different levels of moisture in the test while it is rather more pronounced on the viability of the eggs.

The moisture absorbed by the eggs in the initial stages is sufficient for the completion of the development.

Eggs in the advanced stages of development are not so adversely affected by lower temperature as those in the early stages of development.

Eggs in the advanced stages of development are adversely affected by higher temperature while it is not the case during early stages of development.

Eggs fail to hatch when exposed for 3 days to higher alternate temperature ($50^\circ$C).

The development of the hoppers is fast and rate of survival is higher at $35^\circ$C and 75% R.H. The development of hoppers is less when they are reared below or above this combination of temperature and humidity. They fail to develop at $10^\circ$ and $45^\circ$C.
(16) The females readily oviposit in the moist sand.

(17) Temperature has pronounced effect on the development of the adults of this grasshopper. A temperature of 35°C is suitable for egg-laying. Irrespective of humidity conditions the females do not oviposit at 10°C and 50°C.

(18) The fecundity of this insect is practically the same when reared at the same temperature with 45% and 75% R.H.

(19) The hoppers reared in crowded condition take 2.2 to 2.73 days more to become the adult than the hoppers reared in isolated condition.

(20) The rate of mortality is high when the insects are reared in crowded condition as compared with the individuals reared in isolation.

(21) No significant difference is observed in the weight and morphometrics of one day old grasshopper when reared either in a crowd or as a single pair.

(22) The maturation period is prolonged in the grasshopper reared in crowded condition than the grasshopper in isolated condition.

(23) Crowding in comparison to isolation not only delays the maturation period but also decreases the fecundity.

(24) The scarcity of food and the crowded condition promote cannibalism. This is greatly reduced amongst the late instar hoppers and adults.
PART III

V DEVELOPMENT OF VARIOUS STAGES IN RELATION TO DIFFERENT ECOLOGICAL FACTORS DURING THE DIFFERENT MONTHS OF THE YEAR

(1) REVIEW OF LITERATURE

No work has been done on the development of various stages of *S. prasinaferum* Walk. in relation to different ecological factors during the different months of the year, although it has been studied very extensively in other acridoids / *Oxys velox* (Rao, 1921), *Colemania sphenarioides* (Uvarov, 1928), *Poccilacerus pictus* (Pruthi and Nigam, 1939), *Kraussella amabili*, *Caloptenopsis clauneptia*, *Amphiprosanthis gregarii*, *Hieroglyphus dageensis*, *Macronymocha speciosa*, *Spathostereum nigroteniatum* (Joyce, 1952), *Nymeleotettix maculatus*, *Chorthippus brunneus*, *C. parallelus*, *C. vagans*, *Oncocatus ventralis*, *Gomphocerippus rutilus*, *Stenobothrus lineatus*, *C. albo-marginatus*, *O. viridulus*, *Macostethus grossus* (Richards and Waloff, 1954), *Chortoecus trachyrurus* (Kezan, 1954; Grewal and Atwal, 1960), *Anarchus punctatissimus* (Katiyar, 1955), *Atractomorus crenulatus* (Agrawal, 1955), and *Parahieroglyphus bilineatus* (Katiyar, 1956). It is concluded from the literature available that the acridians are very abundant from the middle of August to November, since temperature, humidity and food are favourable for development, in comparison with other months of the year.
(2) **DEVELOPMENT OF VARIOUS STAGES OF SPATHOSTERNUM PRASINIFERUM WALKER IN RELATION TO DIFFERENT ECOLOGICAL FACTORS DURING THE DIFFERENT MONTHS OF THE YEAR.**

The present author studied the development of *S. prasiniferum* Walk. in the different months of the year by making collection for half an hour every week from August 1969 to July 1971 from localities within 396 meters in and around the Acridians Experimental Field Station, Scindia Fort, Aligarh.

(A) **General observations**

In India this grasshopper breeds throughout the year, but they are more numerous from the middle of August to November. It has been observed that after monsoon showers these grasshoppers emerged in small swarms but usually remained confined to their breeding areas. From June their number considerably increased and they were found feeding on *Zea mays*, *Sorghum vulgare*, *Pennisetum typhoides*, *Saccharum officinarum*, *Oryza sativa*, *Echinochloa colonaum*, *Hemarthria compressa*, *Sesaria verticillata*, *Cynodon dactylon*, *Cyperus rotundus*, *Sorghum halepense*, *Solanum melongena*, *Abelmoschus esculentus* and *Solanum nigrum*. They continued to feed on these plants till September. During October and November this grasshopper also attacked *Triticum aestivum* and continued to feed on *Saccharum officinarum*, *Cynodon dactylon* and *Sesaria verticillata*. From December to March they were usually found feeding on the plants on which they had been feeding during October and November, but they were fewer in number and their activity was very slow. During the month of May they were seen seeking...
shade and shelter from the sun.

(B) Adult

The adults of this grasshopper were usually found throughout the year (Plate XVI and XVII) but were more numerous from September to November. From the adult population, the observations were collected about the sexual maturity, copulation and oviposition.

1) Sexual maturity

In order to identify stages of sexual maturity of the adults in a wild population prior knowledge of their weight under laboratory condition is extremely useful. This has already been discussed under the sub-heading 'weight and maturity'. On an average the weight of caged mature females is found to be 169.91 mgs. Female grasshoppers were collected from field, weighed, marked and released in selected plots for some days. These were recaptured and weighed. The weight was recorded from July 20, 1969 to November 23, 1969. The results are included in Table 26.

It is evident from Table 26 that the average weight of the field sample reached a steady level of 169.92 mgs. on 17.8.1969. Afterwards the weight of all the females fluctuated about this average mature weight. This relative steady weight in the later part of the season may be taken as the average mature weight for the year under consideration. All the released females recaptured 8-20 days after marking were found to be sexually mature.
<table>
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<th>Week ending</th>
<th>Number of females marked and released</th>
<th>Average weight (mg) of female at the time of release</th>
<th>Average number of female recaptured each week</th>
<th>Average weight (mg.) of recaptured female in each week</th>
<th>Average number of days the female recaptured</th>
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<td>152.00</td>
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<td>4</td>
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<td>169.93</td>
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</table>
(ii) **Copulation**

Copulating pairs were observed from third week of June to first week of November. Copulating pairs were observed mostly on the ground, seldom on the plants. Copulation began usually in the morning, seldom at any other time of the day. The copulation was very frequent from the second week of September to the first week of October.

(iii) **Oviposition**

Oviposition was observed from the last week of June up to the third week of November and also from third week of February to April. There was no oviposition between the last week of November and the second week of February. The maximum oviposition was observed from the middle of September to the middle of October.

*S. prasiniforum* Walk. deposited its eggs in the superficial layers of the soil in damp places or at the leaves which were found flooded with water. This grasshopper seems to prefer sandy soil around the crop area or in the bare patches among cultivations for oviposition. These bare patches appear in the cropped field after weeding.

(iv) **Egg-pod and eggs**

The egg-pods and eggs of *S. prasiniforum* Walk. were found throughout the year, they were, however, numerous in November, i.e., at the end of oviposition period of the season and in April. Their occurrence in large numbers in April may be due to inactivity of the adults during December and January when they lie dormant and start oviposition from
February to April. The number of egg-pods was at its lowest ebb from second week of June to last week of August as the adults were fewer in number during this period and hatching was at the highest level.

(v) Hatching and hoppers

In June 1970, the hoppers hatched out in considerable numbers (Plate XVI) from the eggs laid in the previous rainy season and during the months of February, March and April, 1970. The hatching stopped in July 1970 due to heavy rain-fall. From the second week of August to the first week of September the hoppers again hatched in large numbers from the remaining eggs of previous season and from the eggs of new generation (Plate XVII). The number of hoppers began to decline from the second week of September and continued up to the last week of November. This may be due to the emergence of adults from hoppers which hatched during August and September. In the first week of October the number of hoppers again increased which was probably due to hatching of eggs laid during August and September. Fewer hoppers were found from December 1970 to second week of March 1971. Later the hopper population increased from the third week of March to the second week of April. This was due to late winter shower in the second week of March. The hoppers were very few in number and were founds seeking shade and shelter from the sun during the second week of April to the third week of May.

The hoppers in 1971 hatched out in the last week of May up to the last week of June and in the following month it stopped (Plate XVII). There were three generations of this grasshopper in a year.

*S. prasiniform* Walk. seems to prefer the sandy loam around the cropped area or in bare patches among cultivations for oviposition. Katiyar (1955, 1956) observed the same in *Aularchus punctatus* and *Parahieroglyphus bilineatus*. Uvarov (1928) observed *Colemania sphenarioides* depositing eggs preferably in the black soil.
The females of *S. prasiniferum* Walk. lay eggs in the moist soil. Some other acridoids also preferred moist soil for oviposition, viz., *A. cynanai*, *H. decanensis* and *S. nigroaenatum* (Joyce, 1952), *A. cremulata* (Agrawal, 1955), *A. punctate* (Katiyar, 1956). On the other hand, some members of the family Acrididae including *K. amabili* and *G. gaulaoppsis* (Joyce, 1952) deposit their eggs in the cracks of dry soil while *M. speciosa* (Joyce, 1952) and *C. trachypterus* (Kevan, 1954) laid their eggs in wet soil.

It is evident from the laboratory findings that eggs of *S. prasiniferum* Walk. laid in the sand would not hatch unless there is sufficient moisture in the sand at a depth of 1.6 to 2.7 cm. The percentage of hatching increases if the moisture in the sand is 8 per cent. The eggs develop at a sufficiently fast rate and the viability is found to be highest at 35°C. At higher temperature the speed of development is faster but the viability is reduced. The hoppers develop faster and better at 35°C and 75% R.H. The gonads mature earlier at this combination of temperature and humidity. The fecundity of this grasshopper is also higher at this combination of temperature and humidity. Such favourable conditions in the field are most likely to be met during the monsoon months when not only the hoppers hatch out but seeds also begin to germinate. The resulting vegetation in the environment is a favourable food factor for the abundance of grasshopper population.
Such conditions are not likely to be obtained in nature during the months of December, January, February, April and May. Various stages of grasshopper develop very slowly during the months of December, January and February due to the low temperature and scarcity of food in nature. During hot and dry months of April and May the eggs if laid are bound to die out due to desiccation as the soil moisture at a depth of 1.8 to 2.7 cm. is less than 2 per cent. Most of the hoppers and adults also die because the food-plants dry up. The highest population is observed during August and September and that is the time when the climate and food conditions are most favourable.

The evidences given in the present work thus explain the determining factors which fluctuate the population of this grasshopper. Further, observations of the ecological conditions during the course of a year can be utilised to predict to a certain degree the population density of this grasshopper.
(4) **CONCLUSIONS**

The results on the studies of various stages of *S. prosiniferum* Walk. in relation to different ecological factors during the different months of the year are summarized as below:

(1) In India this grasshopper breeds throughout the year, but more numerous from the middle of August to November.

(2) The adult population increases from the third week of June and become sexually mature two or three weeks later, i.e., about the second or third week of July.

(3) During the months of June, July, August, September, October and November, the insects continue feeding, mating and egg-laying, but become gradually sluggish and by the end of November most of them are dead.

(4) The eggs are laid in different situations according to the conditions. In dry weather they are laid in soil, but if the field is flooded, they may be laid between the leaves an inch or two above the level of the water.

(5) The eggs hatch in large numbers in June after the early monsoon rains.

(6) As regards behaviour, the young hoppers cluster on weeds, but older ones are more active and move towards the field-crops.

(7) In the field, three annual generations of this species have been recorded. This indicates the absence of diapause.
VI SUMMARY

*Spinosaurus prasiniferum* Walker is a pest of various field crops, garden plants and weeds in the agricultural areas of Maharashtra, Bengal, Bihar, Uttar Pradesh and Punjab. Among the field crops *Oryza sativa*, *Pennisetum typhoides*, *Saccharum officinarum*, *Triticum aestivum* and *Hordeum vulgare* are most susceptible. Among the weeds *Echinochloa coloma*, *Setaria verticillata*, *Cynodon dactylon*, *Cyperus rotundus* and *Sorghum halepense* are commonly infested. This grasshopper has also been found feeding on garden plants like *Solanum melongena*, *Solanum nigrum* and *Abelmoschus esculentus*

The development of various stages of this grasshopper has been studied in the constant temperature room at $33^\circ \pm 1^\circ \text{C}$, $70\% \pm 5\%$ R.H. where 12 hours' light altered with 12 hours' darkness. The insects were fed on the bundles of cut weed, *Cynodon dactylon*. The results are summarised as given below:

The general body colour of the female is green while that of the male is brown. The postocular band is well marked. The central area of the tegmina has a longitudinal black streak, which is generally not prominent in the male but is well marked in the female. This streak is quite variable, sometimes it is entire, but more frequently with white transverse markings. Occasionally it is seen broken up into fine dark spots.
Both the male and female adults of this grasshopper were dissected to study the changes during the maturation of gonads. The number of ovarioles in the adult females was found to vary from 3 to 5. The number of small ovarioles was found to increase with age. After the first oviposition roughly as many egg rudiments are produced in the ovariole as the number of eggs that would be laid in the succeeding oviposition. The weight of the male and the female increases with the sexual maturation. The fluctuation of weight after first oviposition in the female and after the first copulation in the male is probably due to the elaboration of the reproductive organs.

The male copulates with the female on an average $3.5 \pm 0.223$ days after emergence. During copulation the male mounts over the back of the female and protrudes the aedeagus which is inserted into the opening of the spermathecal duct. After the copulation is over, the female moves her hind legs up and down therefore the male may dismount and then she moves away. The process of copulation takes 8 to 49 hours. The female starts oviposition on an average of $8.7 \pm 0.366$ days. At the time of oviposition the female bores holes in the moist sand with the valves of ovipositor closed. When the hole is completed the frothy secretion is ejected which is partly absorbed by the sand which hardens to form the wall of the egg-pod. A part of it is also deposited at the bottom of the egg-chamber about 1 cm. in thickness on which the eggs are laid one by one in four rows to form a compact mass. In case the micropylar pole of the egg points toward the base of the pod, the female gradually retracts its abdomen as the chamber gets filled up with the eggs. The whole process
takes from 2 to 4 hours. The average oviposition and post-oviposition periods are 16.9 ± 1.441 and 2.7 ± 0.270 days respectively.

The egg-pods are more or less cylindrical in shape. They vary from 1.2 to 2.2 cm. in length and 0.25 to 0.3 cm. in diameter. There are 6.4 ± 0.393 egg-pods per female.

The subcylindrical elongated and curved egg measures 0.4 x 0.346 cm. in size. When freshly laid the egg is light yellowish brown which changes to dark yellowish brown colour after about 10 days. Before hatching the egg measures 0.456 x 1.406 cm. The vermiform larva hatches out on an average of 20.6 ± 0.065 days. Soon after reaching the surface of the soil, the larva attains the form of first instar hopper by passing through the intermediate moult.

The hoppers moult six times before they reach the adult stage. The males become adult 6.67 days earlier than the females. The average hopper duration is 37.59 ± 0.28 days for males and 44.25 ± 0.883 days for females.

The body colour of first instar hopper is yellow with slightly reddish brown head. Wing-pads are indistinct, the spicules of the mandibular teeth are acute. In the second instar hoppers the spicules of the mandibular teeth are rounded. The wing-pads are distinct in the second and third instar hoppers. But the spicules of the mandibular teeth are acute in the third instar hoppers. While in the fourth instar hoppers the wing-pads are well developed and the spicules of the mandibular teeth are rounded. The wing-pads turn upward in the fifth instar hoppers.
but extend posteriorly only upto the posterior margin of the first abdominal segment. While in the sixth instar hoppers the wing-pads extend posteriorly just beyond the second abdominal segment.

The effect of some ecological factors on the development specially on the maturation of gonads has been studied in the constant temperature room. The ecological factors - food-plant, temperature, humidity and density were taken into consideration and the results are summarised as below:

Four different plant species with one standard were placed in the cage at $35^\circ \pm 1^\circ C$, $75\% \pm 5\%$ R.H. One hundred grasshoppers starved for 24 hours were introduced into the cage to study food preference. It was found that the first, second, third and fourth instar hoppers prefer weeds, like E. coloquium, H. compressa, S. verticillata, C. decylion, C. rotundus and S. halenense. While the fifth, sixth instar hoppers and adults prefer the field crops - Z. mays, S. vulgaris, E. typhoides, Q. sativa, T. aestivum and H. vulgare. If plants of first preference are not provided to the grasshopper, it may subsist on such plants as S. melongena, A. esculentus, S. nigrum and S. officinarum though not much to its liking.

Newly hatched hoppers were reared on different diets and the adults obtained from them were also fed on the same diets. The development is accelerated when the grasshoppers were fed on the mixed diet of Q. sativa and E. coloquium. While the development of hoppers and adults is poor when fed on S. vulgaris and C. rotundus respectively.
Freshly laid eggs of this grasshopper were placed at different temperatures (10\(^{\circ}\), 25\(^{\circ}\), 30\(^{\circ}\), 35\(^{\circ}\), 40\(^{\circ}\), and 45\(^{\circ}\)), 45% and 75% sand moisture. Best results of viability and incubation period are obtained at 30\(^{\circ}\) and 40\(^{\circ}\)C respectively. The incubation period at different levels of sand moisture in the tests is more or less the same. But the best results of viability are obtained at 8% sand moisture. Irrespective of the moisture conditions the eggs failed to hatch at 10\(^{\circ}\) and 45\(^{\circ}\)C. The development of the eggs kept in contact with 8% sand moisture for 4 days and then transferred to 100% atmospheric humidity is almost the same as when the freshly laid eggs are either kept at 8% sand moisture for 6, 12 and 16 days and then transferred to 100% atmospheric humidity or 8% sand moisture throughout.

Fresh eggs when kept for 4 and 72 days at 10\(^{\circ}\)C in a refrigerator are found to be adversely affected by the exposure, but those of advanced stages are not so severely affected.

Freshly laid eggs and those which have already been incubated for 5 and 10 days at 35\(^{\circ}\)C are exposed to 50\(^{\circ}\)C for one day, hatch out in larger numbers than those which are kept for 15 days at 35\(^{\circ}\)C and then exposed to 50\(^{\circ}\)C for one day. None of the eggs hatched in the latter condition. All the eggs failed to hatch when exposed to 50\(^{\circ}\)C for 3 days.

The best results on the development of hoppers are obtained at 35\(^{\circ}\)C and 75% R.H. when they are tested at different levels of temperature and humidity. The hoppers failed to develop at 18\(^{\circ}\) and 45\(^{\circ}\)C.
The adults of this grasshopper were reared in pairs in small glass jars at different levels of temperature and humidity. Best results of the development were obtained at 35°C. No significant difference has been observed in the development of the adults reared at different levels of humidity.

Freshly hatched hoppers were reared in isolated and crowded conditions at 35°C ± 1°C and 75% ± 5% R.H. The rearing density affects the development of this grasshopper. The development is somewhat better when the hoppers are reared in isolated condition than those which are reared in crowded condition. But the density has no significant effect on the morphometrics and the weights of the one day old adults.

The hoppers of each instar and adults were kept in small and large jars in fed and starved condition to study cannibalism. The rate of cannibalism increases due to the scarcity of food and crowded condition.

Observations on the development of various stages in relation to different ecological factors during different months of the year of this grasshopper were recorded by making collections for half an hour every week from August 1969 to July 1971 from localities within 396 meters around the Acridians Experimental Field Station, Scindia Fort, Aligarh. The results are summarized as below:

The weight records of the field samples of the females show that they reach a steady level of 169.92 mg. on 17.8.1969. The average weight of the females fluctuated about this average. The females
recaptured 8 to 20 days after their release were found to be sexually mature at all times.

In India this grasshopper breeds throughout the year, but is abundant from the middle of August to November. They survive on a variety of host plants in different months of the year and during inclement weather they bury themselves under the fallen leaves and other debris.
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