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BY

S. Mahdihassan.

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INTRODUCTION.

Until 1918 the writer was unaware of the important bearing on the yield of lac of the sex-ratio of the lac insect, although such yields have been known to vary in different seasons and localities. No mention of the subject is to be found in the literature and the impression was naturally left that the ratio remains constant. At Lingal, in Hyderabad, Deccan, an instance was recorded for the first time from personal observation where the entire generation of a lac insect, *Lakshadia communis*, growing on *Butea frondosa*, consisted of winged males and thereby resulted in the natural self-extermination of the colony. In 1919 cultural experiments were undertaken in Bangalore, utilising different species or broods and various available trees as hosts, to ascertain the range of variability in the sex-ratio. It was found that the moisture-content of the eggs at the time of fertilisation as well as the specific constitutional response of the insect to its environment form two distinct factors in the sex-ratio determination, while temperature and the nature of the host-plant are very little concerned therein. This has already been referred to in this Journal [1] and in the light of such information it becomes advisable to ascertain directly the proportion of female insects in every generation. This should be done before the new generation is exposed to unfavourable conditions leading to mortality, and necessitates sex identification at the earliest opportunity, i.e., immediately after fixation. A sex-ratio determined in the entire absence of mortality alone can indicate the actual quality of the brood used for inoculation and thus provide one important factor for predicting the yield of the forthcoming crop. In the following pages are set out actual observations which, it is claimed, establish the possibility of recognising the sex before moulting commences.

[1] *This Journal*, 1924, 7, 136.

HISTORICAL.

I. *Sex-ratio Determination.*—The earliest reference to the sex-ratio is by Roxburg [1] who says 'The male insects I have found to-day (6th December, 1789). A few of them are constantly running among the females most actively; as yet they are scarcely more, I imagine, than 1 to 5000 females.' The following year Roxburg's second [2] communication appeared with a few additions to his illustrations and previous descriptions. It would seem that what he mistook for a male lac insect was probably a female of the chalcid parasite attacking the species of lac insect *Lakshadia communis*, provisionally named *Erencyrtus Dewitzii*. His figure and description of the adult form of female lac insect, on the other hand, correspond very closely with the full-grown winged male lac insect.

The above ratio is also mentioned in Ure's *Dictionary of Arts and Manufactures* [3] quoted by Carter and no doubt traces its origin to Roxburg's original statement. It is evident however that the ratio 1 : 5000 cannot be taken as referring to the sexes of lac insects. Carter [4] is the only authority in the literature who gives a sex-ratio finding, stating, 'It was observed that in some parts there were almost if not quite as many male as female incrustations (cells) present, in others not so many.'

A much later statement on this point is made by Young [5] who says 'About six weeks to two months after swarming the males appear, but they are few in number in proportion to the females, so that, in order to fertilise every cell, each male must be able to impregnate a hundred females.'

Misra [6] as late as 1919 makes no reference to any correlation between the sex-ratio and the production of lac and for the first time speaks of this in the 1923 edition of his Bulletin [7] as follows, 'In some places and at variable seasons the majority of the resinous cells on the plants are those of the males. When this happens the incrustation is thin and the crop is poor. Whether this is due to the vigour of the trees on which the insects feed or to the periodic seasonal appearance in connection with the parthenogenesis which prevails in the case of lac insects is not well understood in the

[1] 'Asiatic Researches,' London, 1789–90, **2**, 361. Reproduced in *Agric. Ledger*, 1901, **9**, 197.

[2] *Phil. Trans.*, 1791 (reprinted 1809), **17**, 62.

[3] *Agric. Ledger*, 1901, **9**, 205.

[4] *Ann. and Mag. Nat. Hist.*, 1861, 3rd Series, **7**, Part I, 1, Part II, 363. (Vide *Agric. Ledger*, 1901, **9**, 198 and O'Conor, *Lac: Production, Manufacture and Trade*, 3rd Edition. Government Press, Calcutta, 1876, 71–83).

[5] *Ind. Forester*, 1909, **35**, 31.

[6] *Proc. 3rd Ent. Meeting*, Pusa, 1919, **2**, 782.

[7] *Agric. Res. Inst., Pusa*, Bull. 142, 3rd Edition, 1923.

particular case. This phenomenon I have seen to occur not only in the case of *ber* (*Z. Jujuba*) and *arhar* (*Cajanus indicus*) but also *Albizzia Lebbeck* and *Shorea talura* in Mysore. In the case of the latter recently I found that when the *Shorea talura* brood was put on *arhar* there too the majority of the incrustation consisted of male cells. In one instance at Bangalore, when *Loranthus Sp.* growing as a parasite on a *Shorea talura* tree, became infested with lac derived from *S. talura*, the majority of the cells in this case too were those of the male.'

II. *Earlier Attempts at Sex Identification.*—Although a quantitative examination of the sex-ratio shortly before sexual maturity could easily have been undertaken, with the exception of Carter, no one seems even to have attempted it. This is perhaps natural if it be assumed that sex-ratio variability was generally unknown.

The numerous attempts at early sex differentiation after Carter seem to have been made with an entirely different object, viz., to study the metamorphosis of the sexes. Here again Roxburg [1] is the first to mention a female crawling larva as being distinct from the male, and he gives a short description of the former, accompanied by an illustration. However, he confesses with regard to the male, 'The larva I am as yet unacquainted with,' and as this prevents comparison, his claim to early recognition of the female sex can hardly have any justification, specially remembering that he wrongly identified the sexes even in the adult stages. Carter [2] makes a casual reference to the absence of dimorphism of the sexes in the earliest stage of lac insects by saying, 'All are alike, apparently, when first attached'. Mc Kee, [3] who acknowledges Carter as the source of his information on the biology of the lac insect, says with regard to the larvæ that, immediately on fixation, 'The male and female are identical in size and shape'. G. Watt [4] also says, 'At this stage it is impossible to distinguish the sexes,' but this statement is probably based on the results of other observers. Lowrie [5] confirms the above observation by saying, 'At this stage the distinction between the male and female cannot be traced'. Stebbing [6] also mentions, 'That it is impossible to observe any distinction of sex at this stage of life'. Misra [7], [8] in two editions of his Bulletin published at ten years' interval, says, 'At this time there is very little difference between the male and female insects'. The only other reference on this point is by Imms

[1] *Phil. Trans.*, 1791, 17, 64.
[2] *Agric. Ledger*, 1901, 9, 204.
[3] *Ind. Forester*, 1876, 1, 279.
[4] *Agric. Ledger*, 1901, 9, 193.
[5] *Proc. Central Provinces*, Forest Conference, 1908, Government Press, Nagpur, 1910.
[6] *Ind. Forest Memoir*, 1910, 1, Part III, 5.
[7] *Agric. Res. Inst. Pusa*, Bull. 28, 2nd Edition, 1913, 12.
[8] ,, ,, ,, ,, ,, 142, 3rd ,, 1923, 39.

and Chatterjee [1] who state that 'In the newly hatched larvæ the sexes are indistinguishable by any external characters and it is not until after metamorphosis has set in that the separation into sexes becomes evident.

We have examined a large number of the newly hatched larvæ of *Tachardia Lacca* (*Lakshadia indica*) and other coccids and have been unable at this stage to find any external manifestations of the sexes.

In the light of the latter part of this statement, it seemed advisable to consult the available publications of those coccidologists who, working with more favourable material, might have discovered a means of differentiating the sexes which would have a bearing on the study of lac insects.

In this connection Maxwell-Lefroy [2] states that according to Green 'in some species, sex is distinguished in the earliest larval stage' but he gives no further details nor any reference to published results. Simanton [3] finds that the Terrapin scale of the peach, *Eulecanium nigrofasciatum* Pergande, exhibits sexual dimorphism in the first stage, the male having six anal ring hairs, the female eight.

Kuwana [4] mentions that in the case of the Chinese wax insect, *Ericerus pela*, Chavannes, sex differentiation can be traced even in the egg stage, those of lighter colour producing male larvæ, and the darker ones females. Moreover in the first larval stage the male can be distinguished from the female by stouter antennæ and by the presence of delicate marginal hairs on the body and a dark median line on the back.

Signoret found that the larvæ of *Gossyperia ulmi* exhibited a difference in the number of antennal joints which he interpreted as a secondary sexual character; this significance was later assumed to be correct by Howard [5] in confirming Signoret's observation. Kuwana [6] established this structural difference as regards *G. ulmi*, but found so few larvæ exhibiting such dimorphism that on this account he hesitated to attach any importance from the standpoint of sexual differentiation.

Present Researches.

The material for the present researches was derived largely from *L. mysorensis* which is commercially propagated on *Shorea talura* but

[1] *Ind. Forest Memoir*, 1915, 8, Part I, 17.
[2] *Manual of Entomology*, London, 1923, 283.
[3] *United States Dept. Agric.*, Bull. 351, 1916, 27.
[4] *Philippine J. S.*, 1923, 22, 393.
[5] *Insect Life*, 1889, 2, 36.
[6] *Bull. Imp. Central Agri. Expt. Station*, Japan, 1907, 1, No. 4, 219.

numerous observations have also been made on *L. communis* to which greater importance is attached since this species shows a very wide variation in sex-ratio. Observations were extended to other species, e.g., *L. indica* growing on *Butea frondosa*, brood of which was obtained from Palamau.

EXAMINATION OF STRUCTURAL CHARACTERS.

In the first place, methods of differentiation were attempted which were suggested by previous successful observers of coccids. Thus search was made for a difference in the number of anal ring hairs but the additional pair mentioned by Simanton as characteristic of the female *Eulecanium* was not found in the female lac insect. This is shown in Fig. 9, Pl. III, which presents a female larva of the first stage ready for moulting and possessing six hairs which are again shown further enlarged in Fig. 10, Pl. III, whilst Fig. 4, Pl. I, shows three hairs of one side. The anal ring hairs of the male larvæ are best seen in Fig. 14, Pl. V and also number six; Fig. 3, Pl. I representing a male larva shows the three hairs in profile. As a matter of fact no variation was discovered among the hairs or setæ on any part of the body either with regard to their structure or number.

The lac insect being ovoviviparous lays no eggs, although it is stated to do so by several writers, amongst the oldest being Saunders [1] and among the most recent Misra [2] and consequently no observations could be carried out on their eggs analogous to those of Kuwana on the Chinese wax insects. One insect showing colour dimorphism has been studied with this object. In Kashmir (Jammu State) experimental cultivation of lac has been undertaken on *Acacia catechu*. The insect is the same as that named *Tachardia ficii* by Green. Brood lac was obtained through the courtesy of Mr. Nagarkatti, Member for Industries, and through the Forest Department of the State. On cultivation it was found that males and females each exhibited two forms, being both yellow and red and consequently colour could not be associated with sex as is evidently the case in the eggs of Chinese wax insects and adult of other organisms, e.g., the crab [3] *Paralithodes Camtschatica* where the female has reddish, and the male colourless blood.

Kuwana's criticism that since only a few larvæ showed antennal variation in *G. ulni*, such variation would not indicate sexual dimorphism, holds true only in cases where the sex-ratio of a

[1] *Phil. Trans.*, 1789 (reprinted 1805), **16**, 554.
[2] *Agric. Res. Inst., Pusa*, Bull. 142, 1923, 43.
[3] *J. Coll. Agric. Tokyo*, 1916, 5, No. 4.

generation approaches equality. In *L. communis* the brood swarming from monsoon-fed brood lac consists of males in such a preponderating ratio that only a few among a thousand would exhibit sexual dimorphism. The task of discovering any dimorphism, much less a structural one, in such a generation is very difficult, if not futile. The generation swarming from non-monsoon or dry weather brood lac consists of as many as thirteen females to one male, where again it is not easy to compare males and females of the same generation. On the other hand it should be quite easy to find structural variation between larvæ which swarm at the end of the monsoon known to consist almost entirely of males and those that belong to the non-monsoon brood lac, where females are never less than half the population and where the ratio may be even more favourable to them. Such an attempt, however, gave only a negative result.

In this connection it may be mentioned that the structure of the antennæ is very variable among coccids. The winged male of *L. communis* usually possesses ten joints in the antenna but sometimes nine. A mutant species of *Coccus viridis* named *C. Colemani* (K. K.),[1] hitherto characterised by three joints in the antenna, cannot always be so distinguished since some individuals recently [2] examined contained seven joints in the antenna, exhibiting 'reverse mutations, regaining that which had previously been lost.' [3] Under these circumstances antennal characters would form a very unreliable basis for distinguishing the sexes.

All anatomical structures common to lac insects and other coccids, when examined for structural variation, gave negative results. There was, however, one character special to lac insects and consequently not referred to by other investigators of coccids which seemed of interest. The brachial plates, according to Chamberlain's [4] latest nomenclature, equivalent to the stigmatic plates of Green, Imms and former authors, contain more than five pores which are clearly illustrated by Imms and Chatterjee in Fig. 9, Pl. II of their Memoir, the larvæ being derived from a North Indian species, *L. indica*. An examination of the brachial plates of the full-grown first stage larvæ of *L. nagoliensis* (on *Schleichera trijuga*) from Raipur and Sohagpur, *L. mysorensis* (on *Shorea talura*) from Bangalore and *L. communis* (on *Ficus mysorensis*) also from Bangalore, showed that the number of pores usually varied between seven and eleven. This variation was noted in different individuals of the same generation and thus gave hope that it might be due to a difference in

[1] *Dept. of Agric. Mysore*, Ent. Bull. No. 4, 1918.
[2] Private Communication.
[3] M. C. Coulter, *Outlines of Genetics*, University Press, Chicago, 1923, 116.
[4] *Bull. Ent. Res.*, 1923, **14**, 152.

sex. A critical examination, however, proved that in a few cases even the same individual did not possess identical numbers of pores in the two brachial plates and, like antennal characters, these structures offer little information in the study of either species or sexes of lac insects. It was noticed, however, that in typical cases the male larva was provided with brachial plates containing fewer pores suggesting its smaller wax-secretory requirements, and this gives the impression that Fig. 9, Pl. II of Imms and Chatterjee represents the brachial plate of a male larva and probably of the winged form which is most common in the generation swarming from the rain-fed brood lac. No details, however, are given to corroborate any of the above statements.

DYNAMIC POINT OF VIEW.

In consequence of these difficulties an endeavour has been made to approach the study of early sex differentiation not from a morphological aspect but from what may be called a dynamic point of view, by watching the differential manner of growth exhibited by the sexes, as distinct from the static method concerned in merely analysing fixed anatomical details.

This work was developed in two independent directions. One consisted in finding where the ratio was favourable to one sex so that more of this sex could be expected in a given number of larvæ, and the other in observing the actual changes exhibited by individuals of each sex as they developed.

In a previous paper [1] the writer has mentioned that in every species the monsoon-fed brood lac gives rise to a generation most favourable to the male, the range differing with the degree of moisture and the nature of the insect species. With the trivoltine species *L. mysorensis*, the maximum divergence between the sexes was found to be in the ratio of four males to one female and this occurred in monsoon-fed brood lac although frequently the ratio consisted of two males to one female. Winged males were also more common in this generation than in others. The generation of larvæ produced by the post-monsoon brood lac gave the ratio most favourable to females, varying between seven females to one male and two females to one male; it also contained the least evidence of winged males. The third or pre-monsoon crop gives a generation where males and females may be in equal number or there may occur two males to one female when a few of the males may be winged also. Moreover when one and the same brood stick was used for inoculating different branches, the sex-ratio among the resulting colonies differed, the number of

[1] *This Journal*, 1924, 7, 136.

males increasing with the later swarming of the larvæ; the experiment was made with the monsoon-fed brood lac of two species, *L. mysorensis* and *L. indica* from Palamau. A careful selection of material in the light of these observations has been very helpful, first in furnishing colonies for early sex identification and later in confirming sex-ratio findings recorded in the earliest stage of fixation by subsequent countings after metamorphosis had begun. Such a task would be almost impossible in generations such as those mentioned by Young where there may be a hundred females to one male or, as was found from personal experience, in the generation given by monsoon-fed brood lac of *L. communis* where the converse holds true, viz., more than a hundred males to one female. The best material for study was naturally a generation where, from previous knowledge, the sex-ratio could be expected to approach equality so that the male and female could often be seen side by side and the findings could not be in favour of either sex, alternate individuals being usually of the opposite sex.

A further fact which has been overlooked by several writers is that the young crawling insects, as they leave the mother cell, are provided with a ceriferous coat often dusted with a powder of another soft wax, this covering giving the larva a whitish appearance. On the basis of such an observation being reported, 'Sir G. Watt does not even think it impossible actually to evolve a white insect.' [1] Chuckerbutty [2] is the only authority who correctly describes the visual appearance of a typical larva as 'pink'. Lowrie [3] on the contrary says that they resemble 'dots of red ink'.

Misra [4] remarks, 'When the eggs mature small deep-red insects come out.' Imms and Chatterjee [5] mention that 'The newly hatched larvæ are pale light crimson in colour' and their illustration Fig. 1, Pl. I represents it actually as bright carmine. It is true that lac insects of the genus *Lakshadia* always contain a red dye, yet the dorsal surface of the larva is also protected by a thick coat of hard wax. In this connection a sentence may be quoted from Carter of which no notice has been taken by any subsequent writer. He says, 'All begin to secrete from their bodies the resinous (ceriferous) substance even before they have fixed themselves to the bark.' [6] The crawling larva of course has no lac or resinous layer on its back but instead has the one of wax referred to above. Similarly with the insects named by Green, *Tachardia ficii* and *T. albizziae* which consist of red and

[1] R. Mukerjee, *Foundations of Indian Economics*, Longmans, Green & Co., London, 1916.
[2] Quoted in *Agric. Ledger*, 1901, 9, 225
[3] Lowrie, *loc. cit.*
[4] *Agric. Res. Inst. Pusa*, Bull. 142, 1923, 38.
[5] *Ind. For. Rec.*, 1915, III (1), 15.
[6] Quoted in *Agric. Ledger*, 1901, 9, 204.

yellow forms, both are provided with ceriferous coats which tend to reduce the visual colour-effect and the appearance when alive is different from that on a slide after treatment with alcohol or xylene. On the contrary, larvæ of pseudo-lac insects *Tachardina lobata*, *T. silvestri* and *T. ternata*, are actually orange red in appearance corresponding to the descriptions given by others for larvæ of commercial lac insects. This is so because the exudation of wax in these cases is very small or almost nil at this stage.

However, this tendency on the part of wax-secreting lac insects to appear whitish rather than deep yellow or deep red varies in different species and seasons. The appearance is least red in two species, *L. nagoliensis* and *L. mysorensis*, which are both characterised by the fact that winged males are very rare among them as compared with other species. What is of interest is to find that both these species show little variation in sex-ratio when compared with species like *L. communis* and *L. sindica*.

In *L. communis*, which at the end of the monsoon consists almost entirely of males, the larvæ at this period may appear pink or inclined to red while in the case of those of the non-monsoon season, when the ratio may be thirteen females to one male, the appearance is generally less bright. When the appearance of the brood of one season consisting of males is compared with the other containing more females the difference is noticeable, but compared between themselves the male and female larvæ do not show any colour difference. There are, however, other reasons to believe that the chemical basis of sex determination and the biogenesis of wax are correlated phenomena from which it may be assumed that the female larva is better protected with wax than the one of the opposite sex. The possession of this thick or thin coat of wax gives the two larvæ a different external appearance although the thickness may not be so prominent as to produce a colour difference at the same time and it is in part such a minute difference which has rendered it possible to identify the sexes in the earliest stage of their independent existence.

Dynamics of Growth exhibited by the Sexes.

The adult male, in agreement with the common conception of an insect, has a long flat body with six legs. During metamorphosis the major axis of the body, connecting the capital and anal ends, remains unchanged and the insect throughout its life continues more or less flatly adherent to the surface of the twig. It thus undergoes expansion in all directions and to use Avasia's description 'The male insect looks like the original larva somewhat increased in size'[1] so

[1] Forest Pamphlet No. 4, Government Press, Calcutta, 1909, p. 1.

much so indeed that to Carter, when he saw them for the first time, they 'Appeared so like original young ones that he thought they must be a few stragglers of a later evolution.' The full grown female on the contrary appears very unlike an ordinary insect, looking like a miniature pear.

Carter [1] says, 'Thus we see that the increase of size which takes place in the female insects, from its locomotive to its ultimate development in the fixed state, is chiefly effected by an enlargement and elongation of the body between the mouth on the one hand and the part from which the three tufts project on the other; for the oral extremity simply becomes elongated and the three openings of the body remain as near together in the resinous incrustation at the end as they were at the commencement.' The axis of the body connecting the head and the anal end in the full-grown female is no longer parallel to the surface of the twig as it was in the larval stage, but is actually perpendicular to it. This is in consequence of the direction of growth being mainly in height so that the sides grow disproportionately more than the dorsal or ventral surfaces. This characteristic was most pronounced in the species *Lakshadia nagoliensis*, where some individuals were found so long that they might be described as being all length and no breadth. Similar cases have been found only among the species of commercial importance, i.e. of the genus *Lakshadia*. This tendency of the female to grow in height is apparent from the very beginning, i.e., as soon as it exhibits any sign of growth and, compared with the larva of the other sex, it appears to grow like a flea in height, while the male may be said to grow in length, like a cockroach. Figs. 1 and 2, Pl. I, represent in profile full-grown first stage larvæ of both the sexes bearing evidence of the dimorphism exhibited in the manner of growth, the female being more raised (specially shown in the elongated areas 5b and 7b) than the winged male which is slightly the longer of the two and in which the areas 3b, 5b are flatter.

Recognition of the First Stage Larvæ.

It may here be mentioned that the first stage larva, either male or female, whether it is approaching moulting or has just attached itself to the tree, is easily recognised by the presence of two long major apical hairs and the anal ring-hairs which now are only six in number; as soon as moulting has occurred the long hairs drop off and the anal ring acquires ten hairs.

Fig. 19, Pl. VII, shows a wingless male larva immediately after its first moult. The fact that it has just moulted is demonstrated by

[1] *Agric. Ledger*, 1901, 9, 202.

the tuft of anal ring-hairs, which now number ten and resemble a thick brush projecting from the old aperture of the cell intended for only six hairs. The opening is seen quite small in Fig. 20, which represents the cell of a female larva of the same age as Fig. 19 and which has also just undergone its first moult.

DISARRANGEMENT OF DORSAL WAX PLATES.

Attention may now be drawn to Fig. 11, Pl. IV, illustrating a larva of *L. communis* in the first stage. On the back there can be clearly seen the shield of hard wax with a matted surface referred to previously as helping to give the insect its pink or even whitish appearance. Careful study reveals that this dorsal shield never disappears from the mass of incrustation and undergoes no further development, thus retaining the original form until in response to growth it undergoes distortion in a certain systematic fashion.

After fixation, hard wax is produced in the form of pencils from glands in localised regions situated on the sides and not from the dorsal surface. These pencils (w. p., Fig. 5, Pl. I) form part of the architecture of the cell and being embedded in the mass of lac exudation are concealed from view, while the original shield of wax is never hidden from view thus enabling observation throughout the entire life of the insect. In Fig. 5, Pl. I, is seen the dorsal shield of wax (No. 1, 5, 5a and 8) as exuded by the larva prior to fixation, disconnected in two regions on account of the development of the insect body, and also the wax pencils secreted by the first stage larva and freed from the mass of lac. Inasmuch as the direction and manner in which the body expands vary in the two sexes, the plates constituting the shield accordingly separate differently and in a way specific to each sex. The observations on this shield and the shape and disarrangement of the plates as growth progresses form very valuable means of sex differentiation.

A young larva, as shown in Fig. 14, Pl. V, for example, has thirteen body segments, the twelfth being represented by a pair of major apical hairs (Fig. 14 m. a. h.) and the thirteenth by anal ring-hairs (Fig. 14 a. r. h.) and naturally these last two segments require no protecting coat. The skin constituting the remaining eleven segments is delicate and is protected by the wax shield of which each plate (numbered in Fig. 14, Pl. V) is secreted by wax glands situated in each segment of the larval body. When growth begins the skin distends and when dilation is sufficiently marked the original uniform continuous arrangement of plates shows a change in two main regions, between segments 2 and 3 and 7 and 8, with the result that wax plates 1 and 2 become divided from numbers 3 to 7 and the latter from 8 to 11, thus dividing the shield into three parts. This is shown in Fig. 6, Pl. II, Fig. 12, Pl. IV, and 19, Pl. VII, as seen from the dorsal surface; the disarrangement of the shield freed from the mass of lac is seen in Fig. 5, Pl. I, while Fig. 2 shows the female cell with its shield similarly divided into three regions, as seen in profile. As mentioned before the female grows vertically to the plane of attachment and consequently even by the time it is ready for the first moult it shows a 'height increment' sufficient to distinguish it from the male of the same age which on the other hand shows a characteristic progress along the longitudinal axis.

In Fig. 2, Pl., I, the female cell on the right is seen more raised, growing as it were by enlargement of the ventral skin towards the sides and its height is specially noticeable in the anterior region where it resembles a steep hill while that of the male cell is far more sloping. The chitinous brachial plate on the skin shown by the dark aperture (Fig. 2, b.o.) and the anal tuft are both more raised in the female cell. Again the back corresponding to plates 3 to 7 is far more raised than the remaining segments of the same body and is specially marked by a 'fault'-like fall in level of the dorsal strata between segments 7 and 8. Fig. 1 representing a male cell, in spite of the distortion in the original arrangement of wax plates, shows a gradually arched back instead of the upheaval noticeable in the female cell. The most marked change has again occurred between wax plates 7 and 8, but here it is lengthening, or separation longitudinally. Sometimes this longitudinal growth is very prominent, e.g., in Fig. I where the side portions marked 5a, 6a and 7a, belonging to plates 5, 6 and 7 respectively, have been detached and dragged along as it were by the current of growth. The main portions of plates 6 and 7 are no longer vertical, showing the direction as well as the force of growth which gives them a 'fault'-like inclination.

In the full-grown first stage male cell, wax plate 7 is very frequently not found in its original position, placed vertically like a saddle on a back, but is seen inclined or even lifted to such an extent that the plate lies on its side and flat on the dorsal surface like horns on a table. This phenomenon was never observed in a female cell and has been very helpful in the identification of the opposite sex especially of the full-grown first stage winged male (Fig. 1, Pl. I).

Inasmuch as the back of the female is raised, the wax plates also acquire a more arched appearance, but since the other segments 8 to 11 do not act in the same way, the contrast between plates 7 and 8, the former being the last plate of the middle and the latter the first of the hind portion, becomes prominent. When Figs. 21 and 22, Pl. VIII, are compared, it will be seen that in the female, the figure to the right, plate 7 is more arched than the corresponding plate in the male, which is sufficient to account for a greater apparent difference in breadth between plates 7 and 8 in the female cell than is found in the male. Fig. 20, Pl. VII, is a female cell immediately after its first moult and shows the difference between plates 7 and 8 still more prominently while Fig. 19, Pl. VII, representing a male of the same age does not do so. To show that this specific disarrangement of the dorsal plates is due to a difference in the body-outlines of the two sexes in response to their respective manner of growth, Figs. 3 and 4, Pl. I, have been drawn and these should be compared with Figs. 1 and 2. The female has the entire back raised in the region covered by plates 3 to 7 of the wax shield while the skin beneath plates 7 and 8 shows a step-like fall corresponding to what is seen in the cell. It will be noticed at the same time that the back is not arched and the outline of segments 3 to 7 forms more or less a straight line. By comparison the male has a very gentle and uniform arch showing that if the same elongation had occurred, forming a fold, the body would have appeared much smaller, whereas, owing to its stretching in a line, it gives the larva a longer appearance; this explains why the full-grown first stage male larva of *L. mysorensis* (even of the wingless form) is larger than the female cell (Figs. 19 and 20, Pl. VII; Figs. 21 and 22, Pl. VIII). Since in the female the entire back is raised, plates 3 to 7 adhere together while in the male the skin beneath plate 3 is on a higher level than that covered by plate 7, as though there were a gentle hump on its back. This explains why plate 7 and sometimes 6 and 7 of the middle region cannot keep themselves attached to plates 3 to 5 but show an inclination or even turn flat on their sides. If plates 6 and 7 still adhered to the rest they would form a roof-like projection and the space between them and the skin of the body would require to be filled by some exudation, but as this is not the case the above-referred inclination with plate 7 still adhering to the body is the natural outcome.

Early Growth Dimorphism as Precursor of Metamorphosis.

A word of explanation may be offered to account for the phenomenon of dimorphism in the earliest stage of metamorphosis. The full-grown male escapes from its cell through an opening in the posterior region. The cell is perfectly formed during the second stage, i. e., before the second moult of the male. To cope with its future requirement the male larva shows from the very beginning a greater development, especially in the posterior segments. The opening in the cell is made by the secretion of the upper portion of the hind segments separating as a lid. It may also be said here that after the first moult the male, distinguished from the female, secretes only lac resin and therefore there are no further wax pencils produced, whatever wax pencils there are in the cell being those secreted by the first stage larva. The lid just referred to being formed from the products of the second stage larva, is composed largely of lac resin secreted by glands on that portion of the skin which has increased between segments 7 and 8. This explains why growth in length is very prominent in this region even in the first stage male larva. On the other hand, the female has to provide itself with a spine by the time it is sexually mature. This keeps its skin fixed into the cell vault helping the insect to grow mainly in height. This spinoid tubercle also traces its origin to the portion of the skin between segments 7 and 8 of the first stage larva and this explains why a vestige of it can be seen in the form of a fold or a step-like sharp fall in the level of the skin as seen in Fig. 4, Pl. I. In rare cases this fall in level is actually discernible as a gentle fold in the lac coating between wax plates 7 and 8 as is shown in Fig. 8, Pl. III.

Differential Development of the Thoracic Region.

As already mentioned, the male acquires greater development of body but secretes less wax compared to its size. In the second stage it altogether stops secreting wax pencils; secretory activity is restricted to resin production and the cell is provided with a thin coat of lac. The contrary is true of the female, which secretes with growth an increasing quantity both of wax and lac as compared to its size. Briefly the male shows development of body and economy of secretion while the female exhibits copious secretion. The result of such a phenomenon is that the male larva whether wingless or winged, which is smaller than that of the female insect on fixation (Figs. 25 and 26, Pl. IX, Figs. 17 and 18, Pl. VI) by the time it is ready for its first moult, is already longer than that of the female (Figs. 21 and 22, Pl. VIII and 1 and 2, Pl. I). The secretory activities of the female larva do not increase merely with different stages, or after each moult, but are continuous throughout and are therefore evident also at the various periods of the first stage larva. This physiological dimorphism between the sexes was conspicuously observed in *L. indica*, Figs. 12 and 13, Pl. IV. The width in the second segment or across the brachial plates of the male shows the greater expansion of the thoracic region or chest. The female cell, on the contrary, is seen with a thick uniform secretion of lac product especially in the hind region. The expansion of the thoracic region is also seen in the protruding appearance of the cell outline near the area of the brachial openings in Figs. 1, Pl. I and 19, Pl. VII. Even Figs. 6 and 7, Pl. II, which represent the most commonly seen form of the first stage larvæ bear evidence that in the male the thoracic region exhibits greater expansion, a more uniform cell-outline showing the absence of much lac exudation and a greater width of the chest región. Contrasting Fig. 6, Pl. II, a normal form, with Fig. 8, Pl. III, which is an exceptional type of female cell, the rough outline at once indicates the greater lac exudation in the latter cell, while comparing Fig. 6 with Fig. 7, Pl. II, the female cell shows the absence of much expansion of the body where the brachial plate is situated. In the male cell, Fig. 6, Pl. II, it would appear as if the ventral surface of the sides expanded sideways; in the female cell, Fig. 9, Pl. III, the sides are being lifted vertically so that the original appearance when seen from above is still maintained and the brachial opening is not distorted like an elliptical slit as is seen in Fig. 6, Pl. II. Figs. 14 and 15, Pl. V, both belonging to the male, show how early and conspicuously a slit-like aperture is noticeable in some cases in the brachial opening when seen from above. Figs. 12 and 13, Pl. IV, show this contrast between the sexes of the same species and Fig. 11, Pl. IV and Fig. 19, Pl. VIII, likewise, although these belong to different species. Figs. 1 and 2, Pl. I, which are two cells seen from their sides, represent a male with a broader aperture showing thoracic expansion about the long axis and a female, which clearly exhibits expansion in a direction perpendicular to the line of attachment, i. e., in height. It may be emphasised here that the brachial opening in the female cell is narrow and elliptical pointing towards the direction of growth when seen from the side; that of the male appears broader due to greater development of the body on the whole and is conspicuous when seen from above (compare Pl. V, Fig. 15, a male, with Fig. 16, a female).

The appearance of the brachial opening in Fig. 19, Pl. VII, may be mistaken for that of a female and should be compared with that of Fig. 2, Pl. I, but when we compare Figs. 11, Pl. IV and 19, Pl. VII, together with Fig. 2, Pl. I, the sex dimorphism at once becomes evident. Figs. 11 and 19 are, however, drawn showing only three-quarters of the cell.

Figs. 14, Pl. V and 23, Pl. VIII, are of the same species and age and the dimorphism between them due to sex is evident. The male cell is conspicuously broad across the thorax or chest and the wax plates, in response to the side expansion of the body, naturally lie flatter than those of the female cell which is shown with a raised backbone-like ridge along the median line of the cell. The conspicuous brachial opening (b.o. Fig. 14, Pl. V) compares with that of Fig. 12, Pl. IV, being equally broad and reminding one of Fig. 1 seen in profile.

The growth of the anterior region in the male cell does not invariably show a breadthwise direction but may show elongation and a more pointed frontal portion. Figs. 1 and 2, Pl. I, when seen from above, look like Figs. 21 and 22, Pl. VIII, where the triangle connecting the two brachial openings with the anterior extremity is longer. When the breadth of the two cells across the thorax is compared in this particular case, Fig. 22, or the female, appears broader; but when the whole anterior region comprising body segments 1 to 3 inclusive is considered, the male cell shows greater longitudinal development. It will also be noticed that the brachial openings of the above two cells do not show any differences, but even in this case the greater expansion across the thorax as compared with the posterior region is evident. The frontal expansion in the male cell is a precursor of its future requirements. The male has well developed legs antennæ and thorax, features which all disappear in the female after its first moult.

It may be remarked here that all characters which indicate a development of the thoracic region in the first stage larva will indicate the male sex; sometimes this may be indicated by the expansion of the brachial opening, sometimes by the elongation of the frontal region as a whole but it is only after growth has set in that such differentiation is possible.

Growth in the Posterior Region.

The full-grown female is provided with an anal opening in the cell protected by two concave armour-like wax plates from resin secretion so that its power of movement is preserved: hence after the first moult the anal extremity of the larval cell acquires a projecting elongation. The enlargement of this portion of the body and the secretion of wax in the form of pencils characterise the second stage female larva; the male cell, as already mentioned, secretes no further wax pencils in the second stage, and, of course, it does not acquire an anal tube when full grown. Even before the larvæ are ready for their first moult, they show evidence of such dimorphism. In Fig. 2, Pl. I, the female anal opening with a raised bracket-like projection is comparable with the anal opening of Fig. 9, Pl. III, which is rather conspicuously shown and again further enlarged in Fig. 10, which shows the contrast with the male cell in Fig. 1. The bracket-like projection consists of two plates of wax surrounding the anal opening and protruding further in the female cell than in the male. These are seen free from lac exudation in Fig. 5, Pl. I, marked w. pl. They are not wax pencils as they do not divide into threads.

A comparison of the posterior extremities of the male and female body outlined in Figs. 3 and 4, Pl. I, will show a tendency on the part of the female for the anal end to be raised upwards. This is noticeable by a distinct fold on the dorsal skin beneath wax plates 8 to 11. The result of such a slight difference in growth is noticeable in the appearance of the cell where hind plates 8 to 11 form a central raised plateau with furrows on either side. In profile, Fig. 2 is seen with a central ridge like a portion of backbone, plates 8 to 11 being more prominent than the similar region of the male cell Fig. 1.

Fig. 11, Pl. IV, shows the furrows produced by the raising of the central region. They are also prominent in Figs. 8, 9 and 10, Pl. III. In Fig. 10, the furrow is seen as a shaded line between the main portion of wax plates marked 8 and 11 and their side portions marked 8a and 11a. Figs. 6 and 7, Pl. III, show the posterior plates 8 to 11 with a central ridge and furrows represented by two dark lines in the female cell while the male cell is represented having a quite homogenous appearance and a gently arched cover.

Similarly Figs. 21 and 22, Pl. VIII, show the contrast between the sexes, plates 8 to 11 in the median line of the female cell being raised and accompanied by a furrow-like depression parallel to this on either side. The male cell shows a homogenous arrangement more like the original appearance.

It will also be noticed that in the female cell the sides or flaps (5a, Fig. 5, Pl. I) of wax plates 8 and 9 sometimes show distortion or swelling when compared with other plates and this is never observable in the male cell. In Fig. 2, Pl. I, the side of plate 8 is seen swollen while in Fig. 22, Pl. VIII, it is plate 9 that shows this special feature. In Fig. 8, Pl. III, wax plate 8 shows great distortion or separation of the main plate from the side portions and to a lesser extent this is also true of plate 9. The explanation of such an occurrence is as follows.

The wax pencils secreted by the female cell during its first stage are more prominent and acquire a greater width ; those of the male are finer and remain relatively closer to the skin of the larva. The differential direction of growth of these pencils is most prominent on the dorsal surface. Those of the female tend to project upwards and distort the original wax shield which accompanied the crawling larva and which is now lying on the wax pencil. A comparison of Fig. 8, Pl. III, with Fig. 5, Pl. I, will illustrate this point. The wax plates 1 to 7 of the larval shield, including their side portions, do not lie over any wax pencils which arise from the body wall (b.w. Fig. 5) : those secreted from segments 8 to 11 do so and cause this disarrangement. In Fig. 5, the wax pencils secreted after fixation are shown as well as the entire larval shield or plates 1 to 7 ; but the sides or flaps of plates 8 to 11 are not represented since they hide the wax pencils from view and only the central portion forming the backbone-like ridge is drawn. The two furrows in Fig. 8, Pl. III, correspond to the white space in Fig. 5, Pl. I, between dorsal wax plates 8 to 11 and the wax pencils of the hind region, the central ridge-like plateau of Fig. 8 to the dotted plates of wax 8 to 11 in Fig. 5.

The secretion of lac accompanies the formation of these wax pencils and the lac-secreting glands are most thickly distributed in the regions where wax pencils arise. The swellings in plates 8 or 9 are globules of lac accompanying lac pencils. The formation of such globules indicating a female cell is not always observable, but the presence of the above furrows is invariably so, and is a good indication that the cell is that of an immature female. It is evident that the above phenomenon is due to the anal tube trying to raise itself upwards and the wax pencils, being secreted from adjoining portion of the skin, also tend to point upwards.

As distinct from the female, the male builds its cells completely in the second stage and shortly after moults twice before it emerges as an adult. The full-formed male cell (second stage) towards the end is provided with a flat lid which provides an opening in the dorsal posterior region. This lid consists mainly of lac secreted by glands from the portion of skin which enlarged between segments 7 and 8 to which the plates 8 to 11 of the original shield are cemented. The male insect itself is flat and long and as the lid is much more so, the posterior region of the first stage cell is not called upon to show any modification from the original appearance. Comparison between Figs. 1 and 2, Pl. I, and Figs. 21 and 22, Pl. VIII, will show the dorsal surface and narrow longitudinal growth of the posterior region of the male cell. Figs. 6 and 7, Pl. II, show the male posterior region with dorsal surface undisturbed and flat. Figs 15 and 16, Pl. V, show that the change is evident in the case of much younger larvæ.

Correlation between Morphological and Physiological Characters.

The Broad Waist and Parallel Sides of the Female.—As architects the female differs from the male inasmuch as the latter uses very little wax in building the cell; greater secretion of wax by the female has been found to be associated with greater width in the posterior or waist-region. Generalising, one may say that if the waist-region of the female is to exhibit greater growth there must be some potentiality noticeable in the morphological characters even of the youngest stage. Although this might be very small, it might be visible on comparing the two sexes.

Figs. 17 and 18, Pl. VI, represent twenty-four hours old larvæ and bear evidence of dimorphism in shape; the posterior end of the male is longer and narrower giving the larva the shape of a diagrammatic fish while the female on the right has a broader hind region. The same is true of older larvæ, e.g., Figs. 15 and 16, Pl. V. This dimorphism is, however, most prominent in Figs. 12 and 13, Pl. IV, where the specimens are approaching the time of moulting. Fig. 24, Pl. VIII, is about 8 days old and although it belongs to a different species compares more favourably with Fig. 18, Pl. VI, of the same sex than with Fig. 17. Fig 24 gives a more realistic appearance than the pen-and-ink drawing, Fig. 18.

The Flat Back and Tapering Body-Outline of the Male.—It was mentioned that the female produces more wax and possibly even before it is fixed is provided with a thicker coat of this secretion. Fig. 5 shows the wax-plates of the middle region (lettered 5), plates 3 to 7 having a central, thicker and arched portion with the side margins (5a) depressed and flat. This character is also noticeable in the corresponding Fig. 7, Pl. II and Fig. 18, Pl. VI, since the shield no longer shows any further change with the growth of the larva. A contrast between the sexes is evident on comparing the back plates 3 to 7 of Figs. 6 and 7, Pl. II.

Although the thickness and structure of the wax shield in plates 3 to 7 are not always apparent, the male larva as a rule has a gently arched flat back, recalling the common conception of the back of a fish. This is apparent on reference to Figs. 15 and 16, Pl. V, which are of fairly young specimens and represent typical examples. To show how far these drawings are true to life the specimens have also been photographed (Fig. 25). The fish-like, gently-arched, flat back with a broad thoracic region and the longer and more tapering shape of the hind end are evident, indicating the male; the female has a broader appearance in the hind end, with sides more or less parallel when compared to the other sex and has its back raised along the median line with the sides on a lower level and flat. To lead to a better appreciation of these characters it may be pointed out that the larva with the flat back grows flat and long becoming a male, the one with a raised central backbone-like ridge grows solely in height, ultimately looking like a pear or seed and becomes a female. From what has been said immediately above it would seem that Fig. 7, Pl. II, of Imms' and Chatterjees's paper referring to *L. indica* represents a male and the drawing may possibly have been made from larvæ swarming in November from the monsoon-fed brood-lac. Their figure for the brachial plate also appears to belong to the same sex. On the contrary Fig. 4, Pl. XIX of Green's paper illustrating the larva of his *T. ficii* [1] would appear to belong to a female. Probably it was derived from dry season brood, as it was found that brood from Kashmir which swarmed in June gave very few males; but no details are given by Green to support this deduction.

A colony of larvæ where the majority are males is shown in Fig. 29, Pl. X. To illustrate the difference in the external appearance of the

[1] *Ind. Museum Notes*, 1903, 5, 97.

larvæ, Fig. 26 is also reproduced showing a typical sex dimorphism between larvæ four days after fixation.

Size of the Larvæ with respect to Sex.

With the species *L. mysorensis* it was observed that, comparing the crawling stage larvæ of the wingless male and the female respectively, the latter were larger. Fig 26 represents both of them four days old under the same magnification. By the time they are ready for the first moult the male is longer (Figs. 21 and 22, Pl. VIII). When the first stage, full-grown or partially-grown larva of a winged male is compared with the others it is always found to be the longest (Fig. 28). In other words after growth has set in the winged male cell is longest, the wingless male comes next and last of all the female. This is the case with *L. mysorensis*, and is probably also true of all species. With *L. nagoliensis* some crawling larvæ were found conspicuously smaller than the rest, ultimately giving rise to wingless males. The converse that all small larvæ are those of wingless males is possibly also correct. It is chiefly in this case that size helped the study of sex identification.

With *L. communis* again the male is larger throughout the first stage. Size, however, is generally speaking no safe index of the sex of a larva, but the shape of the body is applicable to all species since it is based on the dynamics of growth characteristic of each sex. Difference in size has been very useful, however, in differentiating between full-grown first stage larvæ of winged (Fig. 1, Pl. I) and wingless (Fig. 21, Pl. VIII) males.

Heliotropic Dimorphism.

Many writers have noticed that the larvæ are attracted towards light and when a bundle of brood lac is kept on a fork of a stem they emigrate towards the shoots rather than towards the stem, *vide* Hautefeuille.[1] On this basis Freymouth[2] went to the extent of suggesting that, since larvæ go towards light, economy of brood will result if individual brood sticks are placed at the extreme end of the branches so that the larvæ may find the appropriate condition and thereby avoid the mortality involved in emigration. Lindsay, the latest writer on lac, has also convinced himself on this point by a fresh confirmatory observation.[3] In addition to what is true of all larvæ of lac insects as well as of many other insects, e.g., adult chalcid flies, there is a difference in the heliotropic response of the sexes in the crawling larval stage. The present writer believes this

[1] Dept. of Industries and Commerce, H. E. H. the Nizam's Government, Bull. No. 2, 1924.
[2] *Indian Forester*, 1919.
[3] *Indian Forest Record*, 1921, 8 (1), 10.

is not specific to lac insects since with some other coccids a similar preferential response to light is exhibited by the male larvæ, but comparative observations in this direction have been too meagre for any general statement. It was however found that the sex-ratio in a colony divided into two halves was different, the portion of the twig nearer the source of light showing a settlement of far more males than the remaining portion further away from light. This was true also in those cases where the males were afterwards found to be only wingless. It was found, however, that males swarm later and it would seem that since the females are the first to appear they would naturally occupy the nearest spot leaving the males to move on to more terminal portions. In the light of such an explanation there would be no differential tendency of any kind on the part of either sex. But it was noticed that in colonies where females were in the ratio of about seven to one male, the majority of the larvæ showed no particular choice, their heads being often turned away from the light. Happily such an illustration is given by Imms and Chatterjee (Fig. 3, Pl. I), where eight females are seen, five with their heads towards the reader and three away from him. The authors state that the brood belonged to the dry season which explains the sex ratio being so favourable to the female. On the other hand, where males approached cent. per cent. of the generation, which means invariably winged forms, all pointed in one direction, always facing the source of light unless of course the twig was so small that the surplus population had to retreat, when some fixed themselves on the return journey facing away from light. It appears as though the females being more or less blind grope in the dark while the males with a thirst for light are more decisive in their choice.

Among colonies of *L. mysorensis* such partly-grown individuals were found much longer than others, assisting their identification also by size even before any sign of metamorphosis was apparent. Studies of latter stages showed that full-grown cells of winged males very often occupied such a position. The only conclusion to be drawn was that when a larva showed such special fondness for light and was further characterised by a special length of the body it belonged to a winged male. The writer hopes to reproduce in a future publication a photograph of *L. communis*, consisting almost entirely of winged males, and exhibiting such a characteristic settlement, almost all settling across the twig. This character has never been observed with any other brood which did not consist predominantly of males.

Again Imms' and Chatterjee's Pl. I, Fig. 2, represents a typical instance of a colony settling at November inoculation when the brood derived from monsoon-fed crop consists of a predominantly male population. In this figure two individuals will be seen with their heads almost at right angles to the longitudinal axis showing the insects were trying to take short cuts to face the light; the upper, or one pointing to Fig. 4 of Imms and Chatterjee, is a typical instance of its kind, and will convince any one that the selection of the direction is due to its heliotropic response rather than to direct want of space.

Although it is evident that larvæ of winged males show a heliotropic response no attempt was made to associate this with any structural character since instances are known where larvæ may even be eyeless, e.g., *Dacus olæ*, and yet exhibit photophobic tendencies.[1]

Fig. 28, Pl. X, is attached to show an actual sex-ratio determination and also how in that early stage the winged male, shown with two additional dots, can be distinguished by its length and position across the twig, i.e., facing the reader. Fig. 26 should be compared with Fig. 28 to differentiate the sexes. It will be noticed no mortality has yet occurred and most of the specimens resemble crawling-stage larvæ; though a few have grown much bigger no moulting has yet occurred. The larvæ were not all of the same age as the brood stick of *L. mysorensis* had been kept some time.

CONCLUDING OBSERVATIONS.

Previous attempts to study the metamorphosis of lac insects led investigators to trace sexual dimorphism to the first larval stage. Their illustrations and descriptions go to show that sex differentiation is possible just before sexual maturity while their statements with regard to sex identification at earlier stages are either incorrect, vague or too cursory to admit of verification. No reference exists in the literature prior to 1923 implying any other conception than that the sex-ratio is fixed for all seasons and localities. Carter alone has given a sex-ratio finding which was carried out at the time of sexual maturity ignoring larval mortality.

The present researches were undertaken to determine the sex-ratio before the larvæ were exposed to risk of mortality, i.e., before any sign of moulting could be observed. The object was to judge the quality of brood used for inoculation and provide a valuable factor in forecasting the yield of a crop.

The static methods of morphologists, analysing structural variations characteristic of each sex, successfully employed in the study of other scale insects, gave negative results in the present work. A

[1] *Redia*, 1922, 15.

dynamic view-point was maintained and consisted in observing changes in sex-ratio and in the phenomena of growth exhibited by each sex.

A knowledge of sex-ratio variability greatly helped the study of early sex identity. Variation in the supply of moisture at the egg stage prior to fertilisation and the nature of the species determine the sex-ratio. With *L. mysorensis*, monsoon-fed (July to October) brood lac gave ratios ranging between four males to one female and two males to one female. The post-monsoon, or driest season (November to March), gave progeny where there were as many as seven females to one male and as few as two females to one male. The pre-monsoon season (April to July) although hottest, is accompanied with showers of rain. The generation derived from this brood consisted of males and females in equal ratio or sometimes two males to one female.

The rate of mortality was found to vary with sex in different stages and the survival ratio at the time of sexual maturity was different from that at the first settlement of the colony.

With *L. communis*, the monsoon brood gave rise to a preponderance of winged males with very often less than a single female to a hundred males. *L. sindica* behaves very much like *L. communis* and is perhaps grown in areas flooded by the Indus during inundation. It would be interesting to find if other localities where as a rule only one crop per year is collected, also give rise to such a preponderance of males from brood apparently good but swarming after the monsoon season.

The crawling larva is provided with a shield of wax protecting its skin which with growth shows disarrangement. The male grows flat and long like a cockroach, the female shows height increment, grows like a flea and ultimately looks like a miniature pear or a seed. The full-grown first stage larval cell is made of wax pencils enclosed within a cement of lac. The wax pencils of the hind region show an upward direction of growth in the female and also better development. The full-grown first stage female cell is more raised, the back, or plates 3 to 7 most of all, and has a broader posterior region with a central raised ridge and two furrows on either side. The male cell of the same age is longer and flatter, broader across the thoracic region and narrower and longer towards its posterior end (Figs. 1 and 2, Pl. I, Figs. 21 and 22, Pl. VIII). The crawling stage, or very young larva of the male has a flat back, with a more pointed posterior region, and looks like a diagrammatic fish. The female has a central median ridge with its side margins on a lower level and flat. That there is a difference in appearance of the larvæ is shown by Fig. 26, Pl. IX.

Size is not a useful index of sex but has enabled differentiation between full-grown first stage larvæ of winged males and wingless males. The larvæ of winged males of all species of lac insects are very heliotropic and this is possibly true of other scale insects. This property has further assisted the identification of winged male larvæ.

Fig. 28, Pl. X, is attached showing the results of a sex-ratio determination in a mixed colony carried out early enough to avoid all risk of larval mortality; another Fig. 29, Pl. X, more highly enlarged and consisting of far more males in the first larval stage, is reproduced for the sake of contrast.

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KEY TO PLATE MARKINGS.

a. r. h. Anal ring hairs.

b. w. Body wall. The margin of the actual body of the larva.

b. o. Brachial opening. Opening in the lac cell where the brachial plate is free from lac exudation and from which region filaments of [illegible] wax arise.

b. p. Brachial plate.

c. Canella. Pores which exude wax within the coat of lac and associated with the spiracular [illegible].

cr. m. Crawling larval margin. The crawling larva is protected with a dorsal shield of wax and a thin membrane [illegible] either mouldable lac. The latter corresponds to the shape of the larva; with growth the skin dilates and the original shields of wax and membranes may be still attached to the dorsal surface.

c. t. Canella tract. Just as the brachial plate finds an external expression in the brachial opening the canella in the earlier stages of growth is seen like a cleft in the lac cell.

d. s. Dorsal shield. The dorsal shield of wax is divisible into eleven segments, the most anterior being marked No. 1, while the nearest to the anal end is designated as No. 11. Each plate has a thick central portion with thin flat marginal ends [illegible] as 5a, 6a, &c.

f. s. m. First stage margin. Margin of the cell nearing the completion of first stage.

g. l. Globule of lac. Lac acts as cement filling the structure formed by the skeleton of wax pencils. Sometimes it exudes in the form of globules or drops, very often indicating the spot where a wax pencil is situated.

m. a. h. Major apical hairs.

p. f. s. Proboscis of first stage larva which accompanied the crawling larva.

p. s. s. Proboscis of the second stage seen in the body of the first stage larva ready for moulting.

w. p. Wax pencils. After fixation wax is secreted from all around the body wall in the form of pencils distinct from one another.

w. f. Wax filaments from brachial plates.

w. pl. Wax plates. On either side of the anal tube is a plate of hard wax giving rigidity to that region of the cell and preventing the exudation of wax from blocking the anal aperture.

Plate I.

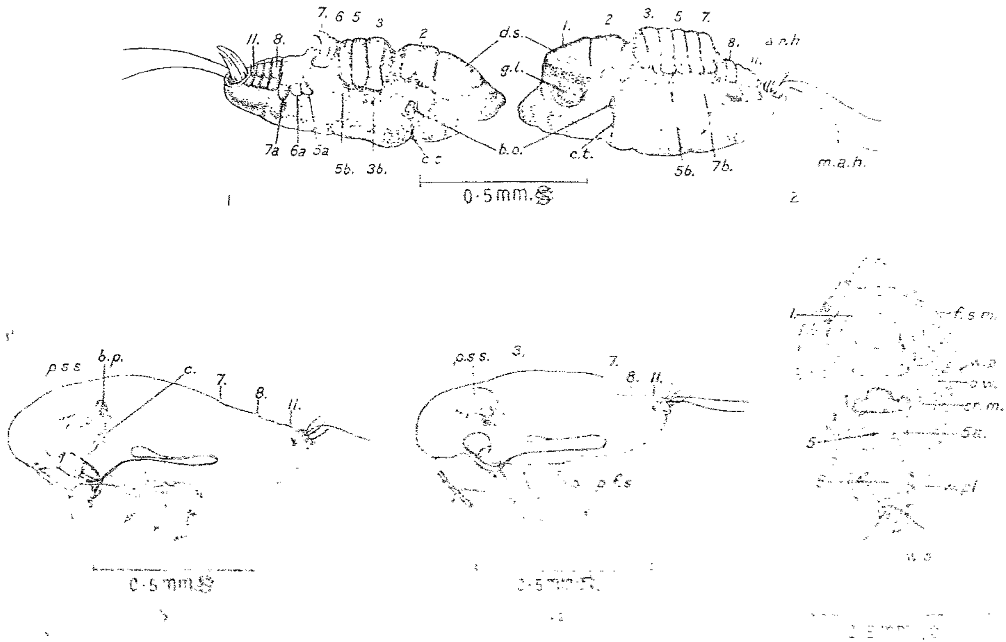

11.
8.
7. 6 5
3
2
7a
6a
5a
5b.
3b.
c.c
d.s.
g.l.
b.o.
1.
2
3.
5
7.
8.
a.n.h
c.t.
5b.
7b.
m.a.h.
0·5mm.
1
2
p.s.s
b.p.
c.
7.
8.
11.
0·5 mm.
p.s.s.
3.
7.
8.
11.
p.f.s
f.s.m.
cr.m.
5a.
5

PLATE I.

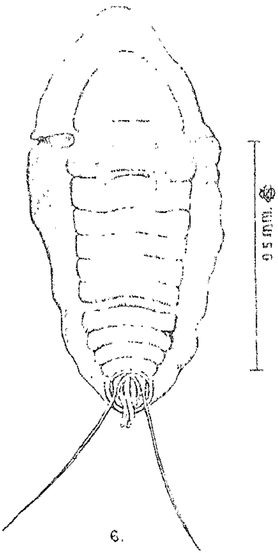
Fig. 1. *Lakshadia mysorensis :* First stage cell of winged male almost ready for moulting, from a colony growing on *Cajanus indicus*, drawn on 25th September, 1923.

Fig. 2. Female cell from the same colony.

Fig. 3. *L. communis :* Body outline of a full grown first stage winged male, after treatment with cold caustic solution, drawn on 18th December, 1923, from a colony growing on *Cajanus indicus* which yielded only winged males. Brachial plate (*b.p.*) in this case, like the proboscis near it (*p.s s.*), belongs to the second stage larval skin seen through the skin of the first stage larva.

Fig. 4. *L. mysorensis :* Body outline of a full grown first stage female growing on *Acacia Farnesiana*, drawn on 12th September, 1923 date of settlement 23rd August, 1923.

Fig. 5. *L. mysorensis :* A full grown female cell after treatment with cold caustic solution which dissolves the lac resin, leaving the skeleton of the wax pencils. Plates of dorsal shield Nos. 1, 5 and 8 are marked. The side of plate 5 is shown as 5a. Wax pencils projecting from body wall are shown as w.p.



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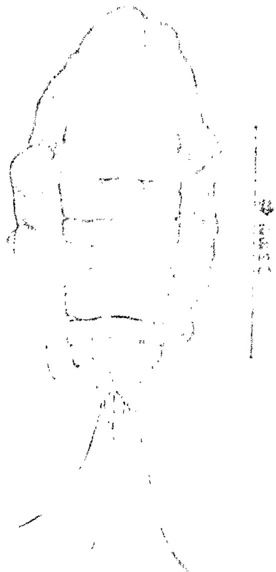
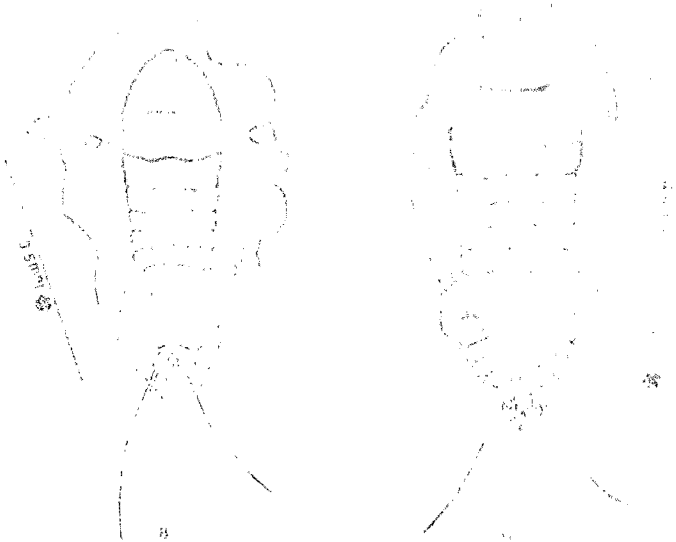


PLATE II.

Fig. 6. *L. communis:* Full grown first stage male cell from a colony growing on *Guazuma tomentosa*, drawn on 28th November, 1922.

Fig. 7. Female cell from above colony.



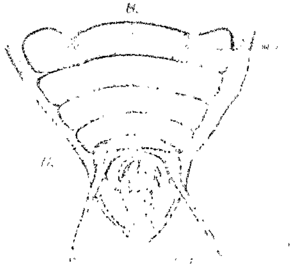
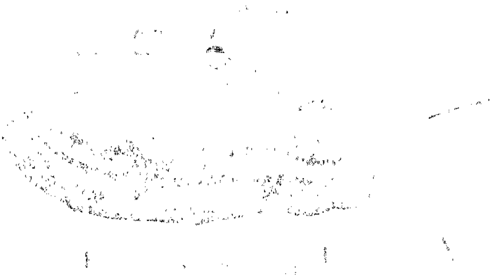


PLATE III.

Figs. 8 and 9. *Lakshadia communis:* Female cells from the same colony as Fig. 6, Plate II. The cell illustrated in Fig. 9 is shown again in Fig. 27.

Fig 10. Anterior portion of female cell (Fig. 9), enlarged to show 6 anal ring hairs and 2 major apical hairs.



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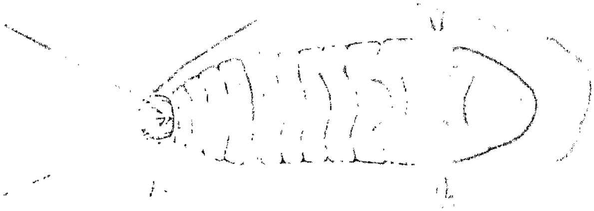

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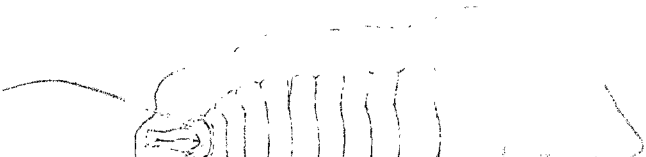
0 5mm.



13.

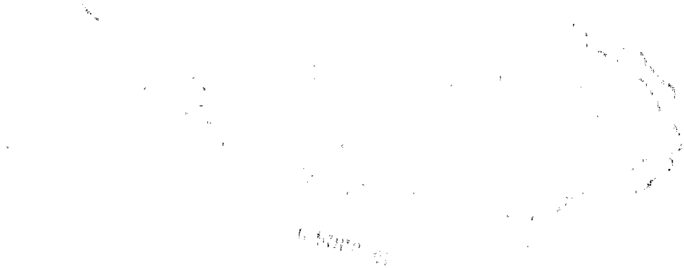
0·5 mm

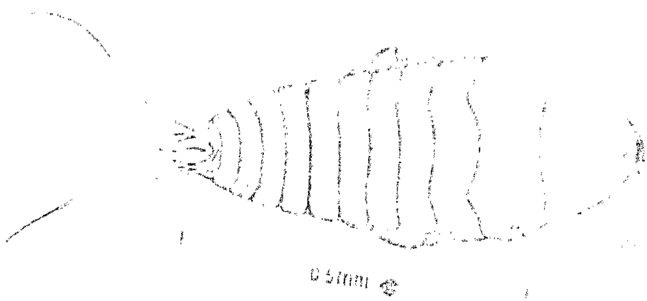
PLATE IV.

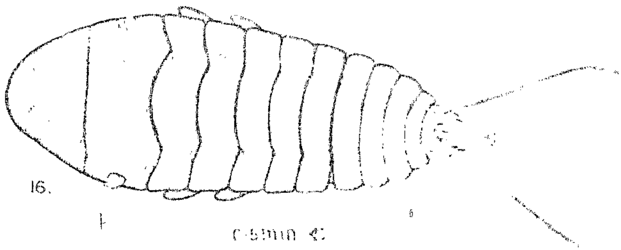
Fig. 11. *L. communis :* Female first stage cell not fully grown, from a colony inoculated on *Cajanus indicus.* Drawn on 8th January, 1923.

Fig. 12. *Lakshadia indica :* Full grown first stage male cells. Brood was obtained from Palamau from *Butea frondosa.* Inoculated on 21st October, 1922, on *Z. jujuba* and drawn on 25th November, 1922.

Fig. 13. *L. indica :* Female cell from the above colony.







16.

PLATE V.

Fig. 14. *L. mysorensis:* Male first stage larva, still incompletely grown from a colony growing on *Shorea talura*, Dorasanipalya representing about 13 days' growth during the favourable monsoon season. Drawn on 17th September, 1921.

Fig. 15. *L. mysorensis* : Male first stage larva from a colony growing on *Cajanus indicus* and drawn on 5th December, 1922, about 10 days after fixation, but on account of the season represents a younger stage of growth than Fig. 14. This specimen is shown again in Fig. 25—the male.

Fig. 16. Female larva of *L. mysorensis* four days old drawn on 29th November, 1922, growing on *Shorea talura*. This is shown again in Fig. 25—female larva.

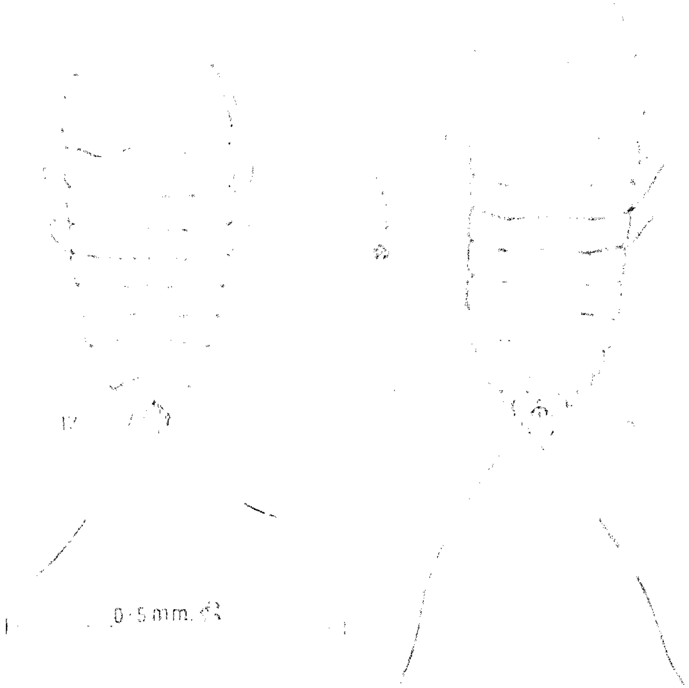

0·5 mm.

PLATE VI.

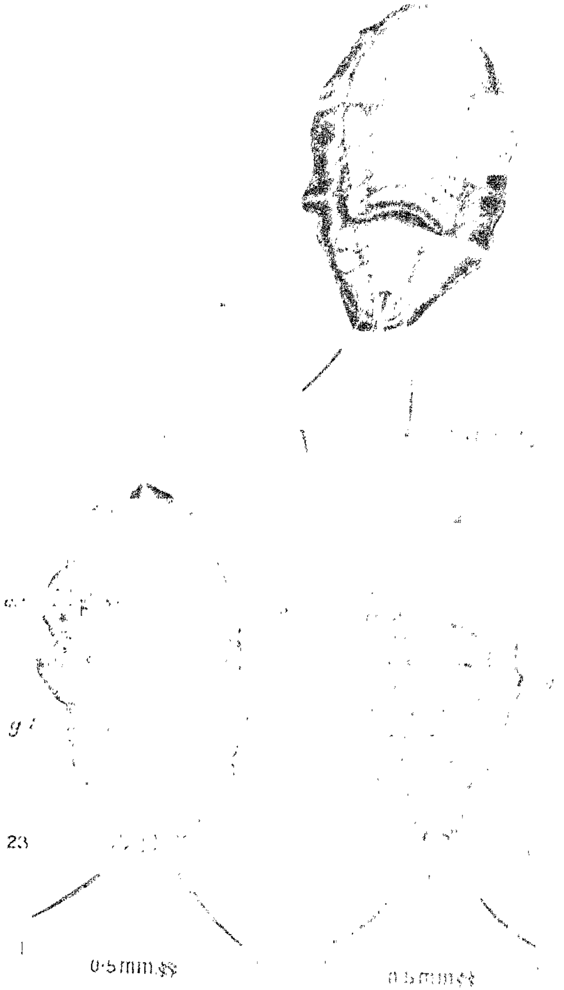
Fig. 17. *L. communis*: Larva first day after fixation, drawn on 25th November, 1923. The rest of the colony all became winged males.

Fig. 18. *L. communis*: Drawn on 12th November, 1922, first day after fixation. The rest of the colony consisted of females and winged and wingless males growing on *Cajanus indicus*. This illustration is a good example of a typical female larva; the broad shape of the anal segments 8 to 11 taken as a whole, together with the raised back, seen here as a backbone-like ridge and due to the thick wax plates of segments 3 to 7, form a good indication of the sex.

PLATE VII.

Fig. 19. *L. mysorensis:* The male has just completed its first moult. From a colony growing on *Shorea talura*, Dorasanipalya. Drawn on 14th November, 1921. The absence of major apical hairs and the tuft of anal ring hairs now consisting of ten, five shown on one side, indicates the passage from the first to the second stage larva. The wax filaments from the brachial plate are shown protruding copiously from one side; they are brushed off from the other to show the shape of the cell in that region with its brachial opening (b.o.) and a white tract of wax (c.t.) secreted from canella pores associated with the spiracular opening.

Fig. 20. *L. mysorensis:* Female at the same stage of metamorphosis as Fig. 19. Drawn on 5th December, 1922. The anal ring hairs are not drawn to show the small opening of the anal aperture which was occupied by six hairs, but after moulting is occupied by ten which together give the appearance of a thick brush.



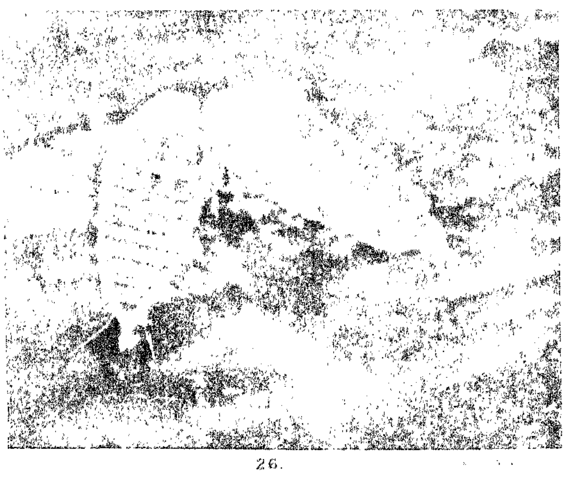
23

PLATE VIII.

Figs. 21 and 22. *L. mysorensis* : A pair of cells of different sexes both of exactly the same age and quite ready for moulting, growing on *Cajanus indicus.* Drawn on 22nd August, 1922. In this species the full grown first stage cell even of the wingless male is larger than the female cell of the same age.

Fig. 23. *L. mysorensis* : Immature female cell from a colony on *Shorea talura* at Dorasanipalya, drawn on 4th November, 1921. Wax plate No. 1 of dorsal shield is seen cracked and is not to be mistaken for two separate plates. This cell represents an unsystematic disarrangement of wax plates but indicates its sex by the parallel sides, the good secretion of lac from the sides, and absence of any lengthening along the major axis.

Fig. 24. *L. mysorensis* : Drawn on 22nd October, 1921, from a colony growing on *Shorea talura* at Dorasanipalya not older than 8 days and possibly slightly younger, bearing close resemblance to a larva just fixed. Its female sex is further indicated by the globule of lac seen arising from its side.



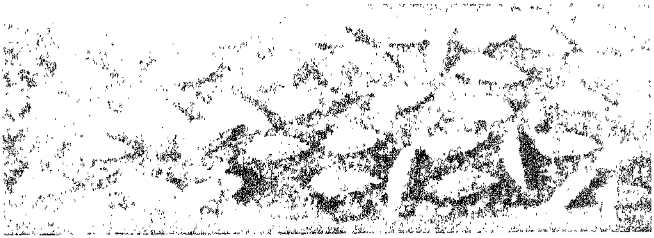
26.

MACROPHOTOGRAPHS, PLATE IX.

Fig. 25. *L.* [illegible] *:* Male and female, the figure to the left being the female, of different ages and from different host-plants and also slightly different in magnification but bearing close resemblance to larvæ just fixed. They are the same as illustrations 15 and 16 ; the macrophotograph is intended primarily to increase the value of the illustrations.

Fig. 26. *Lakshadia mysorensis :* Male (wingless) and female larvæ photographed on the fourth day after fixation on *Cajanus indicus* on 8th December, 1922. They were together as shown here and represent the male, at this stage, as slightly smaller than the female.

Fig. 27. *L. communis :* The same as Fig. 9, Plate III. The conspicuous white spot between segments 7 and 8 is due to a little soft wax having fallen there.



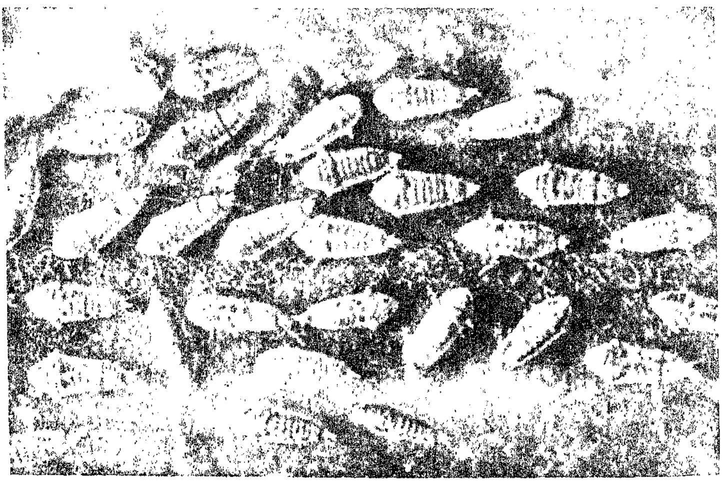


PLATE X.

Fig. 28 An illustration of sex ratio determination in a young colony of *L. mysorensis* showing a majority of female cells. Brood was obtained from Thondebhavi (Kolar Dist.) through the courtesy of Mr. B [illegible] and inoculated on *Cajanus indicus*. Photograph was taken on 5th September, 1923, and represents cells in various stages of growth. Larvae of winged males are shown with two dots and settling across the long axis of the twig towards the direction of light.

Key to fig. 28.

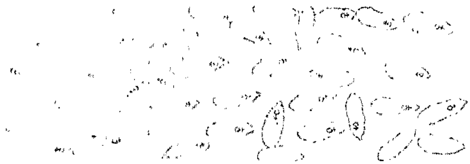


Fig. 29. A sex ratio detrimental to propagation. Brood of *L. mysorensis* from *Shorea talura* obtained from Dorasanipalya and inoculated on *Cajanus indicus* on 4th November, 1922. The photograph was taken on 24th November, 1922. This portion of the colony showed no sign of mortality, but, on account of the season, poor rate of development This illustration is on a much greater scale of magnification than the previous one It will be noted that brood, as in this case, derived from the monsoon season consists of very many males, while the generation developing during the monsoons, but derived from the pre-monsoon crop, as in the former illustration, consists of more females.

Key to fig. 29.