CHAPTER 1
LIFE HISTORY AND SEXUAL DIMORPHISM

1. INTRODUCTION

The life history of Oryctes rhinoceros has been worked out by Friederichs and Demandt (1922), Cherian and Ananthanarayanan (1939), Gressitt (1953), Nirula (1955a), Goonewardena (1958), Kurian and Pillai (1964), Catley (1969) and Bedford (1976a). It is quite evident from their reports that the size as well as duration of the immature stages is liable to enormous variation according to the changes in its environment. Temperature, atmospheric humidity, moisture content of the breeding medium, nature and quantity of the available food etc. play a vital role in the development of the larvae (Kurian and Pillai, 1964; Nirula, 1955a). Climatic and nutritional conditions can affect larval duration and adult size (Catley, 1969). Duration of egg stage is affected by temperature (Nirula, 1955a). Hence it was felt desirable to study the life history of this beetle under the conditions prevailing in our laboratory to plan the experiments under the ambient conditions.

The adults of O. rhinoceros exhibit considerable variation in body size, length ranging from about 3.5 cm to 5 cm (Nirula, 1955a; Kurian and Pillai, 1964). Preliminary
studies on the reproductive behaviour of this insect have indicated that body size is a factor that can affect several aspects of reproductive behaviour; hence it has also become necessary to have an idea regarding the size range of individuals that can be obtained from laboratory rearing under specified conditions. Besides, complete data on the bionomic changes occurring during the metamorphosis of this insect has not been given by any of the authors. Hence some data on the bionomics of the life stages has also been incorporated in this chapter.

Hurpin (1953), Menees (1957) and Elliott (1964) have described an organ - the so-called 'organ of Herold' - as located on the penultimate abdominal sternite in the male larvae of some scarabaeids. Bedford (1974) has also referred to the organ of Herold present on the ventral side of the 9th abdominal segment in some of the third instar larvae of Oxycanus rhinoceros as indicative of male sex. However no further details are available regarding this apparatus of Oxycanus rhinoceros. Studies have hence been carried out to understand the structure and fate of this larval sexual characteristic.

During certain phases of the present research work sexing the animals in the pupal stage had become necessary and since no method of sexing was available attempt was made to meet that purpose, the result of which has also been
reported in this chapter.

That the adult beetles exhibit sexual dimorphism is quite well-known with the popular contention that the horn of the males is longer than that of the females. Thus Nirula (1955a) and Kurian and Pillai (1964) state that the males can be distinguished from the females by the size of the horn. However according to O'Connor (1953), "the horn can be either short and triangular, or long and curved. Often the female has a short horn and the males a long one, but this characteristic varies considerably, male being found with a typical female horn and vice-versa". Monty (1978) has also stated that "the horn of the female insect is generally very small, but even in a male the horn can be small so that it is not a reliable characteristic" for sex determination. However, no author has studied the horn size in relation to the body size of this insect. Hence this relation has been worked out and discussed in the present chapter.

Moreover, attempts that have been made to disclose other elements of sexual dimorphism, if any, of the adults have culminated in the discovery of a new secondary sexual characteristic pertaining to the metathoracic tarsi, the details of which are also dealt with in this chapter.
2. MATERIALS AND METHODS

2.1. Rearing of animals

The present account on the life history and bionomics of O. rhinoceros is based on ten animals in which the whole process of metamorphosis, from egg to adult, has been pursued in the laboratory under conditions of 23-32°C, 75-90% relative humidity and approximately 12:12 photoperiod.

Eggs were obtained from mated female beetles confined individually in glass jars 8.5 cm diameter and 18.5 cm height having perforated lid and one fourth filled with fine steam-sterilized cowdung. The cowdung was kept moist by periodical sprinkling of water and was analysed daily for the presence of eggs. Freshly laid eggs were transferred individually into similar glass jars (8.5 cm diameter x 18.5 cm height) containing sterilized cowdung as the rearing medium; the eggs were covered by the medium 3 cm below the surface and close to the glass wall to facilitate observation. The development was followed daily, and whenever necessary, the measurements of life stages were taken by removing them out of the medium carefully. Once the egg hatched the dung was replaced by a fresh lot at 5-day intervals until cocoon formation was initiated. Once cocoon
was completed, a small part of it was broken off from its top so as to make a small window through which the different stages could be taken out for measuring; it also enabled one to observe the metamorphic changes taking place within.

2.2. Larval sexing and organ of Herold (OH)

Twenty mature field-collected third instar larvae showing dense accumulation of fat body were divided into two groups on the basis of the presence or absence of the OH, a dark externally visible 'V' shaped mark present on the middle of the 9th abdominal sternite. They were allowed to complete metamorphosis and the sex of the adults developed from each group was noticed, to determine the role of OH on larval sexing.

The OH-region of the exuvia cast off by the larvae during ec dyses was examined under a binocular microscope.

The 9th (penultimate) abdominal sternite of a large number of individuals of various instars from first instar to late prepupa raised in the laboratory was examined carefully under a binocular dissection microscope, to locate and identify the OH if possible.

Dissection

The structural details of the OH were further studied after dissecting out the organ from mature third
instar larvae under Insect Ringer (Sodium chloride (NaCl) 7.5 g; Potassium chloride (KCl) - 0.35 g; Calcium chloride (CaCl$_2$) - 0.210 g; Distilled water - 1000 ml) and observing it under a dissection microscope.

The fate of the OH was studied by extirpation and implantation experiments.

**Extirpation of organ of Herold**

For extirpation of OH, three-month-old third instar larvae, raised in the laboratory from field-collected first or second instar larvae as described under 2.1, were first cleaned thoroughly with water and alcohol-soaked cotton. They were then held under a binocular dissection microscope without anaesthesia and a small oblique cut was made close and parallel to one side of the organ with the help of a clean sharp blade. The OH was then pulled out gently through this opening and its connection with the cuticle was detached using fine sterilized forceps. This operation was performed on ten individuals. For sham-operated controls, the cuts were made likewise but the OH were not removed. The operated larvae were kept singly in clean sterilized glass jars (6.5 cm diameter x 13 cm height) for two days for the wounds to heal. They were then left over sterilized cow dung, which was replenished at 5-day intervals, for feeding and subsequent metamorphosis.
Implantation of organ of Herold

For implantation, the OH dissected out as above was kept in Insect Ringer. It was then implanted immediately into a female larva of same age, without anaesthesia, through a small transverse slit made on the 9th abdominal sternite a little above the centre so that the implant could be adjusted to occupy a position corresponding to that of the OH in the male. For sham-operated controls, a small piece of larval cuticle extirpated from the 9th abdominal sternite of male larvae of same age was implanted instead of the OH. All the operated animals were maintained as described above for extirpation experiments.

Apart from the sham-operated controls, five normal larvae of either sexes were also maintained similarly for comparison.

Secondary sexual characteristics of the pupae as well as of the adults developed from the larvae were examined. Twenty days after adult emergence they were dissected out and their reproductive system examined.

2.3. Pupal sexing

Twenty pupae, raised in the laboratory from field-collected larvae as described above, were screened thoroughly under a binocular dissection microscope while
alive, with the purpose of detecting consistent morphological difference, if any, between individuals.

The two kinds of pupae, as could be differentiated on the basis of various morphological differences on the ventral side of their abdominal extremity were allowed to complete metamorphosis and the sex of the adults emerging out from each kind was noticed.

2.4. Adult sexing

The whole body of a large number of male and female beetles was examined carefully under a binocular dissection microscope after anaesthetising with ether. Since the antennae, palpi and other appendages showed a tendency to loose their segments to varying degrees with ageing and mutual interaction, fresh 5-day-old beetles were used for this purpose.

In order to study the details of tarsal segments, the first and second segments of the tarsi of the metathoracic leg were cut and removed from ten male and ten female beetles of 40 mm length, and examined carefully under a binocular dissection microscope. The number of hairs present along the inner margin of these two segments were counted.
Morphometric studies

The linear distance from the front of the base of the horn to the tip of the abdomen was measured. This was taken as the length, indicative of the size of the beetle.

Horn length of the beetles belonging to 14 size groups ranging from 30 mm to 43 mm with 1 mm difference was also measured. Beetles of required body sizes were selected from the laboratory stock culture. Horn length of at least 10 individuals of each group was measured. Sex of the individuals was also noted.

Body size of adult beetles of either sexes from the following three kinds of populations was measured to test whether body size was a sexually dimorphic character:

(a) A population of beetles raised in the laboratory from first instar larvae collected from a dung heap on the same day.

(b) A population of beetles collected from the same coconut plantation on the same day.

(c) A miscellaneous population of beetles obtained from different field-sources at different times.

2.5 Statistical analysis

The data were analysed using 't' test.
3. OBSERVATIONS

3.1. Life history and bionomics of *O. rhinoceros*

Figures 3-10 (Plate 2) show the various stages from egg to adult in the life cycle of *O. rhinoceros*.

**The egg (Fig. 3)**

The freshly laid eggs were white, opaque, and oblong measuring a mean of 2.8 mm in length (range 2.3 mm - 3.5 mm) and 1.5 mm in breadth (range 1.3 mm - 2 mm). It took a mean of 12 days (range 10-26 days) for hatching. At the time of hatching the eggs were 3.8 mm in mean length (range 3.3 mm - 4 mm) and 3 mm in mean breadth (range 2.8 mm - 3.3 mm) with perfect oval shape and a dirty brown colouration.

**The larvae (Figs. 4-7)**

There were three larval instars in the life cycle. At the time of hatching all the larval instars appeared as spongy, delicate, and white, including the head capsule. Within the first few hours the head capsule turned yellowish brown, and then gradually, over days, to reddish brown and deep brown, with progressive hardening. With the commencement of feeding, which generally occurred within a day after the emergence of each instar, the body attained an
ashy grey colouration owing to the food engulfed.

**First instar larva (Fig.4)**

The newly emerged first instar larva had a mean length of 7 mm (range 6.5 mm - 7.8 mm) and a mean breadth of 2.97 mm (range 2.7 mm - 3.4 mm), with a head capsule width of 2.95 mm (range 2.8 mm - 3.3 mm). This instar lasted for a mean period of 12.8 days (range 11 - 15 days) towards the end of which it acquired a mean length of 28.1 mm (range 26 mm - 30 mm) and a mean breadth of 5.88 mm (range 5.5 mm - 6.6 mm).

**Second instar larva (Fig.5)**

The fresh second instar larvae measured a mean of 29 mm in length (range 28 mm - 30 mm) and 6.48 mm in breadth (range 6.2 mm - 6.7 mm). Its head capsule had a mean width of 6.5 mm (range 6.3 mm - 6.6 mm). This instar had a mean duration of 15.6 days (range 13-18 days). Just before moulting into the third instar it had a mean length of 42.8 mm (range 38 mm - 47 mm) and a mean width of 12.8 mm (range 12 mm - 13 mm).

**Third instar larva (Figs.6&7)**

This instar, which was also the last larval instar, measured a mean of 44 mm in length (range 40 mm - 48
mm) and 10.76 mm in breadth (range 10 mm - 11.4 mm) in the beginning. It had a head capsule of 10.6 mm mean width (range 10 mm - 11 mm).

The third instar larvae were capable of consuming large quantities of food within a short span of time. The voraciousness of their feeding activity was reflected in the fast rate of accumulation of fecal pellets in the medium. This instar was a highly prolonged stage, its duration showing great individual variation - the mean duration being 103.8 days, ranging from 61 to 148 days. Towards the end of this period, when it began to form the cocoons, the larva attained a mean length of 79 mm (range 68 mm - 89 mm) and a mean breadth of 19.8 mm (range 17 mm - 22 mm).

Cocoon formation

The full grown larva at the end of the third instar was creamy white in colour owing to the massive accumulation of fat body. Now the larva ceased to feed and restricted itself to a selected site within the medium, generally towards its bottom, where it had to form a cocoon out of the medium. In making the cocoon the larva pressed its body against the medium that surrounded it by a kind of rotatory movement of the whole body. As a result the medium comprising the cocoon wall got compacted leaving a spacious room within, around the animal. The inner wall of the cocoon
thus formed was further polished by rubbing the back of its body against the surface. A black fluid fecal matter and a secretion discharged through the mouth functioned as cementing substances. It took 8-12 days for cocoon formation. The fully formed cocoon did not have any connection to the outside. The cocoon was usually formed with the glass surface of the jar constituting a part of it, thus enabling one to witness the metamorphic changes taking place within.

Prepupa (Fig.8)

By the time cocoon was fully formed the larva had already begun its transformation into the prepupa. The first visible sign of the prepupal transformation was the appearance of wrinkles on the dorsal side of the penultimate segment. It occurred about 5-9 days after the beginning of cocoon formation. Most of the time, and invariably if disturbed, it exhibited a characteristic writhing movement. The prepupa had a dirty cream colour but with the nearing of pupation it became brownish due to the pharate pupa within. At this stage the prepupa measured a mean of 54 mm in length (range 49 mm - 62 mm) and 18 mm in breadth (range 15 mm - 21 mm).

The prepupal stage lasted for a mean of 9.4 days (range 8-11 days). At the end of this period the writhing
movements became vigorous and it underwent moult resulting in a pupa. The prepupal exuvia remained close to the pupa for many days before gradually getting absorbed into the medium.

Pupa (Fig. 9)

The pupa was initially white. Gradually it turned brown and by the end of the pupal period became dark brown. It had a mean length of 43 mm (range 34 mm - 51 mm) and a breadth of 21 mm (range 17 mm - 25 mm). It had a mean duration of 18.8 days (range 16-21 days). At the end of this period the adult emerged out of the pupa by the final moult.

Even at the time of emergence from the pupal case the adult had its head, prothorax and appendages rather hard and tanned brown. However, the rest of the body - including the forewings (elytra), hind wings, meso-metathoracic and abdominal regions - were delicate, and white in colour except the posterior margins of the sternites which revealed an orange colouration in the very beginning. The hind wings were in a fully extended condition beneath the locked-up elytra; within 2-3 hours they got neatly folded up beneath the elytra in a gradual stepwise manner. The intromittent organ also remained protruded out for some time, to be retracted gradually during the first few hours.

The parts of the body which remained colourless at
emergence soon got tanned, and within about 2-3 hours attained an yellowish orange colouration which then changed gradually to brown.

The adult (Fig.10) remained within the cocoon for a mean period of 6.8 days (range 4-9 days) after which it came out rupturing the cocoon. At that time it had a shining body with a uniform brown colouration. It had a mean body length of 38 mm (range 30 mm - 46 mm) and a breadth of 19 mm (range 16 mm - 23 mm) (Fig.11, Pl.2 depicts the great variation in body size between individuals). The beetles came to attain the final black colouration only after a long period of about two months. With ageing, body surface became coarser.

The dimensions and duration of various stages are given in Table 1.

3.2. Organ of Herold (Fig.12a,Pl.3; Fig.19a,Pl.4)

All the larvae which possessed the OH (see Fig.12a, Pl.3) (12 larvae out of the 20) developed into male beetles while the rest of the larvae without the OH (Fig.12b, Pl.3) developed into female beetles.

Structure of organ of Herold (Fig.20, Pl.4)

In the mature male third instar larvae of
O. rhinoceros the OH was quite easily detectable, even with unaided eye, as a conspicuous dark 'V' shaped mark containing within it a dark brown triangular chitinous plate-like structure, the whole embedded against the contrasting background of the dense mass of white fat body, and visible externally through the transparent cuticle on the ventral side of the 9th abdominal segment, at about its middle. Upon dissection the dark mark of the OH appeared as a translucent bag-like structure containing the triangular chitinous plate (CP) within (Fig.20, Pl.4). The bag had a pair of tubular antero-lateral arms (ALA) and a short stem with which it was attached to the cuticle. Arising distally from each arm was a pair of long thin translucent cords. Being extremely delicate and likely to be confused with the tracheoles, it was difficult to trace them fully. However it was observed that each of the outer distal cords (ODC) ended into the testis of its side while the inner distal cords (IDC) fused with the ventral nerve cord at the region of the 9th abdominal ganglion.

The OH was detectable even in the first instar larva though upto about 5-day old second instar it was represented only by a minute scar, visible only under high magnification and optimum illumination conditions; from about the mid-second instar (7-day old) onwards it became detectable even without the help of a magnifier. Then
onwards and until the larvae began to accumulate fatbody, i.e., upto about three week old third instar, it was the chitinous part of the OH that appeared more distinct, the outer bag-like portion remaining rather invisible. However, with growth of fatbody the outer bag became more prominent.

In the freshly emerged second and third instar larvae the chitinous plate of the OH appeared as white opaque triangular patch.

The OH was detectable in the prepupal stage also, though less conspicuously, due to the shrinkage of cuticle.

An examination of the exuvia shed by the prepupa revealed that the chitinous plate of the OH was also shed along with the old cuticle; the ecdysial furrow stopped just in front of the OH, rendering the OH-area of the exuvia intact for examination.

**Tracheal disposition in relation to the OH (Figs.19a&b,P1.4)**

Another externally visible sexually dimorphic characteristic concurrent with the presence of the OH also become apparent during these studies. In the male larvae, some of the tracheal branches adhering to the ventral wall of the 9th abdominal segment on either side converged towards the OH, describing a conspicuous 'V' shaped configuration (Fig.19a,P1.4). In the females the tracheal branches, though present, did not show such confluence,
hence the characteristic 'V' pattern was absent (Fig.19b, Pl.4).

Unlike the OH, the tracheal branches grew less prominent with the growth of fat body. Hence this character was not diagnostic of the sex in larvae beyond the age of about 2 week old third instar, but it was a definite criterion for sexing the first and early second instars during which the OH remained less prominent.

Fate of the organ of Herold

Adult beetles developed from the normal and sham-operated male control larvae of OH-extirpation experiment revealed a fully developed male reproductive system consisting of the paired testes, vasa efferentia, vasa deferentia, ejaculatory duct, a pair of accessory glands and the phallus (see Fig.26, Pl.5 for normal male reproductive system). However in the beetles developed from the OH-extirpated larvae the reproductive system developed incompletely and consisted only of the testes, vasa efferentia and varying lengths of the vasa deferentia; the rest of the system, namely, the ejaculatory duct, accessory glands and the phallus were absent. A marked degree of individual variation was also observed with respect to the length of the vasa deferentia developed in them.

The beetles developed from the OH-extirpated
larvae exhibited bare round pygidium as in the normal male.

Majority of the OH-implanted female larvae (8 out of 10) did not show any development of the implant; they developed into perfectly normal female adults like the normal and sham-operated female control larvae. However, there was a single instance in which considerable degree of development of the implant could be observed. Thus one of the implanted larvae developed into a female adult with an easily distinguishable partially developed male external genitalia hanging outside the body through the genital aperture (Fig. 21, Pl. 4). The male component revealed a soft and hollow phallus contrary to the normal hard and rather solid one, and having parts corresponding to the basal piece (BP) and distal ring-like segment (RS) of normal phallus (see Fig. 27, Pl. 5 for normal phallus). However the basal piece was bulbous unlike the normal tubular one and the distal segment was straight instead of being inclined to the rest as in normal ones, but with its tip bifurcated as in the normal. The rest of the system was rather indistinguishable, being represented by a dried up strand of tissue (DS) with its distal end showing a funnel like expansion that remained attached to the vaginal floor (VF). A similar strand of dried up tissue was also seen projecting out through the aedeagal tip. In all other respects it was a normal female with a bushy and conical pygidium.
One of the OH-implanted larvae developed only up to the pupal stage and then died; hence the development of the implant could not be followed.

3.3. Sexual dimorphism in the pupa
(Figs.13a&b,Pl.3; Figs.22a&b,Pl.4)

A thorough screening of pupae under the binocular dissection microscope revealed that they could be differentiated easily into two categories on the basis of certain morphological differences visible on the ventral side of their abdominal extremity. In the first category the last two abdominal sternites, namely the 9th and 10th, could be distinguished as separate (Fig.13a,Pl.3; Fig.22a,Pl.4). Also, the 9th sternite carried towards its posterior end a slightly elevated and rather oblong median zone with an indentation (IND) at its hind end (Fig.22a,Pl.4). All the pupae which showed these characteristics developed into male beetles. In the pharate adults which were remaining within the pupal cases the aedeagal tips could be seen as being protruded out, with the tip remaining attached to the site of indentation. Evidently, the pupal indentation corresponded to the genital opening of the male.

In the second category, instead of the separate 9th and 10th sternites, the pupae revealed only a single fused sternite. This last abdominal sternite possessed
anteriorly a pair of rounded and slightly convex lobes, the right and left lobes, bearing in between, and immediately behind the 8th sternite, a small well-marked shining area carrying a minute slit-like depression (DE) at its middle (Fig.13b,Pl.3; Fig.22b,Pl.4). All such pupae gave rise to female beetles and it was found that in the pharate adult stage the shiny area of the pupa was overlying a conical tuft of long hairs bordering the anterior margin of the adult genital opening and that the depression corresponded to the genital opening of the female.

The pupal exuvia discarded during adult emergence preserved their genital sternites rather intact as the ecdysial furrow did not extend up to that region; hence an examination of the exuvia could also disclose the sex.

Secondary sexual characteristics of the pupae developed from OH-extirpated and OH-implanted larvae (Figs.23&24,Pl.4)

The pupae developed from the OH-extirpated larvae lost their typical male appearance. Instead, they revealed a so-called "pseudofemale" appearance in which the 9th abdominal sternite was divided into right and left lobes by a vertical cleft as in the females, and a 10th sternite was invisible. However the shiny area with depression found in the female was absent (Fig.23,Pl.4).

The normal and sham-operated control larvae of the
OH-extirpation experiment gave rise to pupae with normal male secondary sexual characteristics.

The genital area of the one exceptional pupa developed from the OH-implanted larva which later developed into the female with male genital parts revealed a predominantly male appearance (Fig.24,Pl.4). In addition to the normal female characteristics it also showed a prominent median elevated area as in a male, but without indentation.

One more pupa, developed from OH-implanted larva but died without further metamorphosis also was found to exhibit these characteristics, which could be described as "mixed-sex" characteristics (Fig.24,Pl.4). The pupae from all other OH-implanted larvae and from the normal and sham-operated control larvae of the OH-implantation experiment showed the normal female secondary sexual characteristics.

3.4. Sexual dimorphism in the adult

Metathoracic tarsi (Figs.15-18,Pl.3)

A careful screening of the whole body of *O. rhinoceros* under a binocular dissection microscope disclosed a highly prominent sexually dimorphic morphological characteristic associated with the metathoracic tarsi. The first tarsal segment from the metathoracic leg of either sexes possessed a dense comb of
long slightly curved hairs arranged along its inner margin, clearly visible even to unaided eye (Figs.15-18, Pl.3). This hairy fringe (HF) with its hairs slightly overlapping, did not reveal any noticeable difference between the sexes. Thus the hairy fringe of male beetles of 40mm body length possessed a mean of 31.7 (SD = 1.6) hairs (n = 10; range 29-34) while the females of same length had a mean of 31.5 (SD = 1.9) hairs (n = 10; range 30-36), the difference between the sexes was not significant ('t' = 0.2480; P > 0.10). The length of these hairs also appeared similar in both sexes.

However the second tarsal segment also carried a fringe of hairs (HF) in both sexes, and this disclosed pronounced differences between the sexes. In the females the fringe of hairs in the second segment was prominent so as to be detected easily with unaided eye (Figs.16&18, Pl.3) whereas in the case of the males these hairs were poorly developed (Fig.15&17, Pl.3) and was very difficult to detect them without a magnifying lens. In the females the hairs in the second tarsal segment were greater in number and longer than in the males (see Figs.17&18, Pl.3). Thus there were a mean of 13.7 (SD = 1.15) hairs (n = 10; range 12-16) in the second fringe of the female beetles of 40 mm length, as opposed to a mean of only 7.5 (SD = 1.17) hairs (n = 10; range 6-9) in the male beetles of same length. This difference between the sexes was highly significant also
('t' = 11.877; P < 0.001). The hairy fringe of the first segment being identical in both sexes, the relative differences between the fringes of the first and second segments with regards to the number and length of the hairs was much more pronounced in the case of the males than in the females. The relative height of the second fringe in relation to the height of the first fringe presented the easiest diagnostic characteristic pertaining to the hind tarsi. Thus in the case of the females the level of the fringe in the second segment reached almost as far as the level of the fringe in the first segment (Fig.18, Pl.3) while in the males the level of the second fringe reached about half the level of the fringe in the first segment (Fig.17, Pl.3). When compared to the difference in the number of hairs in the second segment between the sexes, difference in the relative height of the second fringe with respect to the first fringe between the sexes was the most easily discernible characteristic as it could be realized without any counting or measuring, by simple visual observation, even without magnification, by holding the tarsi, against light.

**Relationship between horn size and body size**

Male beetles ranging in length from 30mm to 43mm possessed horns varying in length from 2.9mm to 12mm whereas
the female beetles belonging to the same range of length revealed a much narrow range for their horn length, from 2.4mm to 7.8mm (Table 2). There was thus a considerable degree of overlap in horn size between the sexes (Fig.25, page 40). Statistical analysis revealed that there was no significant difference in horn length between the sexes ('t' = 1.9713; P > 0.05). Further analysis of the data showed that the horn length exhibited the phenomenon of allometric growth in both sexes, that is, not only that there was an increase in absolute length of the horn with the increase in body length, but there was an increase in its relative length (i.e., in relation to body length) also (Table 2). Thus the horn length: body length ratio (HL:BL) was only 0.08 in the 30mm females while it reached to a much higher value of 0.18 in 43 mm females. Similarly in the case of the males the HL:BL ratio was 0.096 in the 30mm males and 0.279 in 43 mm males. Like the horn length, the HL:BL ratio also overlapped between the sexes, but to a much lesser extent. It was also quite obvious that for any given length of the body, the HL:BL ratio was greater in the males than in the females (see Fig.14a&b, Pl.3). Thus the mean HL:BL ratio was 0.1709 (SD = 0.0606) for the males while it was only 0.123 (SD = 0.0335) for the females. This difference in HL:BL ratio between the sexes was found to be statistically significant also ('t' = 2.550; P < 0.05).
Analysis of the data also revealed that for every 1mm increase in body length from 30mm, the horn length increased by a mean of 0.7mm in the case of the males, and by a mean of 0.42 mm in the case of the females.

Adult body size

The male beetles among the population of laboratory-emerged beetles revealed a mean body length of 36.9 mm (n = 14; range 32-43mm) whereas in the females it was 36.7 mm (n = 14; range 31-44mm). The difference in body length between the sexes was not significant statistically ('t' = 0.15746; P > 0.10).

The male beetles collected from the coconut plantation had a mean body length of 34.9 mm (n = 40; range 28-42mm) while the females were of a mean length of 36.3mm (n = 30; range 31-44mm). This difference in size was not significant ('t' = 1.8523; P > 0.05).

In the population consisting of heterogeneous field-collected beetles the males revealed a mean length of 40.6 mm (n = 10; range 38-45 mm) and the females, 41 mm (n = 5; range 37-45 mm); this difference between the sexes was not significant ('t' = 1.1834; P > 0.10).

The body length of the beetles from the 3 populations are given in Table 3.
Table 1. Size and duration of the instars of *O. rhinoceros*

(Each measurement represents the Mean + Standard Deviation of 10 animals)

<table>
<thead>
<tr>
<th>Stage of the animal</th>
<th>Size (in mm) at the beginning of the instar*</th>
<th>Size (in mm) at the end of the instar**</th>
<th>Width of Head capsule (mm)</th>
<th>Duration of the instar (day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egg</td>
<td>2.80± 1.50± 0.410 0.278 0.205 0.163</td>
<td>3.80± 3.00± 0.205 0.163</td>
<td>12.00± 4.966</td>
<td></td>
</tr>
<tr>
<td>First Instar</td>
<td>7.00± 2.97± 0.457 0.211 1.449 0.339 0.171</td>
<td>28.10± 5.88± 1.449 0.339 0.171</td>
<td>12.80± 1.398</td>
<td></td>
</tr>
<tr>
<td>Second Instar</td>
<td>29.00± 6.48± 0.942 0.147 2.820 0.421 0.105</td>
<td>42.80± 12.80± 2.820 0.421 0.105</td>
<td>15.60± 1.837</td>
<td></td>
</tr>
<tr>
<td>Third Instar</td>
<td>44.00± 10.76± 2.708 0.397 7.702 1.988 0.339</td>
<td>79.00± 19.80± 7.702 1.988 0.339</td>
<td>103.80± 27.903</td>
<td></td>
</tr>
<tr>
<td>Prepupa</td>
<td>54.00± 18.00± 5.011 2.309</td>
<td>9.40± 1.349</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pupa</td>
<td>43.00± 21.00± 6.306 2.943</td>
<td>18.80± 1.619</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adult</td>
<td>38.00± 19.00± 5.676 2.666</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Measured at the age of one day
** Measured just before entering into the next stage
Table 2. Correlation between horn size and body size in the males and females of *Q. rhinoceros*

<table>
<thead>
<tr>
<th>Body length (mm)</th>
<th>Horn length* (mm)</th>
<th>Horn length/Body length (HL/BL)</th>
<th>'t' value with level of significance P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>30</td>
<td>2.9</td>
<td>2.4</td>
<td>0.0960</td>
</tr>
<tr>
<td>31</td>
<td>3.2</td>
<td>2.7</td>
<td>0.1030</td>
</tr>
<tr>
<td>32</td>
<td>3.6</td>
<td>2.9</td>
<td>0.1125</td>
</tr>
<tr>
<td>33</td>
<td>3.9</td>
<td>3.1</td>
<td>0.1181</td>
</tr>
<tr>
<td>34</td>
<td>4.3</td>
<td>3.3</td>
<td>0.1264</td>
</tr>
<tr>
<td>35</td>
<td>4.8</td>
<td>3.7</td>
<td>0.1371</td>
</tr>
<tr>
<td>36</td>
<td>5.4</td>
<td>4.1</td>
<td>0.1500</td>
</tr>
<tr>
<td>37</td>
<td>6.1</td>
<td>4.6</td>
<td>0.1640</td>
</tr>
<tr>
<td>38</td>
<td>7.0</td>
<td>5.0</td>
<td>0.1842</td>
</tr>
<tr>
<td>39</td>
<td>8.0</td>
<td>5.6</td>
<td>0.2050</td>
</tr>
<tr>
<td>40</td>
<td>8.9</td>
<td>6.1</td>
<td>0.2225</td>
</tr>
<tr>
<td>41</td>
<td>9.8</td>
<td>6.6</td>
<td>0.2390</td>
</tr>
<tr>
<td>42</td>
<td>10.8</td>
<td>7.2</td>
<td>0.2570</td>
</tr>
<tr>
<td>43</td>
<td>12.0</td>
<td>7.8</td>
<td>0.2790</td>
</tr>
</tbody>
</table>

Mean HL/BL 0.1709 0.1238

* Mean of the horn length from five individuals
** Not significant
*** Significant at 5% level
<table>
<thead>
<tr>
<th>Serial No. of population</th>
<th>Details of the population</th>
<th>Sex</th>
<th>Body length (mm) (Mean+S.D)</th>
<th>'t' value for body length between the male and female with level of significance P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Laboratory-emerged Male</td>
<td>36.920+</td>
<td>(14)*</td>
<td>t = 0.15746** Ps &gt; 0.10</td>
</tr>
<tr>
<td></td>
<td>beetroles reared from 1st instar larvae obtained from the same dung heap on the same day</td>
<td>3.173</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>36.714+</td>
<td>(14)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.729</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Field-collected Male</td>
<td>34.90+</td>
<td>(40)</td>
<td>t = 1.8523** Ps &gt; 0.05</td>
</tr>
<tr>
<td></td>
<td>beetroles obtained from the same coconut plantation</td>
<td>3.535</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>36.33+</td>
<td>(30)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.682</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Beetles collected Male</td>
<td>40.60+</td>
<td>(10)</td>
<td>t = 1.1834** Ps &gt; 0.10</td>
</tr>
<tr>
<td></td>
<td>from various field sources at different times</td>
<td>2.118</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>41.00+</td>
<td>(5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.162</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Figures in parentheses represent the number of individuals measured

** Not significant
Description of Figures

Figs. 3-10. Various stages in the life cycle of *O. rhinoceros* (Original size)

Fig. 3. Eggs
Fig. 4. First instar larva
Fig. 5. Second instar larva
Fig. 6. Early third instar larva
Fig. 7. Late third instar larva
Fig. 8. Prepupa
Fig. 9. Pupa
Fig. 10. Adult
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Fig. 12a. Ventral view of the abdominal tip in mature third instar male *O. rhinoceros* larva
(The arrow indicates the organ of Herold)

Fig. 12b. Ventral view of the abdominal tip in mature third instar female *O. rhinoceros* larva

Fig. 13a. Ventral view of male *O. rhinoceros* pupa

Fig. 13b. Ventral view of female *O. rhinoceros* pupa
(The arrow indicates the shiny area with depression)

Fig. 14a. Female adult of *O. rhinoceros*

Fig. 14b. Male adult of *O. rhinoceros*

Fig. 15. Metathoracic tarsus of male *O. rhinoceros*

Fig. 16. Metathoracic tarsus of female *O. rhinoceros*

Fig. 17. First two segments of the metathoracic tarsus of male *O. rhinoceros*.

Fig. 18. First two segments of the metathoracic tarsus of female *O. rhinoceros*.

Abbreviations used:

9AS - 9th Abdominal segment; 10AS - 10th Abdominal segment; H - Horn; HF - Hairy fringe; PG - Pygidium; S1 - First segment; S2 - Second segment
Description of Figures

Fig. 19a. Ventral view of the abdominal tip in the early third instar male larva of *O. rhinoceros*.

Fig. 19b. Ventral view of the abdominal tip in the early third instar female larva of *O. rhinoceros*.

Fig. 20. Organ of Herold in mature third instar male larva of *O. rhinoceros*.

Fig. 21. Components of the male reproductive system developed from the organ of Herold implanted into third instar female larva of *O. rhinoceros*.

Fig. 22a. Ventral view of the abdominal tip in the male pupa of *O. rhinoceros* (the arrow mark indicates the median elevated zone with indentation).

Fig. 22b. Ventral view of the abdominal tip in the female pupa of *O. rhinoceros* (the arrow mark indicates the shiny area with depression).

Fig. 23. Ventral view of the abdominal tip of 'pseudofemale' pupa developed from OH - extirpated third instar larva.

Fig. 24. Ventral view of the abdominal tip of 'mixed - sex' pupa developed from OH - implanted third instar female larva.

Abbreviations used:

A - Anus; ALA - Anterolateral arm; BP - Basal piece; CP - Chitinous plate; DE - Depression; DS - Dry strand; IDC - Inner distal cord; IND - Indentation; MEZ - Median elevated zone; ODC - Outer distal cord; OH - Organ of Herold; RL - Round lobe; RS - Ring-like segment; TB - Tracheal branch; VF - Vaginal floor; 8 - 8th abdominal segment; 9 - 9th abdominal segment; 10 - 10th abdominal segment.
Fig. 25. Relationship between horn length and body length in *O. rhinoceros*
4. DISCUSSION

4.1 Life history and bionomics

Although many authors have made references to the size or duration of one or the other stage of O. rhinoceros, systematic data on the life cycle of this insect has not been available. However, even from what has been presented by the different authors it is quite obvious that the different life stages are susceptible to considerable variation with respect to size and duration.

The life cycle parameters determined during the present study conform to some of the previous reports by some authors while differ from yet others. The freshly laid eggs in the present study were smaller (2.3-3.5mm x 1.3-2 mm) when compared to the size reported by Goonewardena (1958) (3-4mm x 2-3mm); the incubation period lasted for a mean of 12 days, as also reported by Catley (1969), though Monty (1978) and Sison (1957) reported it as 15 days, Kurian and Pillai (1964) and Nirula (1955a ) as 10 days and Goonewardena (1958) as 8.72 days. The first instar larvae revealed a mean length of 7mm in the present study, almost similar to that reported by Monty (1978) (7.6mm) while Goonewardena (1958) reported it as 8.7mm. Its duration was 12.8 days in the present study, against the 15.8 days reported by Goonewardena (1958). The second instar had a
mean length of 29mm and a duration of 15.6 days (range 13-18 days) in this study while Goonewardena (1958) reported it as 34.2mm and 18.34 days respectively. Catley (1969) reports an almost similar range (12-18 days) as in the present study.

During the present study also it was the third instar larva which showed the greatest degree of variability with respect to size and duration, as have already been reported by other authors also. The full grown larva ranged from 68mm to 89 mm in length while Nirula (1955a) reports it as 75mm-125mm; its duration was 61-148 days in this study while Catley (1969) gives it as 90-120 days and Bedford (1976a) as 60-65 days and Goonewardena (1958) as 72-103 days.

Mini and Prabhu (1986) have observed that the third instar larvae of *O. rhinoceros* that have passed a certain critical stage of development would undergo precocious metamorphosis if deprived of food, forming diminutive adults, below average in size. The larvae reached this critical stage by around the age of 48 days. Those below the age of 35 days, if subjected to starvation, succumbed to death, after varying periods depending on their age. It is thus clear that a certain extent of feeding and growth is essential for the larvae to attain competence for metamorphosis. Larval feeding regime upto the attainment of competence for metamorphosis can hence be designated as
"obligatory feeding regime" as distinct from the "facultative feeding regime" that follows. It appears that the adult size can be influenced by the duration of the facultative feeding regime.

The prepupal duration, determined during the present study (mean of 9.4 days) was greater than that reported by Catley (1969) (8 days) and Cherian and Ananthanarayanan (1939) (7.07 days), and Goonewardena (1958) (16 days). None of these authors have mentioned the size of the prepupa, which was found to be 54mm x 18mm in this study; the pupae were much smaller (34-51mm in length and 17-25mm in breadth) than that reported by Nirula (1955a) (50-70mm x 20-25mm). Pupal duration was 18.8 days in the present study as against 17.9 days reported by Goonewardena (1958), 20.8 days by Sison (1957), 20 days by Nirula (1955a) and Kurian and Pillai (1964) and 20.4 days by Cherian and Ananthanarayanan (1939). The adult size varied from 30mm to 46mm in length and 16mm to 23mm in breadth in the present study. Nirula (1955a) reports it as 35-50mm and 14-21mm respectively. High variation in adult size has also been reported by Cumber (1957) and Monty (1978).

4.2. Sexual dimorphism in larva: the organ of Herold

Herold (1815) has regarded a club-shaped
invagination found on the 9th abdominal sternite of the male larvae of some lepidopterans as the rudiment from which the external genitalia and much of the internal reproductive tract develop. Since then similar structures have been discovered in many other lepidopterans and termed variously as "Herold sches organ" (Verson and Bisson, 1896; Meisenheimer, 1909; Heberdey, 1931; Wittig, 1960; Dewes, 1972), "Herold's organ" (Jones et al, 1984), "genital pouch" (Drecktrah et al, 1966), "claviform body" (Joubert, 1965), "Primary nodule" (Joubert, 1967), or "genital disc" (Reinecke et al, 1983). Homologous structures have been discovered in a number of coleopterans also and were named as the "genital pocket" (Metcalfe, 1932), or the "organ of Herold" (Hurpin, 1953; Menees, 1957; Elliott, 1964).

The OH of the different scarabaeid larvae belonging to the three sub families Melolonthinae, Dynastinae, and Aphodinae namely Melolontha melolontha (Hurpin, 1953), Aphodius tasmaniae (Elliott, 1964) and O. rhinoceros (present observations) respectively, show conformity in their basic structural pattern in being a bag-like organ with a chitinous structure. However it differs greatly in details in different species regarding the shape and relative size of these components. According to Elliott (1964) such differences noticed between the sub families can be of taxonomic significance. In the scarabaeid Costelytra
zealandica the OH revealed differences even between the different populations of the same species (Elliott, 1964).

The present work shows that in *O. rhinoceros* OH gives rise to the phallus, ejaculatory duct and the paired accessory glands, as can be evidenced from the absence of these organs in the adult males developed from the OH-extirpated larvae. The OH was presumed to be the precursor of the accessory glands in the species of Melolonthinae (Hurpin, 1953; Elliott, 1964) though they made no mention of the origin of other parts from it. Also, Hurpin did not mention anything about the two pairs of cords connected distally to the OH though he had represented them in his diagram.

The present studies showed that the adults formed from the OH-extirpated larvae had normal vasa deferentia originating from the testes, though there was considerable individual variation in the length of the vasa deferentia in these adults. Evidently the vasa deferentia in *O. rhinoceros* are mesodermal in origin, developing from the outer pair of translucent cords extending between the testes and OH in the late third instar larvae. Thus assuming the origin of the vasa deferentia from the outer distal cord, the variations observed in the length of the vasa deferentia among the adults formed from the OH-extirpated larvae can be well explained as due to difference in the length of the distal
cords that came out and got extirpated along with the OH when the OH was pulled out of the larvae during extirpation. Solid cords of tissue reaching from the testes to the OH have been reported in a number of lepidopterans like Bombyx mori (Verson and Bisson, 1896), Solenobia triquetrella (Florin, 1945), Choristoneura murinana (Wittig, 1960) and Ostrinia nubilalis (Jones et al, 1984) in which they were found to be the presumptive vasa deferentia of mesodermal origin and referred to as the genital cords.

The present observations regarding the origin of the male reproductive ducts of O. rhinoceros are of interest in view of the discrepancies reported from the various insects with regard to the origin of the different parts of the system. The ectodermal origin of the phallus and the median ejaculatory duct is fairly well-accepted (Metcalfe, 1932) but the origin of the paired ducts of the reproductive system is a matter of dispute. According to Muir (1918) and Pruthi (1924) they are wholly ectodermal in origin in many coleopterans as also in many other insects like honey bee (Michaelis, 1900), Doryctus gallicus (Seurat, 1899), and Platygaster (Kulagin, 1897-8). In some coleopterans like Sitodrepa panicea, Anthonomus pomorum and Gastroidea polygoni it is partially ectodermal and partially mesodermal, the extent of each part varying with the species (Metcalfe, 1932). However a completely mesodermal origin is
attributed to the paired reproductive ducts in *Cimex lenticularis* (Christophers and Cragg, 1921-2), *Bombyx mori* (Verson and Bisson, 1896) and *Xiphidium* (Wheeler, 1893). The present studies in *O. rhinoceros* also are in conformity with the wholly mesodermal origin of the vasa efferentia and vasa deferentia.

According to Escherich (1894) the male accessory glands in coleopterans can be either ectodermal arising as the diverticulum of the ejaculatory duct, or mesodermal, originating from the vasa deferentia. However Bordas (1898, 1899a,b) states them to be all mesodermal while Pruthi (1924) regards them all ectodermal. The present studies in *O. rhinoceros* show that the single pair of accessory glands are ectodermal in origin as they arise from the ectodermal OH.

The adult males developed from the OH - extirpated larvae were apparently like the normal ones, with the exception that they were incapable of copulation; however they exhibited all other courtship activities vigorously, and since these activities were not interrupted by copulation, prolonged and persistent courting could be observed. Also, since these adults are devoid of accessory glands, they can be used to compare the role of accessory glands in the reproductive behaviour of this insect.
4.3. Sexual dimorphism in pupa

Morphological differences on the ventral side of the abdominal tip have provided the basis of sexing the pupae of many coleopterans like Tribolium (Good, 1936), Sitodrepa panicea, Gastroidea polygoni and Anthonomus pomorum (Metcalfe, 1932). These sex-dependent differences may be in the shape and arrangement of the terminal sternites (Generally the 9th and 10th), in the number, shape and arrangement of the genital lobes, and in the occurrence and position of the gonopore and anus.

The features of sexual dimorphism in O. rhinoceros pupae show some similarities with those of Sitodrepa panicea, Gastroidea polygoni and Anthonomus pomorum. In the males of these species the 10th sternite is intercalated between the 9th sternite and the 9th tergite, and the gonopore and the genital lobe(s) are situated on this 10th sternite; the median elevated area of O. rhinoceros corresponds to the genital lobe of the others.

The female pupae of O. rhinoceros resemble those of S. panicea and G. polygoni in having no distinct 10th sternite and the right and the left lobes as well as gonopore being on the 9th sternite, the latter occupying a position in between the lobes and immediately below the 8th sternite.
That these secondary sexual characteristic of the male pupae of *O. rhinoceros* develop in association with the development of genitalia has got experimental evidence during the present studies. Thus the male pupae having no genitalia (i.e., those developed from the OH-extirpated larvae) failed to reveal the specific male characteristics namely the separate 9th and 10th sternites, the median elevated zone and the indentation. Instead a single segment with a pair of genital lobes as in a female was visible but the other female characteristics namely the shining area with depression was absent. Because of the superficial resemblance to female pupa they were called "pseudofemale" pupae.

The female pupae with male genitalia developing within (i.e., the two exceptional female pupae which developed from the OH-implanted larvae) revealed the male characteristic namely the median genital lobe; but without indentation, in addition to the normal female characteristics. Because they possessed the characters of both sexes they were called "mixed-sex" pupae.

The possibility that the pseudofemale and mixed-sex appearances could be artifacts developing due to surgical manipulations was ruled out by the observation that the sham-operated control larvae developed into normal pupae despite being manipulated surgically.
It is thus evident that the dimorphic characteristics related to the sternites and genital lobes is male type if there is full development of male genitalia, and the absence of male genitalia will cause them to develop into the female type. The female type seems to be the basic pattern, as it can result from the absence of male type as seen in the pupae from OH-extirpated larvae.

The gonopore was absent in the male pupae resulting from OH-extirpated larvae and it was of female type in the pupae resulting from OH-implanted female larvae. Evidently the nature and position of the gonopore is determined in relation to the development of the original genitalia.

4.4. Sexual dimorphism in adult

Pygidium

A definite and most easily detectable secondary sexual characteristic of the adult is the nature of the pygidium (the last visible abdominal segment). In the females the pygidium is covered over by a dense coat of long hairs whereas in the males it is rather glabrous with very few hairs (O'Connor, 1953; Nirula, 1955a). Cumber (1957) has observed great individual variation with regard to the number of hairs present on the pygidium in both sexes and
suggested loss of hairs due to ageing as responsible for this difference. Observations made during the present studies indicated that the sexual difference in pygidial hairs existed even among freshly emerged beetles. Evidently this difference is basically based on sex though it can possibly be modified by the loss of hairs due to ageing. Besides this difference the present studies revealed another element of sexual dimorphism - the pygidium has a more or less conical outline in the female while it is rather round in the male. These two characteristics together provide the accurate method of sexing than if they are considered singly.

Unlike in the pupae, the secondary sexual characteristics on the abdominal tip (pygidium) of the adult was found to be developing independent of the genitalia. Thus the pygidium was of male type (round with a few hairs) even when the genitalia was absent, i.e., in the adults from OH-extirpated larvae, and of female type even when an additional male genitalia was present, i.e., in the adult developed from OH implanted larva.

**Metathoracic tarsi**

Sexually dimorphic differences associated with the metathoracic tarsi are found among several coleopterans like some carabids, staphilinids, and cucujoids (Evans, 1977).
Such differences can be of varying types, mostly designed to perform sex-specific functions. Thus the male *Dytiscus* possesses hairy modifications forming adhesive pads underneath their front tarsi to serve as clapping organs; in some cryptophagids the males have one segment less in their hind tarsi (Evans, 1977). Hairy modifications on the appendages performing non-sexual functions have also been met with among beetles; closely set rows of stout hairs forming hairy fringes along the inner side of the hind legs of *Dytiscus* aid in swimming (Wigglesworth, 1964). However the functional significance of the hairy fringes on the hind tarsi of *O. rhinoceros*, detected during the present study as being more prominent in the female with a greater number of longer hairs, is not clear. They resemble the so-called antennal cleaners found on the front tarsi or tibiae of many carabids and staphylinids (Evans, 1977) but their position in *O. rhinoceros* is not conducive for performing that function. A plausible function seems to be in cleaning the pygidial hairs. The presence of relatively well-developed fringe in the second tarsal segment of the females can then be correlated with the presence of densely packed hairs in the female pygidium.

Relationship between Horn size and Body size in the adult

The present studies have revealed that the horn of
O. rhinoceros exhibits allometry. The difference in the relative size of an organ which is dependent on the absolute size of the individual is known as allometry, and is found in many species of animals (Evans, 1977). The jaws of the male stag beetle *Lucanus cervus* is an example (Mathieu, 1969).

Because of the allometric growth pattern the difference in horn size between the sexes is negligible among smaller individuals of *O. rhinoceros*, rendering it difficult to sex them on the basis of horn size. However the difference between the sexes becomes greater as the body size increases (see Table 2). Thus among the beetles of size range of 30mm to 34mm the difference in average horn size between the sexes is very narrow, ranging from 1mm to 1.9mm, but among the beetles of 35mm to 43mm this difference is fairly evident, ranging from 4.2mm to 8.3mm. However, owing to the considerable degree of overlap in horn size between the sexes the absolute size of the horn cannot be used for sex determination; the difference in absolute horn length between the sexes is statistically insignificant also. Thus although Nirula (1955a) and Kurian and Pillai (1964) state that the males can be distinguished from the females by the size of the horn, the present studies have revealed that it is not practical to use absolute horn length for diagnosing sex. Monty (1978) also is of the opinion that the horn size
is not a reliable characteristic for sex determination.

However, the present studies have revealed a sex-specific relationship between horn size and body size in *O. rhinoceros*. Thus for every 1 mm increase in body length from 30 mm, the males reveal a mean increase of 0.7 mm in horn length while in the females this increase in horn length is only 0.42 mm. A method for sex diagnosis can be formulated on the basis of this information— that is, by checking whether the horn size-body size relationship of a given individual is fitting into the male pattern or female pattern. If the individual is a male of x mm body length, its horn length can be calculated approximately by the following formula:

\[
HL(x_{\text{mm} \delta}) = HL(30_{\text{mm} \delta}) + (x_{\text{mm}} - 30_{\text{mm}}) 0.7_{\text{mm}}, \text{ in which,}
\]

- \(HL(x_{\text{mm} \delta})\) = Horn length of the male of x mm body length,
- \(HL(30_{\text{mm} \delta})\) = Horn length of the male of 30 mm body length
- 0.7 mm = increases in horn length per 1 mm increase in body length in the male.

Hence \(HL(x_{\text{mm} \delta}) = 2.9_{\text{mm}} + (x_{\text{mm}} - 30_{\text{mm}}) 0.7_{\text{mm}}\)

Similarly, if it is a female of x mm body length,

\[
HL(x_{\text{mm} \varphi}) = HL(30_{\text{mm} \varphi}) + (x_{\text{mm}} - 30_{\text{mm}}) 0.42_{\text{mm}}, \text{ where,}
\]

- \(HL(x_{\text{mm} \varphi})\) = Horn length of the female of x mm body length,
HL(30mm ♂) = Horn length of the female of 30mm body length
          = 2.4 mm
0.42 mm = Increase in horn length per 1 mm increase in body length in the female.
Hence HL(xmm♀) = 2.4 mm + (x mm - 30mm) 0.42mm

Hence if the Horn length of the given beetle approximate the calculated value for the male it will be a male; otherwise it will be a female.

Body size of the adult

Body size is a common sexual difference in many coleopterans. In some beetles like Barypithes araneiformis and some carabids and cerambycids the females are larger than the males while in the stag beetle Lucanus cervus, Hercules beetle Dynastes hercules, the atlas beetle Chalcosoma atlas and some scarabaeids the male tends to be larger (Evans, 1977). In the case of O. rhinoceros conflicting reports exist as regards the relative size of the sexes. Thus Nair (1978) reported that the males are larger than the females while Cumber (1957) states that the females are on average slightly larger than the males. During the present studies three kinds of populations were examined, namely, a population of laboratory-emerged beetles
raised under identical conditions from an early stage of development, a population of beetles collected from the same field on the same day, and a population of beetles collected from different areas/localities at different times. These observations revealed that there was no significant difference in body size between the sexes. Not only that the size varied over a wide range in each sex but there was also an almost full extent of overlap in body size between the sexes.

The discrepancy between Cumber's observation mentioned above and the present report may perhaps be due to the difference in the criterion selected for determining the size. Cumber (1957) has used wing length as the criterion. But *O. rhinoceros* being a brachelytrous species wing length may not always reflect body size appropriately. Hence for the present study the linear distance between the front of the base of the horn to the tip of the abdomen was selected as the criterion. Pinto and Mayor (1986) has also used this method for measuring the size of the beetle *Meloe niger*, which also is a brachelytrous species, with the assumption that linear body measurements correlate with weight in all species.