Study on the development of sorghum chafer (*Pachnoda interrupta* (Oliver) (Coleoptera: Scarabaeidae) under different physical and edaphic factors

By

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A thesis presented to School of Graduate Studies
in partial fulfillment of the requirements for the degree of
Master of Science in Biology (Insect Science)

Department of Biology
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December 2002

Acknowledgements

I am very grateful and wish to express my sincere thanks to my research advisor Dr. Emiru Seyoum with out whose great concern, encouragement and guidance, the work would have been difficult to materialize.

Sincere thanks are also due to my co-advisor, Ato Senshaw Aysheshim for his excellent guidance and frequent advice and above all for his encouragement and allowing me to use his laboratory utilities.

Special mention and thanks go to Ambo Plant Protection Research Centre (APPRC) for the fundamental contribution, I owed the center in general and particularly the center Manager Ato Ketema Abebe in giving me permission to use facilities at the center. Dr. Mohamed Dawud, in giving me technical advice and Ato Zerihun Beshir for assisting me during the survey work. Ato Wondirad Mandefiro, from the Nematology Department of the center for his computer use related support. The kindness and hospitability I obtained from all departments and all workers of the center is unforgettable.

My sincere gratitude goes to w/t Hiwot Lemma of the MOA, Department of Crop Protection and Production Technology and Regulatory Department (CPPTRD) for providing me with reading materials and useful information.

I would like to thank the Educational Bureau of the South Ethiopia Nation, Nationalities and Peoples Regional State for sponsoring me to pursue this postgraduate training programme. Similarly I am grateful to the International Center of Insect Physiology and Ecology (ICIPE) for providing me financial support for the research part of my training through African

Regional Post-Graduate Programme in Insect Science (ARPPIS) and AAU, Department of Biology. My admiration and thanks also go to AAU, Department of Biology, especially to Dr. Kifle Dagne, Head of the Department and the secretaries for all their supports during my study here.

The contributions varying from moral, material to technical support I obtained from my friends including Ato Tessema Jembere, Amerga Reda Zemedikun Habte, Indrias Folla, Legesse Toma, Tekilu Bekele, Mesfin Tesema, Aklilu Wube, Chane Alemu and Endalkachew Libu were also equally helpful.

I am very pleased to thank Ato Merid Negash and Getachew Bezabih for their valuable support towards statistical analysis and for all constructive comments. My classmates Mr. Sabiiti Stephan Muzeyi, Miss Hellen Namusana and Ato Daniel Getahun are also thanked for their willingness in sharing valuable information on computer work.

Last but not least my heartfelt thanks go to my family, my wife w/o Mulu Teshome, my sister w/t Weyinshet Feleke who were encouraging and caring me and my son Rebel Gebeyehu, who understood my situations during the training period.

Table of Contents

List of Tables

List of figures

List of Appendices

LIST OF ABREVATIONS

ANRS : Amhara National Regional State

APPRC : Ambo Plant Protection Research Center

CSA: Central Statistic Authority (of Ethiopia)

FAO : Food and Agricultural Organization

IAR : Institute of Agricultural Research

Masl : Meters above sea level

MOA : Ministry Of Agriculture

EARO : Ethiopian Agricultural Research Organization

ANOVA : Analysis Of Variance

DMLT :Duncan's Multiple Range Test

SE: Standard Error

CPPTRD: Crop Protection and Production Technology and Regulatory Department

ABSTRACT

A laboratory study supported with field observations was done on the life cycle, the effect of physical and edaphic factors on the development of *Pachnoda interrupta* (Oliver) (Coleoptera: Scarabaeidae). The food preference and factors contributing to extended diapause of the adult were also included in the study. The laboratory study was conducted at four different temperature regimes (20, 25, 30 and 35 ^{0}C) and four soil moisture levels (9, 17, 23 and 29%). Soils collected from Afar, Tikur-Inchini, Guder River near Ambo were used separately and mixed with different proportion of cow-dung to note its effect on laral development. Based on the information obtained from farmers in the infested area eight types of food substances were tested for their effect as bait.

In the life cycle study (at 25 ^{0}C & Moisture 17%) the average oviposition rate was found to be 0.58 eggs/ day/ female. Whitish soft shelled eggs were laid separately in soil varying (strata) from 3-18 cm. in depth. The mean number of incubation days of egg was 9.63±1.4 ranging between 8 and 13. Larval development took an average of 59.09 ± 1.94 days ranging between 42-73. Body length was constantly increasing till around 52 days where it reached 30.2 mm and was shrinking latter and measured 28mm at about the 70th day. Larval head capsule width, however showed discontinuous, but constant increase and at an average 3.14±0.01mm was measured in final days (62-70). Pupal development ranged from 18-30 days with an average of 24.47 ±3.5 days. The depth of pupation site was found to be dependent on moisture level. When soil moisture is less the larvae went down deep in to the soil to pupate and when it is high, they remained in the upper layers. Soil temperature however did not show significant effect on pupation depth. The adults required an average of 93.79± 1.8 days, ranging from 68-116 to emerge. The laboratory study and the field observation confirmed that

P. interrupta are univoltine insects but the adults have two phases (emerging seasons). The first phase emerges directly from pupa, and it is non reproductive and worst pest of crops such as sorghum and maize and enters in to the soil for diapausing for about nearly 8 months. The stable temperature in the soil especially under tree shades, food reserve particularly fat contributes for long lasting diapause. This emerges as second phase synchronized with rains and flowering of non crop plants such as *Acacia* spp., and this is the reproductive phase. Beetles of this phase feed mainly on flowers, mate, lay egg in the soil and die.

The presence of cow-dung in the soil was found necessary for completion of the life cycle. The cow dung serves the larvae as food. and essential for growth, however when its concentration increased exponentially, the growth rate decreased, but the total life cycle shortened. Soil moisture and temperature have also shown significant effects on percentage survival and developmental rate. Moisture levels of 17 and 23%were found to be more important as compared with moisture regimes beyond and below these. Temperature of 25 and 30°C were found to be very essential for survival of larvae and for the completion of life cycle. Among the eight food substances tested as bait, ripe banana was most preferred followed by ripe guava. Residues of local beer, 'tej' and 'katicala', roasted maize and sorghum flour were preferred next while non-roasted sorghum flour was the least preferred.

1. Introduction

Sorghum, *sorghum bicolor* (L) Moench is an extremely important staple food in the tropical countries and especially in Africa (Seshu Reddy, 1988). It is one of the major food crops in Africa and Asia (Pathak, 1985). Maize and sorghum are among the major cereal crops grown for food in Ethiopia. Maize ranks first in yield /hectare, fourth in total grain yield and fifth in total land coverage, after 'tef', barley, sorghum and wheat and production of this crop increased gradually and constantly between 1961 and 1974. Sorghum on the other hand, has a tremendous genetic diversity in Ethiopia, which has enabled it to thrive under wider ranges of environment than any other crop in the country. The significant feature of Ethiopian sorghum is that it is the dominant crop in lowlands where drought and poor harvest are common occurrences (Abraham Negasi and AbrahamTadesse, 1985).

Sorghum is the most important of the cereal crops in the semi- arid parts of eastern Africa (Berhane G/Kidan, 1985). Sorghum is a native African cereal, originated in Ethiopia (Dogett, 1988) and Ethiopia is the second largest producer of sorghum in eastern and southern Africa, preceded only by the Sudan both in total area and production (Abera Debelo *et al.,* 1995). It occupies 16-20% of the total cereal production of Ethiopia. Sorghum is used as food, fuel, fodder, and construction material adapted to a wide range of environmental conditions, particularly to drought- prone areas of the country and only second to 'tef'' in "injera" making quality and supports lives of many farming communities (Abera Debelo *et al.,* 1996). Sorghum is grown in all administrative regions of the country, although, Hararghe, Shewa, Wollo, Tigrai and Wellega are major producing regions, under different soil, seasonal and climatic conditions. It is the major crop grown in the higher intermediate and low elevation areas of Ethiopia, third in production, following maize and 'tef' and in area, next to 'tef'(IAR, 1979).

Covering more than 1.5 million hectares of land out of the 9 million hectares covered by all cereal crops and an estimated annual production of over 16 million quintals (CSA, 1999). Sorghum is highest yielding crop in the eastern sub-region of Amhara National Regional State (ANRS) and has no other good cereal replacement due to its unique adaptability to the arid climate and soils (Yitbarek W/Hawariat and Hiwot Lemma, 2000).

The potential yield of this crop is hardly attained and generally its yield in peasant farms is very low (Berhane G/Kidan, 1985; Seshu Reddy, 1988). Small-scale farmers grow sorghum for local consumption and the yield tend to be very low averaging less than half of the world average. In eastern Africa countries, where the world acreage under sorghum is 11.5% grain yield is very low, 1800 kg per hectare against 3951kg/ hectare in the USA (FAO, 1991). One of the major factors, causing instability in the yield is attributed to insect pests (Berhane G/Kidan, 1985; Seshu Reddy, 1988). Insect pests constitute one of the major constraints to cereal production in sub Saharan Africa (Yuodeowai, 1989).

The production of sorghum is threatened by a wide range of both pre and post harvest pests. These include insect pests (stalk borers, armyworm, sorghum shoot fly and sorghum chafer), birds (*Quelea quelea*, chestnut weaver, village weaver, staling, doves and pigeons), weeds (striga spp.) and storage pests (weevils, angoumois grain moths), (Hiwot Lemma, 2000).

In the tropical regions, insect pests are major yield limiting factors (Pathak, 1985). A suit of insect pests affects sorghum. Despite these facts, pest management technology for sorghum lags behind some other crops (Peters and Starks, 1979). Until recently, subsistence crops like sorghum have received little attention (Leuschner, 1995). The worst of all, an insect pest not much familiar to the word has become a challenge to sorghum production in Ethiopia in recent years. Sorghum chafer, *Pachnoda interrrupta* (Oliver) (Coleoptera: Scarabaeidae) is now of primary importance and represents a critical constraint to increased sorghum

production because of the level of damage it inflicts and lack of successful control methods. A preliminary yield loss assessment made by Yitbarek W/Hawariat and Hiwot Lemma (2000), in ANRS was estimated to be 58.2 to 71.29% on sorghum. According (CSA 2000), the annual loss could range from 45-80% on sorghum and about 20 % on maize. During sever infestations it is not uncommon to note complete loss (Clark and Crowe, 1977).

The adult beetle is the damaging stage. It feeds on the flowers and sucks all the contents of the sorghum, maize and wheat grains at milk stage. Schmutterer (1969) stated that *P. interrupta* feeds towards the end of the rainy season, in late September on milk stage grains of sorghum and pennisetum millet heads. Such insect pests attacking panicles of sorghum are especially damaging as they affect crop development at late stage and have direct harmful quantitative and qualitative effects on grain yields. At this late stage of crop development the main production inputs would have already been made which maximizes economic losses and there is also little scope for crop to compensate for damage done so close to harvest (Harris, 1995).

The very little knowledge we have on the biology, site of reproduction, factors contributing for its unexpected outbreak, lack of successful control methods and the sever damage it inflicts, and attack on flowers and panicles are some of the reasons why this work was focused on *P. interrupta*. In this work an attempt was made to survey relevant information on the life cycle of *P. interrepta* in the laboratory, effect of soil type and physical factors such as temperature and moisture on the development of the immature stages. And also depth of pupation site under different temperatures and moistures, baits more preferred and factors contributing for their success in overwintering for a long period.

Objectives

➢ General objectives

♦ To study on the development of sorghum chafer under different physical and edaphic factors

➢ Specific objectives

♦ To study the life cycle of *P. interrupta* under laboratory condition.

♦ To study the possible effect of soil types soil temperature and soil moisture on the development of the immature stages.

♦ To study the depth of pupation site under different temperature and moisture conditions.

♦ To select baits which are more effective in attracting *P. interrupta.*

♦ To study major factors contributing to extended overwintering.

2. LITERATURE REVIEW

2.1 Sorghum chafer (Pachnoda interrupta) and its Distribution

Pachnoda interrupta is a beetle that belongs to the order Coleoptera, the family Scarabaeidae, and sub family Cetoninae (Clark and Crowe, 1977). All species of *Pachnoda* have well-developed hind wings and as in all cetonnids, these can be extended for flight with very little elevation on the elytra. Males can be distinguished from females by the presence of a shallow groove on the underside of the abdomen. The abdomen of the female is convex (Clark and Crowe, 1977). The adult *P. interrupta* is about 13-17 mm long with black body colour. The pronotum and elytra bear yellow brown or red brown spots and strips (Grunshaw, 1992).

Pachnoda interrupta is the smallest species of *Pachnoda* (12-16mm) occurring in Ethiopia, variable in colour from completely black to almost completely pale yellow, with a distinct colour pattern. The pygidium is black usually with four small white spots (Clark and Crowe, 1977). The genus is restricted in its distribution to the African continent, although a few species have been recorded from Arabia and Madagascar (Grunshaw, 1992).

The genus *Pachnoda* contains more than 130 species (Krikken, 1984), but only nine species, one represented by two sub species were identified in Ethiopia and only two species, *P. stehelini* Schauan and *P. abyssinica* Blanford, are regularly found at altitudes above 2000 meters. The other species are found in areas of acacia woodland ranging from 800-1800 meters above sea level. *Pachnoda* is especially common along the eastern scrap slope below 2000 meters and north of latitude 8^{o} N (Clark and Crowe, 1977). Hiwot Lemma *et al.* (1999), reported *Pachnoda* in wider altitudes ranging from 540-1700 masl., in ANRS and Afar Region.

2.2 Biology

Oviposition by caged *Pachnoda sinuata flaviventris* takes place all the year round. The larval period of insects in the sub- family cetoninae is from 1 to 3 years depending up on the species and the environmental conditions. Pupation takes place within egg shaped cocoons made from soil or other substrate particles cemented with larval saliva. The adults, emerge from this cocoon, make their way to the surface and fly off to find food and become sexually matured after twelve months (Donaldson, 1985).

Grunshaw, (1992) studied the biology of *P. interrupta* in Mali on millet fields. According to this author, *P . interrupta* is univoltine and survives the dry season under soil as quiescent adults. Their emergence is synchronized with the first rains of the following year. Newly emerged beetles are characterized by having shiny, bright cuticles and fed actively throughout the day. This new group never has seen mating on the field, unlike the old generation beetles in June.

Unlike Grunshaw (1992) who reported a single female laying up to 24 eggs in one night, Seneshaw Aysheshim and Mulugeta Negeri (2000) revealed an average of 1.8 eggs/ female/ day with maximum of 2.28 eggs/female/day.

2.3 Host plants

The adult of sorghum chafer feeds on the contents of the grain of sorghum of the milk stage. It also attacks *Pearl millet* heads and maize cobs. It is also recorded on flowers of cotton, citrus, *Cordia*, *Acacia*, and *Dichrostachys* (Clark and Crowe, 1977).

The chafer feeds on milky stage grains of sorghum and pennisetum millet heads, but flowers of sun flowers, *Lawsonia alba,* cucumber, *Cassia roses* and the capsules of *Abelmoschus esculentus* are also attacked in the Somalia Republic (Schmutter, 1969). During his field survey conducted in Mali, Grunshaw (1992) found a number of *P. interrupta*, adults aggregated for feeding and mating on *Magnifera indica* (Anacarrdiaceae), *Balantes aegptiaca* (Zygophyllaceae), *Lawsonia intermis* (Lythraceae), *Hezalobus monopetalus* (Annonaceae), *Guiera senegalensis* (Combretaceae), *Psidium gtuitava* (Myrtaceae), *Prosopis africana* (Mimosaceae) and *Ziziphus micronata* (Rhanaceae). *Cordia africana*, *Acacia spp*, Citrus, maize sorghum, millet and cotton are serving as hosts of *P. interrupta* (Tsedeke, 1988).

According to Hiwot Lemma *et al.* (1999), field surveys conducted in the Afar and Amhara regions, indicate that about 37 crop and non-crop plants belonging to more than twenty families were identified as hosts of *P. interrupta.* Field crops like sorghum, maize, sunflower, niger seed, sesame fruit crops like guava and non crop plants like *Abutilon* spp., *Acacia* spp., wild plum, *Ximenia americana* were found to be the most favored hosts of the adult beetles.

2.4 Economic Importance

Pachnoda interrupta is widely distributed across Africa. In several parts of Ethiopia, it is a major agricultural pest. During bad outbreaks whole fields of sorghum are completely destroyed, the adult beetles eating out the contents of the grain in the milk stage. It also attacks millet heads and maize cobs and damages have been recorded on flowers of cotton, *Cordia*, *Acacia,* and *Dichrostachys* (Clark and Crow, 1977). In a study made in some villages in Mali, grasshoppers and *P. interrupta* have been found destroying an average of 50% potential millet harvest with upto ten *P. interrupta* attacking individual panicles (Lock *et al.,* 1988, cited in Grunshaw, 1992).

According to Grunshaw (1992), new generation beetles started to appear during millet flowering and were first observed feeding on pollen, which continued without apparent determinant to grain formation. Yield losses to a range of beetle densities (1-5 and 10 beetles / head) on millet heads have been estimated to range from 9 to 48% in caged trial experiments. Mean population density of 2 beetles per millet heads causes economic damage. One thus can imagine as to what could happen with 30-150 beetles/head of sorghum a common phenomenon in Ethiopia (Hiwot Lemma and Yitbarek W/Hawariat 2000), during outbreaks. The preliminary yield loss assessment made in ANRS by Hiwot Lemma and Yitbarek W/Hawariat (2000) showed a yield loss to be between 58.2 and 71.29%. According to CSA, (2000) annual loss could range from 45-80% on sorghum and about 20% on maize.

2.5 Control Measures

Difficulties in the planning of control of *Pachnoda* arise because of the contrasting habits of the larvae and adults of the species. The following measures might be used against the adult beetles. Use of dwarf crop varieties, which would facilitate both hand collection and chemical control application. Netting screens have been used around valuable fruit trees to check the beetles in their flight. Diversionary crops or non living attractants with bright yellow flowers planted around valuable crops divert beetles to an area where there is less damage and chemical control is easily applied. Compounds, which are fairly persistent and have low mammalian toxicity but highly toxic to *Pachnoda* beetles such as endosulfan or trichlorphon, are more suitable (Clark and Crowe, 1977).

Bending stalks of sorghum, smoking, hand collection of the adult's, toxic baiting, and chemical spraying have been tried by farmers. But apart from reducing, non-was successful in fully controlling the high number of beetles, 30-150/ head (Hiwot Lemma, 2000).

2.6 Effects of soil moisture and temperature on the development

After mating, the female searches appropriate places, such as compost heaps or forest soils for egg deposition (Clark and Crowe,1977). Egg lying could be achieved by placing mating pairs in moist soil (Grunshaw 1992). These statements confirm that female *P. interrupta,* lays eggs in the soil. In the study made on *Lucsta migratoria migratoriodes*, Ackonor (1988) explained that soil moisture is an important weight-determining factor; heavier hatchlings are produced in relatively wetter soils. Temperature has no apparent effect. On another study, Lamb and Gerber (1985) indicated that ambient temperature is known to be the most

important factor governing insect development period. Since meteorological conditions in nature, such as day length, rain and temperature, had little influence on the population of various species, it was anticipated that there were other factors controlling larval survival, which might be determined by rearing all the immature stages of the beetle in the laboratory (Donaldson, 1981).

Donaldson (1985), considering the effect of soil moisture and temperature and by undertaking a preliminary study, set a temperature regime of 24±2 ^{0}C with a relative humidity varying from 50% to 90% for *Pachnoda sinuata flaviventris.*

Insect development occurs within a defined species-specific range of temperature. The lowest within this range is called developmental threshold, at and bellow which development stops (Wagner *et al.,* 1984 Fan *et al.,* 1992). The change in developmental rate is linear in the middle temperature range, fastest at the optimal temperature, and then decreases, along increase beyond the optimum (Wagner *et al.,* 1984). Many empirical models describing the developmental rate of insects as a function of temperature are based on the law of heat summation which describes insect development as a function of heat accumulation above the developmental threshold and at or under the optimal temperature (Arnold, 1959).

In the study made on humidity responses and water balance of riparian species of Bembidiini (Coleoptera, Carabidae), Anderson (1985) concluded the following. The duration of the hydronegative reaction varied with species, age, temperature and relative humidity. The survival time of some species under dry conditions was different. The species on which the study made gain most water by drinking and/or from food. There was no correlation between humidity response and transpiration rate or ability to tolerate dry conditions of the species. There was however correlation between behavior /habitat affinity and humidity responses.

2.7 Overwintering

Insect hibernation is a physiological condition of growth retardation or arrest primarily designated to overcome than optimum temperatures during winter (Mansingh, 1971). Overwintering in insects can be a reaction to short duration, non-cyclic, sudden and an unticipated changes (Quiescence). Or it may be most highly evolved system of dormancy for overcoming cyclic, long-term, extreme environmental conditions (Diapause). Intermediate between these two is Oligopause, a response to moderate, fixed, cyclic and long-term climatic changes (Leather *et al.,* 1993).

The study made in Mali by Grunshaw, (1992) suggested that *P. interrupta* survives the dry season under the soil as quiescent adults with their emergence probably synchronized with the first rains of the following year.

Although insect diapause is genetically controlled, the environmental conditions that insect experiences often determine when, the extent and termination of diapause (Ivans, 1988). The length of diapause is critical for ensuring survival of insects (Dixon, 1987). Despite the diversity of possible pathways for diapause induction, the same few environmental cases are important. Three abiotic (photoperiod, temperature and moisture) and two biotic (nutrition and crowding) cues are known to be important in most insects (Lees, 1989).

The overwintering site is of great importance in determining the survival of the overwintering individuals (Rieux and D' Acrier, 1990). So most insects respond to more than one stimuli to locate a suitable overwintering site (Bale and Pullin, 1991). Tropical insects have often to enter diapause at the height of the dry season to escape condition equally inhospitable as those experienced during winter by insects in temperate climates (Tauber and Tauber, 1973).

At the end of December as the grains become hard enough to be chewed by the beetle the insect begin to hide in the soil and remain as quiescent until it emerges again as a sexually matured adult beetle in the coming June (Seneshaw Aysheshim and Mulugeta Negeri, 2000). Looking in to factors accounting for such long term overwintering would probably contribute towards designing of appropriate control measures.

Control of an insect pest at an overwintering stage is quite an attractive preposition. The pest species is usually at its lowest population level of the year and its individual members are usually inactive and unable to escape predators or control operators with out forgetting that the devices used to escape the rigors of winter can also be very effective means of escaping the control measures. Monitoring the overwintering sates, where an overwintering stage exists that can be easily sampled can make accurate forecasts then a potential predictive system exists for that insect species. For successful prediction and control of insects based on over wintering stage a detailed understanding of the process involved in overwintering is required, an information which is unfortunately available for only a very limited number of species (Leather *et al.* 1993). The present study, therefore, was undertaken based on these general principles: aimed at obtaining basic information on the site and process of overwintering in *P. interrupta*.

3. Materials and Methods

3.1 Field based study

3.1.1 Field survey

A series of field surveys were made in areas regularly infested by sorghum chafer in the Afar and Amhara Regional States. These areas included Awash National Park, Melka-Worer, Shewa–Robit and Kombolcha. The first survey was made in October 2001 around Shewa-Robit covering localities that border the Afar Regional State, and all the way from Showa-Robit to Knombolcha. This is the time when damaging new generations of the pest emerge and attack crops. Observations were made on different host plants, plant parts attacked, and time of the day preferred for heavy attack. Large number of newly emerged insects were collected and transported in rearing jars with removable lids to Ambo Plant Protection Research Centre (APPRC). In the laboratory, these beetles were used for bait (food preferences test) and some aspects of diapause study.

3.1.2 Soil surveys

Several places, based on prior information were selected and dug down to an average of 70cm deep with about 80 cm width and to a length of 1m. Soil surveys were made for two main purposes, for search of different developmental stages and overwintering adults.

The first soil sample survey was made in October 2001 around Shewa-Robit and Kombolcha, in order to identify the possible oviposition sites but with main emphasis on finding developing larvae and pupation sites, carefully searching for eggs, larvae and pupae in the soil.

Consecutive soil sample surveys were made around Melka-Worer right up to Shewa-Robit in November 2001 and March 2002 respectively, now with main aim of looking for overwintering sites. The first was made in November 2001 in Afar Region covering places starting from Awash National Park to Melka- Worer and the second was made in March, 2002 in the ANRS covering places around Shewa Robit. In both cases the diapausing adults obtained were transported with the soil they were found in using rearing jars to APPRC for further study and laboratory analysis. The first group was provided with small amount of water after 40 days to avoid desiccation (Wolda and Delinger,1984), and analysis on them was made after they were kept for 119 days in the laboratory with out being provided with food when they were starting to walk actively (but were not able to fly).

3.2 Laboratory based experiments

All laboratory-based experiments were conducted at Ambo Plant Protection Center (APPRC) Entomology Laboratory.

3.2.1 Rearing the beetle

Rearing cages

Rearing jars were constructed from circular plastic containers (19.5-cm height, 7.87-cm radius and a volume of 3.8 liters) with a removable lid. A circular opening (10-cm diameter) has been cut in the lid and covered with a synthetic fine mesh to inlet air and light.

Sources of insects

Sexually matured beetles of F_1 generation were obtained from APPRC, Department of

Entomology Laboratory. Sexes were segregated and equal numbers of mating pairs were put in rearing jars and supplied with ripe banana as food and allowed to lay eggs. Banana was found to be a suitable diet for the beetles both under laboratory (Seneshaw Aysheshim and Mulugeta Negeri, 2000) and field conditions.

3.2.2 Life cycle study

2.5 kg of soil enriched with cow dung, sun dried, steam sterilized, moistened by 500ml of water to obtain 17% of water to soil by weight (found to be suitable from preliminary observation during the present study) was put in rearing jar.

Eight pairs of sexually matured beetles were placed in a rearing jar and this was replicated three times and placed at 25 ^{0}C (determined by preliminary observation) and allowed to lay eggs.

Eggs

Newly laid eggs were collected every two days, as beetles disturbed daily for egg collection often ceased laying (Donaldson, 1992), and transferred to petridishes (120 mm. diameter) containing Whatman no 1. Filter paper placed on water agar medium. The water agar medium enables to maintain the moisture inside the petridishes, which is necessary for embryonic development (Seneshaw Aysheshim pers. comm.).

Eggs were incubated in temperature ranges similar to that of the parent beetle and were checked daily for hatching. Duration (days) required for egg hatching was checked and percentage of hatching was also calculated. Length, width and volume of ten newly laid eggs and ten others that were nearly approaching to hatching were measured.

Donaldson's (1985) method described below was used to measure the volume of eggs.

$$V=L\text{-}D.\pi.\ (D/2)^2 +4\pi/3(D/2)^3$$

Where: V= volume

L = longer measurement

D = the diameter or shorter measurement

Larvae

Larvae were placed in Petri dishes (120 mm diameter) filled with soil moistened to 17% and incubated at 25 ^{0}C. Every other two days similar soil was replaced and the body length and diameter of the head capsule width were measured in order to establish the duration of each larval instar.

Pupae

Pupae were kept in Petridishes and in soil of similar type to that of the larvae and their duration until emergence of the adult was recorded.

Adults

The newly emerged adults were sexed, measured and placed in rearing jars which contains moist soil and provided with banana as food.

3.2.3 Effect of soil types on the development of the immature stages

This experiment was conducted using soils collected from Melka- Worer (Afar Region), Tikur-Inchini, 40 kms south west of Ambo town, and from Guder- River near Ambo. Manure (cow dung) collected from Ambo Agricultural College Campus dairy farm was also used alone and mixed with these soils at different proportions as mentioned bellow. Analysis for PH, soil structure, soil class and organic matter (OM) was made at the National Soils Laboratory of Ethiopia (Appendix 1). All the soils were sundried, sieved and steam sterilized for 15 minutes at 121 ^{0}C. Five different trials were conducted using the three different soil types and soil types plus manure soils with different proportions replicating each set of experiment three times. These were:

- Treatment (1) included soils from Afar, Tikur inchini and Guder River, natural (separately with out being mixed) and coded 1-3, respectively.
- Treatment (2) included 75% Afar plus 25% manure, 75% Tikur inchini plus 25% manure, 75% sandy plus 25% manure and coded as 4-6, respectively.
- Treatment (3) included 50% Afar plus 50% manure 50% Tikur inchini plus 50% manure, and 50% sandy plus 50% manure soil and coded as 7-9, respectively.
- Treatment (4) Afar, Tikur- inchini and sandy soils which were kept over night in drying oven at 180°C (to minimize OM) and coded 10-12, respectively, and
- Treatment (5) manure soil only (with out being mixed), and coded as soil type 13.

All soils were moistened to appropriate levels (based on the status of the soil being squeezed and easily scrambled). Five newly laid eggs were put in each Petri-dish and kept in similar temperature condition. Egg hatching time and percentage of hatching, developmental rate, survival and duration of larvae, duration and eclosion of pupae and emergence of the

young adults were recorded and compared for the different soil types. Similar soil types were replaced every other two days.

3.2.4 Study on the effect of temperature and soil moisture on the development of the immature stages.

The experiment was conducted using soil, which was made uniform by sun drying , mixing and steam sterilizing and weighting. Four different temperature regimes, 20, 25, 30 and 35 ^{0}C were set up. Soils were adjusted to four different types of moistures, (9, 17, 23 and 29 %) based on the recommendation of Perttunen (1953), cited in Anderson (1985). The desired humidities were obtained by taking distilled water for 100% relative moisture and placing salt for saturated soils. The baseline used to prepare these different soil moistures was the one that was previously used at APPRC, entomology laboratory (Seneshaw, pers.com.). After observing their experience, by reducing into half or doubling or tripling the amount of water to the same amount of soil, the above mentioned moistures regimes were prepared as follows:

- 9% is obtained when 500g of soil was mixed with 50- ml. of water.
- 17% is obtained when 500g of soil was mixed with 100- ml.of water.
- 23% is obtained when 500g of soil was mixed with 150- ml.of water.
- 29% is obtained when 500g of soil was mixed with 200- ml.of water.

These soils were filled in 32 Petri dishes (120mm diameter), 8 for each moisture and four eggs were placed in each . Eight of these Petri- dishes (two with each moisture) were put in all the four-temperature regimes. The development of the different stages was followed every other two days, replacing the soil with its moisture type and putting back again in to its temperature. Numbers of larvae survived, developmental rate, as determined by

measurement of the body length and head capsule width was made every other two days.

3.2.5 Effect of soil temperature and moisture on the depth of pupation site

Twelve pots were filled with soils of four different moisture levels; 9,17,23 and 29% to a depth of 35 cm. and put in three types of temperatures (20, 30 and 35°C). Eight fully developed larvae were put in each pot and waited for the emerging and hanging of the young adults on to the meshed cover of the pot. After the adults had emerged, the soil in the pots was removed to look for the pupal cases. The depth of the soil in which the pupal cases were found was measured, recorded and comparison was made between the depth of pupation formed at different temperature and moisture regimes.

3.2.6 Bait (food choice) test

Attraction response was examined in a free choice chamber as per the techniques of Yadau and Tanwar (1985). A wooden bottom 2 cm thick plate was provided with a central square hole of 1.2-cm deep and an area of 36 cm^2 for the release of insects. Eight additional circular wholes (1.5 cm) in diameter, equidistant (15 cm) from the center of the central hole and between them selves were made around the bottom plate. The olfactory chamber was covered from the top with transparent (glass) lid. The height from the bottom plate to glass cover was 6.5cm. In each of the eight holes, 8 different types of food (bait) substances were placed at a time. The substances selected as bait were chosen based on the information obtained from farmers in the outbreak areas. Farmers used most of these chemicals to mix with insecticides to attract and kill the beetles (lure and kill approach). Twenty five

sexual pairs of active adult beetles hungered for two days were released from the central hole and the chamber was immediately covered. After about half an hour of flying and/ or walking within the chamber, most of the beetles were found settled in one or the other food substance in the holes. The number and sexes of insects in each hole was counted and removed. After washing and sun drying of the plate, fresh, but the same food types were placed in the holes, but now different from the previous ones. In such a way that every food substance was put in every hole. The test was replicated 6 times for each hole so that 6x8 = 48 tests were conducted.

3.2.7 Factors contributing to successful diapause

Pachnoda interrupta diapauses as an adult for about 8 months, November to June. An attempt was made to assess the ecological and physiological factors and feeding conditions contributing to this long diapause duration.

3.2.7.1 Study on environmental factors associated with diapause

The topography, vegetation and other environmental conditions where the dipausing beetles found were noted. The depth of soils of which the beetle diapaused, temperature and other micro-ecological conditions were also noted to see if they have an effect on diapause.

3.2.7.2 Study on effect of physiological factors on diapause

Fresh weight, dry weight, water content, lean dry weight, and fat weight of the beetles were determined using Wolda and Denlinger (1984) method which was modified to be used for both pre-diapausing and diapausing adults. In this method, the difference between fresh and

dry weight is called 'water' and those between dry weight and lean dry weight is called 'fat'; Lean dry weight is the weight of a beetle without its water and lipids. The measurements were made as follows: for the pre-diapausing adults, the very young adults soon after they were carried to the laboratory coded as (day-1), after they were fed for 15 days coded (day-2), and after fed for one month and were coded (day-3). For the diapausing adults, which were collected in March, as soon as they were collected from the field coded as (day-4), and for those allowed to stay in laboratory for 15 days, and coded (day-5). The diapausing adults, which were collected from Melka- worer in November, were analyzed only once, after their stay in the laboratory for around four months and coded as (day-6).

3.2.7.3 Study on effect of feeding on diapause

In order to study whether feeding would result in variation of diapausing conditions among different feeding groups; an experiment was set as follows:

2.5 kg of sun dried, steam sterilized soil which was moistened with distilled water was put in 14 rearing jars. 25 pairs (male and female) of beetles, collected in October 2001 from Shewa -Robit were put in each jar. The jars were grouped into two and 7 experimental groups each provided with 40g of food as follows:

- Group 1: fed daily with variety (banana, guava, residue of local beer, and flour of acacia flower) of food.
- Group 2: fed daily, but only with banana.
- Group 3: every 4 days with variety of food.
- Group 4: every 4 days with only banana.
- Group 5: every week with variety of food.
- Group 6: every week with only banana.
- Group 7: Without any food.

Followed every two days noting for any diapausing symptoms such as less activeness and inability to fly. The numbers of survivals were counted and their weight was measured after 45 days.

3.2.8 Statistical Analysis

One way and two-way analysis of variance were performed to test significance variation in effect of treatments and Duncan's Multiple Range Test (DMRT) at 5% level of significance, was used to separate means using SPSS 10.0 for windows computer software (SPSS Inc. 1989).

Chi squire test (χ^2) analysis was also used to check whether there is a significance sex variation between those that were collected from field and also those that have been selected a particular type of food at 5% level of significance as recommended by Watt (1997).

4. RESULTS

4.1 Life history of P. interrupta

4.1.1 Oviposition

An average of twenty-four mating couples laid 0.58 eggs/ female/ day, or an average of 17.35 eggs per female per month (Table 1). Peak oviposition occurred for about 25 days. Eggs were laid in the soils ranging from about 3 cm. to a depth of 12-cm. No egg was found on the top surface of the soil.

4.1.2 Developmental period

Developmental periods of the immature stages of *P. interrupta* are given in (Table 2). The mean number of days required for egg hatching was 9.63 ± 0.14 and ranged between 8-13 days. The larvae required an average of 59.69± 1.64 which ranged between 42-73 days to complete their development. Growth rate of the larvae (Table 4) was continuous until an average of day 52 when it started shrinking and decreased in length. The head capsule width as opposed to body length showed discontinuous growth and remained unchanged by the time the body length was shrinking. The pupal developmental days ranged from 18-30, with an average of 24.47±3.5. Emergence of the adult required an average of 93.79±1.76 and ranged from 68-116 days, starting from egg laying. A total of 19 adults emerged out of which 7 were females and the rest 12 were males. Though the number of males seems greater than that for females the variation was not significant (P>0.05), (χ^2 =1.316, P=0.251).

4.1.3 Morphology (Structure) of the different developmental stages

Eggs:

The eggs are dull white, have ovoid spherical shape (Figure 1). They are soft shelled and able to bounce nearly half a meter when dropped to the floor. Newly laid eggs measure about 1.16± 0.04 mm. width and 1.33±0.034-mm length. When approaching to hatch, the egg color changes to yellowish, enlarges and measure 1.63±0.042 in width and 2.14± 0.07 mm in length (Table 3). The mean volume of newly laid egg was 0.96 mm^3 and that of an egg approaching hatching was 0.98 mm^3.

Larvae: -

The larvae have three instar periods, which could be grouped based on head capsule width development (Table 4). The larval stage from the first day up to about the 25^{th} day, with mean head capsule width of 1.08±0.32-mm, was considered as instar one. From day 26 to around the 40^{th} day and with an average head capsule width of 1.93±0.04 was taken as second instar. After around the 40^{th} day on wards, with mean head capsule width of 2.88± 0.02 mm was considered to be third instar.

The body length of the larva was not considered to determine the larval instars for the development was more or less continuous up to around the 52^{nd} day in which an average of 30.2 ± 0.28 mm was recorded, and then after, it began to decrease and at about around the 70^{th} day it was found to be 28.76±0.4mm. The larvae had smooth heads, yellow to brown-yellow colour, posses a transverse anal slit fringed with lines of short hairs. They are translucent white throughout most of their age. They however become opaque white towards the end of their larval stage. The larvae have three pairs of thoracic legs, which are claw-less,

but fringed with lines of hairs. However, they don't use their legs for walking, they move on their back by peristalytic fashion. They are active and fast moving, whenever exposed to the surface of the soil, they avoid light and penetrate back in to soil pushing their head downward. The larvae live in and feed on soil, utilizing cow dung as nutrient. They excreted small pebble like soil particles. A pair of thoracic and 8 pairs of abdominal spiracles was observed in the present study (Fig. 1).

Pupae: -

The pupae were formed in an egg shaped cocoon, made of fine soil particles. The inner part of the cocoon was found smooth. In Petri dishes, most of the cocoons were formed below the soil attached with the container. However, in bigger containers; they were formed in the soil (Fig. 1).

Adults: -

Based on both the field observation and the laboratory results, it was confirmed that *P. interrupta* are univoltine insects. According to the present findings, the adults of this species can be grouped into two phases. The first, those that emerge from the soil emerging directly from pupae starting from around the end of August up to the end of September or the beginning of October. Their emergence was synchronized with flowering and seed formation of sorghum, their primary host. These are very active, bright shiny long distance fliers and serious pests, coming out and flying in large number. During the present study, they were observed in large number, around Shewa- Robit of the ANRS, arriving from the direction of the boarder with the Afar Region. They were found feeding on the flowers of *Abution spp.*, sunflower, *Acacia spp.*, *etc.*, but most seriously on sorghum. They were busy feeding actively on the milky stage of sorghum seeds. In the daytime starting around from 9 AM up to around 5 PM, in which an average temperature was 29-30^{o}C, they were

extremely active and flyaway when disturbed or approached. But at around 5:30 PM on wards, they become less active and could be picked up carefully by hand. In the night, they rest usually aggregating on sorghum head or on any other hosts on which they feed. Both in the day and at night, they were observed crowded in the space created between the flag leaf and the sorghum panicle. These first groups of beetles were not found mating both in the field and the long time they were kept in the laboratory. After feeding actively for some days, even by migrating to areas where immature stages of sorghum were found, and after accumulating food, when seeds become matured enough they enter in to the soil. Out of 5574 *P. interrupta* collected from the field 2922 (52.42%) were found to be males and the rest, 2652 (47.58%) were females. Chi-square analysis indicated that there was a significant sex variation (χ^2 =13.08; P=0.000) between males and females.

Many of the beetles were found to be dead during this diapausing period. This can be confirmed from the dead remains of the adults in and outside the diapausing sites. The live diapausing adults were discovered from places that were not exposed to direct sun depending to topography and vegetation cover of a particular site. The depth of the soil that the live diapausing adults were discovered varied from around 10-60 cm. In all cases, in spite of the high environmental temperature, which was ranging from 28-35°C, the soil was slightly moist with temperature range of 23-25.5 ^{0}C.

The second phase is formed from these diapausing adults, when emerged synchronizing with flowering of plants such as *Acacia* spp., *Acacia mellifera*, *Ximenia americana* and others, resulted from rains around June. These groups feed and mate on the flowers, and lay eggs in the soil. Under the field condition, they neither fly long distances nor survive long after ceasing egg laying.

Morphologically, both the first and the second phases are similar. Both have variable colour

from nearly completely black to almost completely pale- yellow but with a distinct colour patterns of elytra (Fig. 1). Pygidium is black and almost always with four white spots. Males are identified by their transverse shallow grooves on the abdomen. Females have a convex abdomen. The average body size from the beginning of pronotum to the tip of elytra is 15.1±0.57 and ranges between 12 and 18mm., while the width across the beginning of the elytra is 7.55±0.24 and in terms of size no significant difference was observed between male and female (Table 3).

Table 1:Oviposition rate of *Pachnoda interrupta* under laboratory condition.

Dates	period (days)	Total no of eggs laid	No of egg per female per day
6-9/9/01	3	76	1.06
10-12/9/01	3	58	0.81
13-15/9/01	3	4	0.06
16-18/9/01	3	20	0.28
19-21/9/01	3	20	0.28
22-26/9/01	4	28	0.29
27/9/01-01/10/01	6	141	0.98
6/9/01-01/10/01	25	347	0.58

*Temperature 25 ^{0}C and soil moisture of 17 were used.

Table 2: Duration of the immature stages of laboratory reared *P. interrupta*

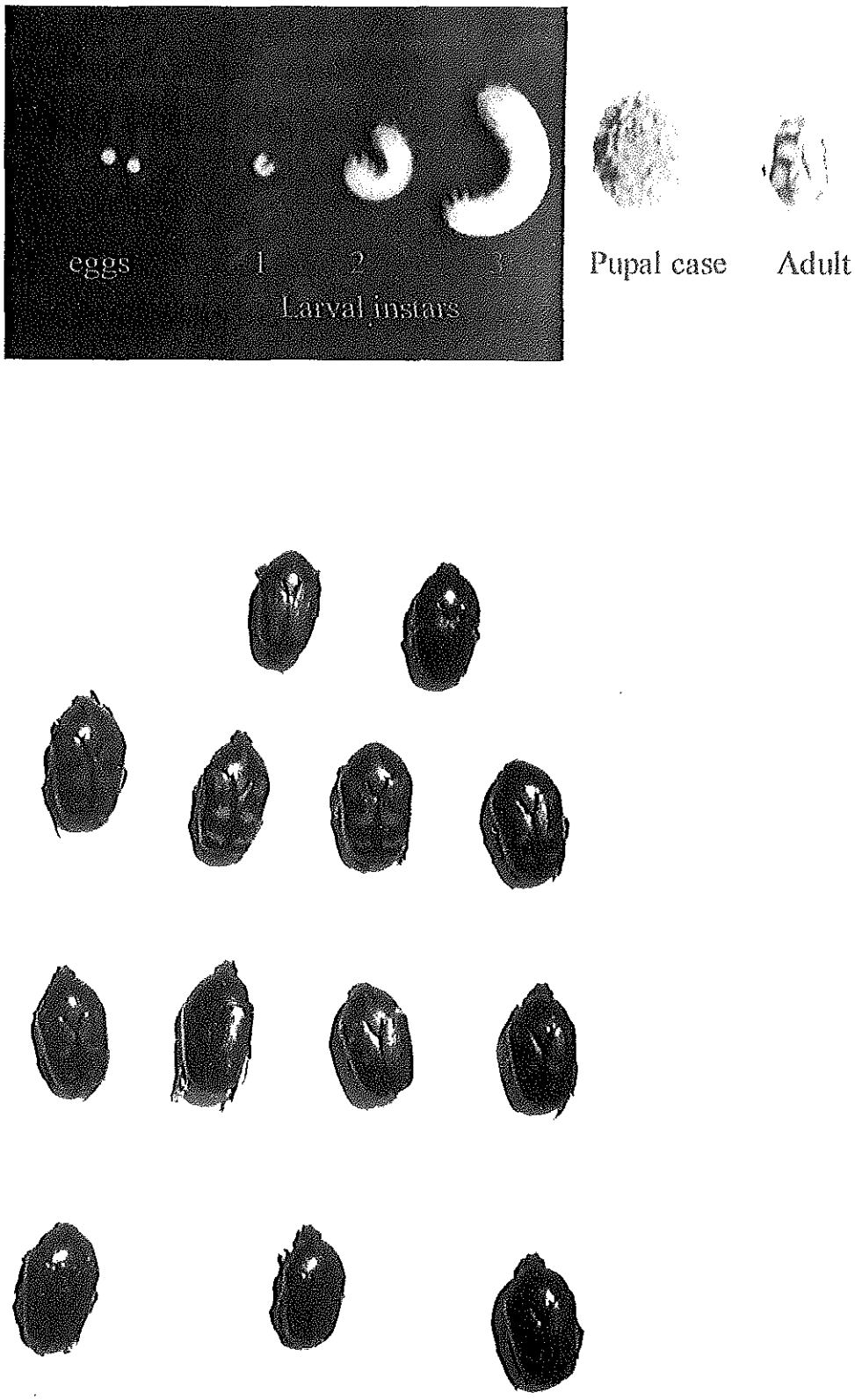
stages	Period of stages(days)	Total numbers observed	percentage survived
	mean±SE		
Eggs	9.63±0.14	48	86
Larvae	59.69± 1.64	28	58.33
Pupae	24.47±0.80	19	67.86
Adult	93.79±1.76	19	100

Table 3: Average size of eggs and adults of *P. interrupta*

Stages		Length (mm)	Width (mm)	Volume (mm^3)
		Mean ± SE	Mean ± SE	Mean ± SE
Eggs	New	1.33±0.03	1.16±0.04	.96±0.07
	Old	2.14±0.07	1.63±0.04	.98±0.07
Adult	Female	15.1±.55	7.2±0.25	
	Male	15.1±0.57	7.9±0.23	

Table 4: Growth rate of larvae as indicated by the width of the head capsule.

Age of larvae (days)	Means ± SE body length (mm)	Means±SE of head capsule width (mm)
1-25	8.74±0.21	1.08±032
26-40	21.15±0.39	1.93±0.04
41-73	28.85±0.19	2.88±0.02



Adults with different colour patterns.

Fig. 1 Photographs of *Pachnoda interrupta*

4.2 Effect of soil types on the development of larvae

4.2.1 Egg hatching and survival of larvae during the first week

Mean number of days required for eggs to hatch and number of larvae survived for a week in the different soil types are shown in (Table 5). Differences in length of days between egg laying and hatching in different soil types had been observed. According to this observation, soil types 8,1,5 and 6 had shown significantly ($P < 0.05$) shorter egg hatching period. On the other hand, soil type 2 and 13 had shown significantly ($P < 0.05$) higher egg hatching period, all the others are intermediate between these two.

4.2.2 Development of larvae and pupae

Mean body length and head capsule width of *P. interrupta* larvae reared in different soil types is given in (Table 6). The results indicate that there was significant variation ($P<0.05$) in body length and head capsule width of *P. interrupta* larvae reared in different soil types. Addition of 25-50% manure to the different soils has greatly improved all the soils for larval growth. The sandy soil, which led to least growth compared with the other two, when used unmixed proved to be the best when 25 and 50% manure was added. However, when the amount of manure was increased exponentially larval growth and survivability decreased. On the other hand, when the organic carbon was minimized through heating, growth of larvae was highly minimized and all larvae died after short time.

4.2.3 Effect of soil types on survival of the different stages

Results on duration (survival) of immature stages and number of adult *P.interrupta* reared in different soil types are shown in (Table 7). According to this result, addition of manure significantly ($P<0.05$) improved by making short the duration of the different stages of *P.interrupta* and the number of adults emerged. In the three burned and the sandy soils, where manure was not added no, larval development was completed and no pupae were formed. In soils from Afar and Tikur Inchini, only few larvae (3 and 2) respectively completed their larval stage, but after pupating for 1,7 and 16 days in the Afar soil, and for 15 and 21 days in the Tikur- Inchini soil they died before emerging to adult.

The mean period required to complete larval stage, was 112 and 90 days in Afar and Tikur-Inchini soils, respectively. These were shortened to 67.13 in Afar and 64.67 in Tikur-Inchini, when the soils were mixed to a quarter of manure soil. The concentration of cow dung (25-50%) which favored more larval growth rate did not however shorten the total life cycle. Addition of more manure favored or resulted in to short life cycle. In the 100% manure soil (with about 10% of organic carbon), the time required from egg hatching to adult emergence was on average 80.4 ± 2.91 days. This time was elongated to 81.3 ± 2.09, 84.4±1.2 and 89.4 ±1.47 when only 50% of manure was added to sandy Tikur- inchini and Afar soils, respectively (Table 7).

Generally, when cow dung was mixed with different soils, it improved both rate and percentage of larval growth and shortened the time required to complete the life cycle of sorghum chafer, especially it greatly improved sandy soil to suit the beetle's development.

Table 5: Mean number of days required for eggs to hatch and number of larvae survived up to the first week in different soil types

Soil type	Incubation period(days) Mean±SE	No.of Larvae
1. Afar natural	6.62± 0.14 ab	13
2. T. inchini natural	7.86 ±0.38d	14
3. Sandy natural	6.85 ±0.3abcd	13
4. Afar + 25% manure	7.45 ± 0.51abcd	11
5. T. inchini 25% manure	6.71 ± 0.29abc	14
6. Sandy + 25% manure	6.77 ± 0.12abc	13
7. Afar+50% manure	7.14 ± 0.23abcd	14
8. T. inchini 50% manure	6.54 ± 0.14a	13
9. Sandy + 50% manure	7.43± 0.39abcd	14
10. Afar- burned	7.69 ± 0.37cd	13
11.T. inchini-burned	7.6 ± 0.4bcd	10
12. Sandy-burned	7.0 ± 0.0abcd	10
13. 100%- Manure	7.8 ± 0.47d	12

Means within columns followed by the same letter are not significantly different from each other; $P<0.05$, DMRT.

Table 6: Mean body length and head capsule width (mm) of *P. interrupta* larvae reared in different soil types

	Soil type	Mean body Length(mm) ± SE	Mean head capsule Width(mm) ±SE
1	Afar natural	4.68± 0.36e	0.59 ±0.04e
2	T. inchini natural	3.86±0.37e	0.48±0.04e
3	Sandy natural	0.99±0.15f	0.18±0.03f
4	Afar + 25% manure	8.87±0.56d	0.91±0.05d
5	T. inchini 25% manure	10.96±0.55ab	1.23±0.11a
6	Sandy + 25% manure	10.87±0.50ab	1.12±0.04ab
7	Afar+50% manure	9.52±0.54cd	1.04±0.05bcd
8	T. inchini 50% manure	10.25±0.64bc	1.09±0.06abc
9	Sandy + 50% manure	11.65±0.59a	1.22±0.06a
10	Afar- burned	0.83±0.13f	0.117±0.03f
11	T. inchini-burned	0.48±0.09f	0.12±0.02f
12	Sandy-burned	0.79±0.13f	0.16±0.03f
13	100%- Manure	8.43±0.61d	0.94±0.08cd

Means within columns followed by the same letter are not significantly different from each other; $P<0.05$, DMRT.

Table 7: Duration (survival) of immature stages and number of adults emerged in *Pachnoda interrupta* in different soil types in laboratory.

Soil type	Days required for the immature to change and for the adults to emerge (from larvae to adult)								
	Larvae			Pupae			Adults		
	Mean days	Nos obser	% of survival	Mean days	Nos obser	% of survival	Mean days	Nos obser	% of survival
1	112±11.79a	3	21.43	-	-	-	-	-	-
2	903±.0b	2	14.29	-	-	-	-	-	-
3	-	-	0	-	-	-	-	-	-
4	67.1±2.2c	8	57.14	27.4±1.21a	7	87.5	93.4±1.21a	7	100
5	64.3±2.24cd	9	64.29	28.5±0.99a	8	88.89	91.9±3.1a	8	100
6	66±2.47c	8	57.14	21.9±1.04b	8	100	87.9±2.45abc	8	100
7	61.2±3.62cd	5	35.71	28.2±2.62a	5	100	89.4±1.47ab	5	100
8	57±2.8cd	7	50.0	24.3±1.87ab	7	100	81.3±2.09cd	7	100
9	57±1.22cd	9	64.29	27.7±0.67a	9	100	84.7±1.20bcd	9	100
10	-	-	0	-	-	-	-	-	-
11	-	-	0	-	-	-	-	-	-
12	-	-	0	-	-	-	-	-	-
13	53.4±2.2d	5	35.71	27±.95a	5	100	80.4±2.91d	5	100

Means within columns followed by the same latter are not significantly different from each other $P<0.05$, DMRT.

4.3 Effect of soil temperature and moisture on the development of immature stages and the depth of pupation

4.3.1 Effect of soil temperature and moisture on the development of the immature stages

The effect of soil temperature and moisture on the mean number of eggs hatched and survival of larvae up to the first week are presented in (Table 8). Comparison between lower and higher temperatures showed a significant effect ($P < 0.05$), on egg hatching and survival of the young larvae until one week from hatching. As the temperature increased, the suitability decreased. The effect of moistures did not show significant effect ($P > 0.05$) on egg hatching and survival of the larvae during the same period. But generally higher number of egg hatching and survival was observed at moistures of 17% and 23% and declined as the moisture decreased to (9%) and increased to (29%) (Lower and upper bounds of moisture tested).

The results on effect of soil temperature and moisture on the development of the larvae is given in (Table 9). Soil moistures showed significant variation ($P < 0.05$) on larval development and survival. Effects of soil moistures of 17% and 23% were significantly superior to larval body growth and head capsule width. As the moisture decreased to (9%) and increased up to (29%), larval growth went on decreasing. Temperatures also caused, significant effect ($P < 0.05$) on the development of all larvae (Table 9). As can

be observed from this table, the larval development rate at temperatures of 20 ^{0}C, 25 ^{0}C and 30 ^{0}C were not significantly different among themselves and all were significantly less than that at 35 ^{0}C.

The effect of soil temperature and moisture on duration of immature stages and emergence of adults is given in (Tables 10 and 11). Soil moisture showed a significant ($P< 0.05$) effect on larval duration and the development of larvae to pupae (Table 10). In the lowest moisture used (9 %), days required for larvae was significantly higher ($P<0.05$), than the rest .The more effect of low moisture was observed, as the failure of pupation so also adult formation. As the moisture increased to 17, 23 and 29%, the time required to complete the lifecycle was not significantly different ($P>0.05$), though it showed a decrease from 80.8, 72.5 to 65 days respectively. But as it can be observed from the numbers completed the total lifecycle, moistures 17and 23%were more suitable. At moisture of 29% only fewer were able to complete and these were only in higher temperatures, 30 and 35 ^{0}C.

Temperature had significant effect ($P<0.05$) on duration and lifecycle completion of *P. interrupta* (Table 11). Larval and pupal duration and total time required for emergence of the adult decreased significantly ($P<0.05$) as the temperature increased to 25, 30 and 35 ^{0}C. At the lowest temperature tested (20 ^{0}C), the time required for larval duration was the longest, pupation did not successfully occurred and none emerged to adult (Table 11). But as the temperature was, highly increased (35 ^{0}C) fewer numbers were able to complete their lifecycle and these were only in higher moistures of 23 and 29%.

4.3.2 Effect of soil temperature and moisture on the depth of pupation site

The effect of soil temperature and moisture on the depth of pupation site is given in (Fig. 2). Soil moisture had shown significant effect ($P<0.05$) on the depth of pupation site of *P.interrepta*. When soil moisture is less (9%), the larvae went down to depth of 26.79 ±0.46cm.into the soil to pupate and when the soil moisture is high (29%), they remained in the upper layers (only 7.83±0.98cm deep) in the soil for pupation (Appendix 4 and 5). Soil temperature however didn't show significant effect ($P> 0.05$) on pupation depth (Appendix 4 and 5).

Table 8: Mean number of hatched eggs and larvae survived for a week at different temperatures and moistures.

Soil moisture (o/o)	Number of larvae survived Mean± SE
9	6.25±1.18
17	7.25±0.48
23	7.75±0.25
29	6.25±1.75
Temperature (° C)	
20	8.0±0.00 a
25	8.0±0.00 a
30	7.4±0.58 a
35	4.5±1.5 b

*Moisture did not show significant variation

Means within columns followed by the same letter are not significantly different from each other; $P<0.05$, DMRT.

Table 9: Mean body length and head capsule width (mm) of *P.interrupta* larvae in different moisture and temperature regimes of soil.

Temperature (^{0} C)	Larval body length Mean±SE	Larval head capsule width Mean±SE
20	7.3 ±0.3b	0.79 ±0.03b
25	7.21± 0.35b	0.77±0.03b
30	7.12± 0.47b	0.74± 0.05b
35	9.6± 0.52a	1.05± 0.06a
Moisture (%)		
9	4.8± 0.28c	0.56± 0.03c
17	10.06 ±0.45a	1.04± 0.05a
23	9.14± 0.49a	0.98± 0.05a
29	7.22± 0.43b	0.76± 0.04b

Means within columns followed by the same letter are not significantly different from each other; $P<0.05$, DMRT.

Table 10 : Mean duration(days) of immature stages and adult emergence of *Pachnoda interrupta* reared in laboratory at different ranges of soil moisture.

Moisture	Days required for the immature to change and for the adults to emerge		
(o/o).	Larvae(Mean ± SE)	Pupae (Mean ± SE)	Adults(Mean ± SE)
9	72.5±8.61b	–	–
17	66.5±4.24a	23.92 ±1.68 a	80.8±4.3a
23	58.71±3.42a	22.5±2.52a	72.25±4.09a
29	59.7±5.12a	17.33±2.44a	65.0±0.00a

Means within columns followed by the same letter are not significantly different from each other; P<0.05, DMRT.

Table 11: Mean duration (days) of immature stages and adult emergence of *Pachnoda interrupta* at different temperatures

Temperature(^{0}C)	Larvae Mean ±SE	Pupae Mean ±SE	Adults Mean ±SE
20	73.0±3.52c	19.63± 2.89c	–
25	72.0± 4.3bc	22.0± 1.26ab	86.75± 2.84c
30	52.0± 4.27a	26.08 ±1.58b	73.86 ±2.96b
35	50.0 ±4.18a	15.0± 0.00a	62.0± 1.73a

Means within columns followed by the same letter are not significantly different from each other; P<0.05, DMRT.

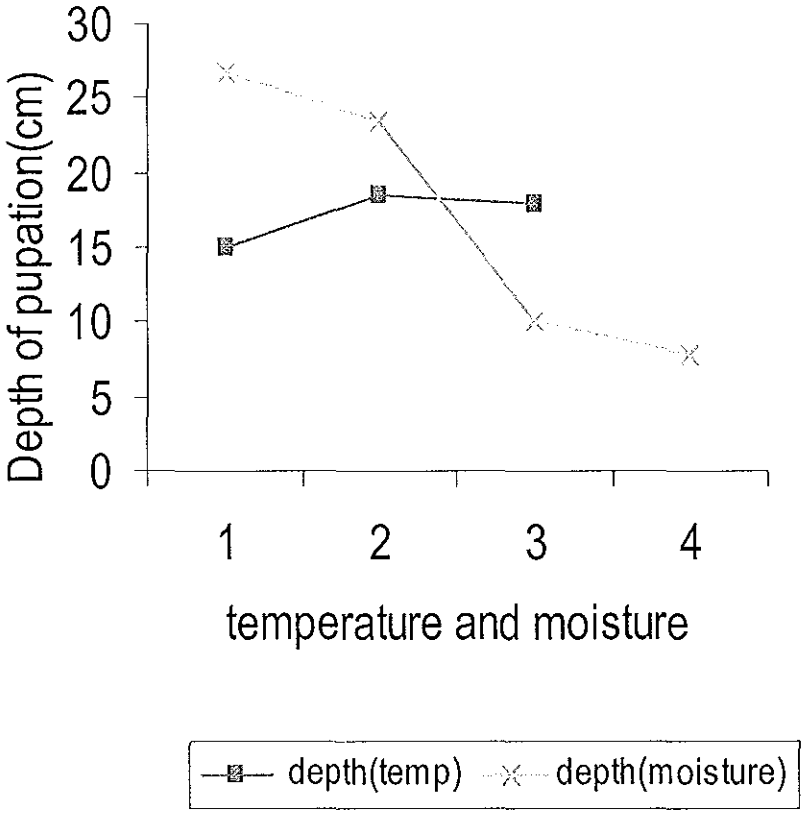


Figure 2: The effect of soil moisture and temperature on the depth of pupation site

4.4 Study on Bait (food choice) test

The results on the numbers of *P. interrupta* adults that preferred a particular food source are given in (Table 12). The number of insects, which have selected a particular type of food source, showed a significance variation ($P<0.05$). Out of eight types of food sources by type used, ripe banana was the most preferred followed by ripe guava. All residues of "katicala","tej' and local beer, corn flour, and roasted sorghum flour were selected, by the target insect with no statistically significance difference between them. None roasted sorghum was found to be the least preferred.

The sex ratio analysis on food sources most preferred did not show significant variation between sexes, but slightly favored to females. Out of the total 732 experimental beetles that chose banana, 383(52.32%) were females and the rest 349(47.68%) were males (χ^2 =1.579,P=0.209). Similarly out of 143 beetles, 78(54.55%) female chose guava, and the rest 65, (45.45%) were males (χ^2 =1.82,P=0.277).

Table12: Mean Number of *P. interrupta* adults attracted to a particular food substance

No	Food type	Means±SE
1.	Residue of " katicala"	1.75±0.29bc
2.	Corn flour	1.85±0.39bc
3.	Banana	15.29±1.35a
4.	Guava	2.98±0.47b
5.	Residue of" tej"	1.44±0.30bc
6.	Roasted sorghum flour	1.65±0.33bc
7.	Residue of local beer	1.65±0.28bc
8.	Non roasted sorghum flour	1.11±0.29c

Means within columns followed by the same letter are not significantly different from each other, $P<0.05$; DMRT.

4.5 Study on factors contributing to diapause

4.5.1 Study on Environmental factors associated with diapause

Searches for diapausing beetles were made in a number of places although live diapausing adults were found only in a few places, (less than 10%) of the places checked. In many places, few or many dead *P. interrupta* were found on or near the surface or deep in the soil.

In the first search which was made in Afar region around Melka-Worer in November 2001, a total of 58, adult beetles out of which 30 females and 28 males were found. The differences in sex of the beetles were not significant at 0.05 level (χ^2 =0.069, P=0.793). The diapausing locations were not exposed to direct sun either because of topography or vegetation cover. *Prosopis juliflora, a* plant, which is not indigenous to the region, was found harboring a considerable number of beetles under its dense shade caused from its very green leaves. The depth in the soil from which insects were found varied from 25-60 cm. In all cases the soil temperature was in the magnitude of 25-25.5 ^{0}C while the environmental temperature at around 9.00 AM was 28 ^{0}C and 35 ^{0}C at around 2:30 PM. Most were found in the free spaces created by roots of the plant in the soil, around and between the roots. These insects were taken to APPRC as mentioned in materials and methods. Twenty-six females and twenty-two males survived in a glasshouse until the 26th of March 2002 (for 119 days), a day on which they were killed for physiological analysis. In this last day, though they were not able to fly, were walking actively.

In the second search, which was made in ANRS, a considerable number of experimental insects were found only in a few places around Shewa-Robit. A total of 131 adult beetles, out

0.05 level of significance (χ^2= .924, P=. 337). In these places the insects were not again exposed to direct morning or after noon sun. In all cases insects were found in soils shaded by trees or shrubs such as *Acacia* spp. and others. The temperature of the soil in all these places was at an average of 23 ^{0}C, while environmental temperature varied from, 27 ^{0}C at 10AM, 29 ^{0} at noon and to 31 ^{0}C at around 2 PM. They were found in a depth of only10-21 cm in the soil. A week before and two days after our arrival there was a small shower of rain as a result of which the soil was comparatively moist. In most of the places, where the beetles were discovered, the soil was rocky or covered by plant debris, and found either between cracks of the rocks or near roots

4.5.2 Study on physiological factors

Results obtained from the study on physiological factors are given in (Figure 3 and 4).

Dry weight (DWT): showed significantly different (P< 0.05) measurements made in different days, both in females and males. Highest body dry weight was measured on day 5 in females and both in day 5 and 6 in males. The least measurement was made on day 1 both in females and males, but in males the same was recorded on day 4. The DWT was found to be intermediate on days 2 and 3 in males and on days 2, 3 and 6 in females.

Fat weight; was found to be significantly different (P< 0.05) both in females and males. In both it was significantly higher on day 2 and 3. Followed by days 4, 1, 5 and least in day 6 but with out statistically significant difference.

Fresh weight (FW); was significantly different (P< 0.05) in both females and males. Highest FW was measured on day 2 both in females and males followed by on days 3, 5 and 6 and 1. The least FW was recorded on day 4.

Lean dry weight (LDW); was significantly different (P< 0.05) both in females and males. In females the highest LDW was measured on day 5 flowed by day 6 and then by 3, 4 and 2, respectively. In males the highest amount was measured on days 6 and 5 followed by on days 3, 2 and 4.The least amount was measured on day 1 in both males and females.

Water weights (WW); showed significant difference (P<0.05) both in females and males. In both sexes the highest WW was recorded on days 1 and 2, but in males similar result was recorded on day 3 also, followed by on days 5 and 4, where as the record on day 6 was the least. The record on day 3 was second followed by on days 4 and 6, while the least measure was on day 5 for females.

4.5.3 Study on effect of feeding

The effect of feeding on diapause conditions is given in (Table 13). Variation in number of survival and weight of beetles has been observed in different feeding programmes. However these variations are highly dependent on provision of food early or late, but not on variety, amount or frequency of feeding. As long as the young adults were fed early in their life and able to accumulate food reserve, they are able to live long with small or even with out food in the later stages of their life, but if they deprived of food early in their adult life they die immediately.

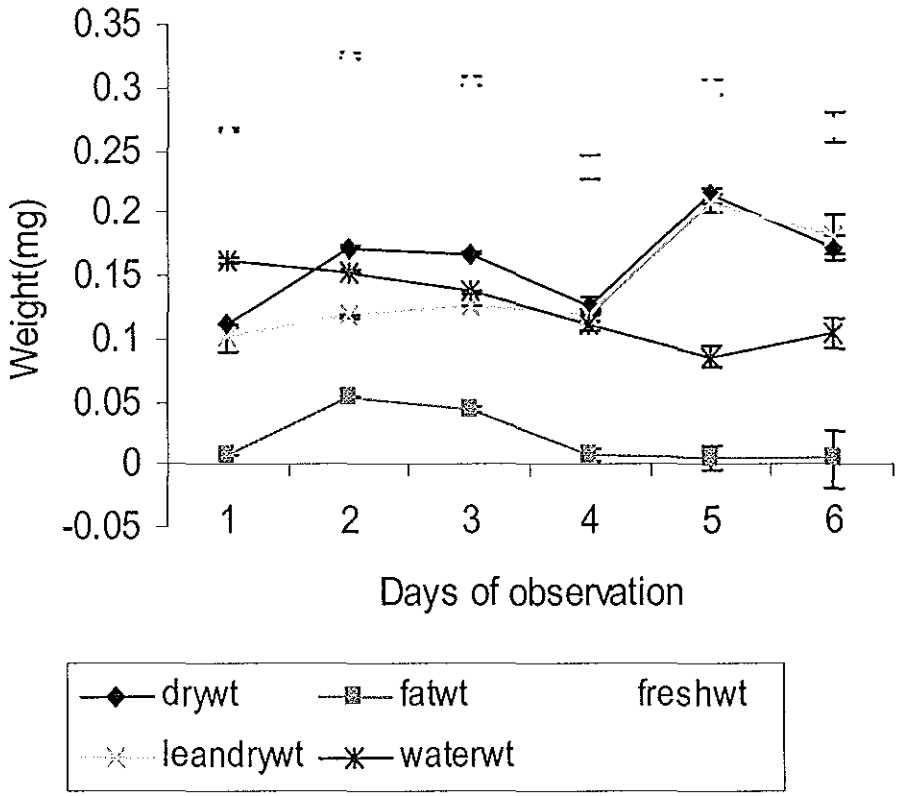


Figure 3: Physiological factors measured for females *P. interrupta* at different days,1-3 (pre-diapause) and4-6 days (during diapause)

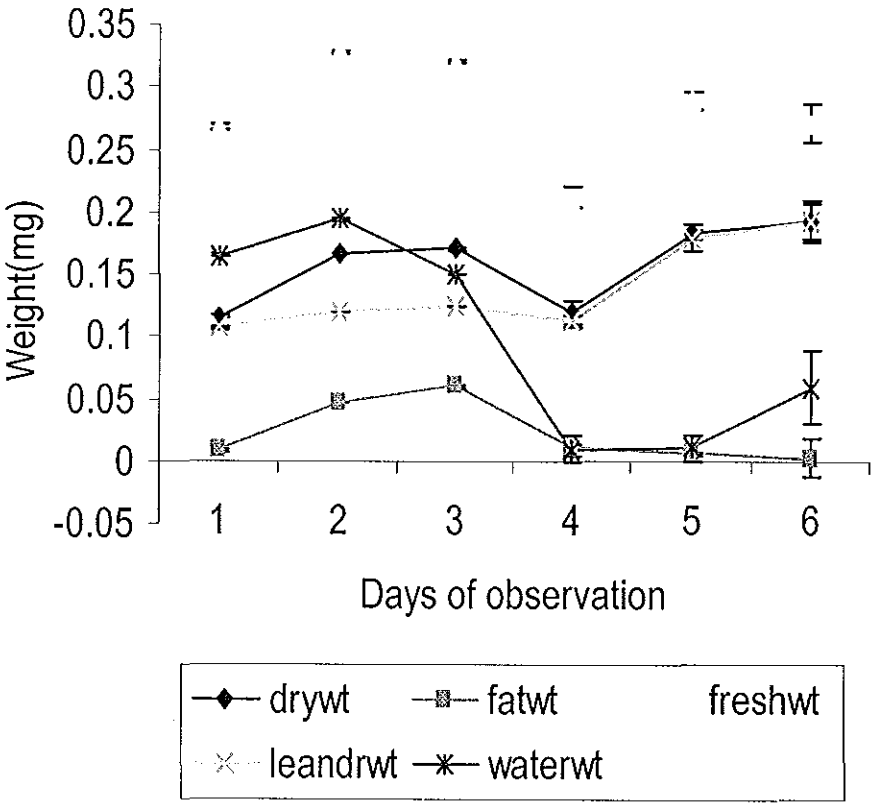


Figure 4: Physiological factors measured for males *P. interrupta* at different days,1-3 (pre-diapause) and4-6 days (during diapause)

Table13: Mean survival and weight of *P. interrupta* adults after being fed for 45 days on different foods and different time interval.

Number	Feeding condition	Mean number of survival		Mean weight(mg) per individual	
		Female	Male	Female	Male
1	Fed daily with- variety of food	21.5±1.5b	23.0±0.0b	6.67±0.63b	7.42±b
2	Fed daily with - banana	23.5±0.5ab	24.5±0.5a	7.71±0.06a	7.72±b
3	Fed every 4 days-variety food	23.5±0.5ab	25.0±0.0a	7.34±0.07ab	8.22±a
4	Fed every 4 days-only banana	24.0±0.0a	25.0±0.0a	7.64±0.28a	7.72±b
5	Fed every week-variety of food	24.5±0.5a	25.0±0.1a	7.56±0.1ab	7.25±b
6	Fed every week-only banana	24.0±0.0a	24.0±0.5a	7.07±0.0ab	7.9±a
7	Not fed	0.0±0.0c	0.00±0.0c	0.0±0.0c	0.00±c

Means within columns followed by the same letter are not significantly different from each other, $P<0.05$; DMRT.

5. DiSCUSSION

An oviposition rate of 0.58 eggs/female/day was obtained on F1-generation of laboratory-reared beetles. This is less when compared to that reported by (Seneshaw Aysheshim and Mulugeta Negeri, 2000), as being 1.8 eggs/female/day. The reason for these differences could be accounted to the source of the insects and in the methodologies used for egg collection. The source of insects used in the present study was laboratory reared and was not exposed to natural environment to collect nutrients, which could have enriched their ovary mainly with amino acids. Many workers who dealt with different insects in this regard suggest that the rate of egg production is higher when insects feed on a diet, which contains protein. Donaldson (1985), who worked on *P. sinuata flaviventris* showed that, the group fed with pollen laid twice as many eggs on the same period as those which were denied of pollen although the time the eggs took to hatch was similar in which 80% of the eggs laid hatched.

In bees similarly as the proportion of pollen in their diet increased their longevity was also positively correlated. Improved ovary development and egg lying in the queen, were also recorded which is probably due to the fact that pollen contains all the essential amino acids (Stanley and Linskens, 1974). The fact that the reproductively matured adults, that emerge during towards the end of June to the beginning of July mainly depend as food on *Acacia* Spp. and other yellow flowers, supports the assumptions mentioned above. Constant disturbance of egg laying adults for egg collection affected egg laying (Donaldson, 1992). So this could be another reason for less oviposition rate observed in the present study.

The size of eggs laid in the preset study ranged from 1.0-1.4mm in width to a length of 1.3-1.6 mm with an average of 1.33±0.034 in newly laid eggs and 1.5-1.9mm in width and 1.9-2.4mm in length averaging 2.14±0.07 in eggs approaching to hatch. These results were in agreement

with that of Grunshaw (1992), in which he found 1.23 mm width and 1.4 mm length in newly laid eggs and 1.72 mm width and 2.10 mm length in eggs at hatching.

In the present results, egg hatching period, (9.63 days) and percentage of survival (86), was less than that of Seneshaw Aysheshim and Mulugesta Negeri's (2000) which according to their reports were 11.3 days and > 95% respectively. The percentage survival of larvae was also less (Table 2) compared to that of Seneshaw Aysheshim and Mulugeta Negeri (2000), which according to their finding was also more than 95%. This discrepancy could be also due to variations in the methodologies used. In the present study, eggs were collected every two days and measurements were taken every four days but in the previous work they took every 5 days for both. Collecting eggs daily would have been more real in determining hatching period, for it were not disturbing egg laying adults (Donaldson, 1992). In the study made on *Anisrrina flvomaculata* (Citoniinae), Donaldson (1992), found that constant disturbance of the larvae to determine instar periods reduced the pupal survival rate from a possible 77% to 37%.

The present findings on average larval duration, 59.69±1.64 days and the total time to complete the life cycle, 93.79±1.76 day were different from that by Seneshaw Aysheshim and Mulugeta Negeri (2000), in which 55.7 and 85.9 days were required for larva, and completion of the total life cycle, respectively. In Grunshaw's (1992), work mean larvae duration was 43.3 falling in the range of 39-50 days. These differences most probably have been, caused because of the differences in temperature regimes used. In the present study 25°C was used, while the above mentioned works were performed at 28±2°C and 30°C, respectively. Ambient temperature is known to be the most important factor governing insect development time (Lamp and Gerber, 1985). The change on development rate is linear in the middle temperature range, fastest at the optimal temperature and then decreases, along increases beyond the optimum (Wagner *et al.* 1984). Even though neither the present study, nor that of Seneshaw

Aysheshim and Mulugeta Negeri (2000) and Grunshaw (1992) did show the optimal temperature, that of Grunshaw (1992) was nearer to optimal as expressed by shorter life cycle. This was confirmed by another part of the present study, which dealt with effect of temperature and moisture on the development of *P. interrupta*. As the temperature increased from 25, 30 to 35 ^{0}C day of larval duration also changed to the next stage and went down from 72.0±4.3 to 52.0 ± 4.27 and 50.0 ± 4.18 consequently (Table 11). The temperature around 30 ^{0}C seemed to be optimal for *P. interrupta*. The shortest larval time at 35 ^{0}C does however not on its own confirm that temperature was the most detrimental, because only few of the experimental insects were able to complete total life cycle. The early immature stages were particularly affected by high temperature. The effect of lower temperature on pupae was also observed as it led to delayed adult emergence where it increased from 62.0±1.73, 73.86± 2.96 and 86.75± 2.84 as the temperature decreased from 35, 30 to 25 ^{0}C and agreed with previous work by Ramesh and Azam, (1988), in which the holding of pupae at lower temperature significantly delayed the adult emergence when compared to the days of emergence held at ambient temperature. Another reason for difference in larval duration could be from the frequency of larval measurement days. The larval period varied enormously from73 to 377 days, most of these being spent in third instar due to disturbance of the larvae to determine instar periods (Donaldson, 1992).

Our observation ceased on 16/01/02, counting 14 males and 11 female adult beetles, 4 months and 10 days after they had begun laying eggs. This is in agreement with that of Seneshaw Aysheshim and Mulugeta Negeri (2000), who demonstrated, the survival of sexually matured beetles for six months after lying, eggs. On the other hand, Clark and Crowe (1977) reported that, once sexual maturity is attained, mating takes place and is soon followed by egg laying and death. These differences could have been due to the differences on experimental places, in

which both the present study and that of Seneshaw Aysheshim and Mulugeta Negeri (2000) were under laboratory conditions as opposed to that by Clark and Crowe (1977) who carried their study under field conditions, where food supply is seasonal.

The instar number and period determination based on head capsule width in the present study showed certain agreement with that of Seneshaw Aysheshim and Mulugeta Negeri (2002),which was based on frequency distribution of head capsule width and found 1st instar below 1.43mm, 2nd above 1.84mm and 3rd above 2.84 mm. A wider variation was observed in instar 1 and also difficulties were encountered in separating 2nd instar from the other two. This difference and the difficulties could have arisen from the difficulty in measuring alive larvae.

Knowing where the breeding site of *P. interrupta* is one of the most serious problems regarding this pest. Based on Clark and Crowe (1977), cow dung is the most important indicator of breeding site in arid areas, Hiwot Lemma *et al.* (1999), during their field observation paid a special attention to search these areas, however did not find larvae in all cattle dung samples nor in goat or sheep dung heaps they looked in to. Mulugeta Negeri, from APPRC entomology department (pers.comm.) similarly dug out soils in different places at different times looking for *P. interrupta* adults in cow dung in Afar region with no apparent successes.

The present study as opposed to previous reports, however, confirms that cow dung (others need to be verified) was very essential for completion of the life cycle of *P. interrupta* in all soil classes (Appendix 1). Sandy, clay, silt alone, or high or less organic carbon content, in acidic basic or around neutral PH, *P. interrupta* did not complete its life cycle. Addition of a small proportion of cow dung to all these soils made the mixtures suitable for this beetle thereby improving and making, the sandy soil most preferred (Tables 6 and 7).

In the present study, depth of pupation had no significant impact, due to soil temperature. This could be explained in relation to the nature of a particular soil in terms of heat transfer. Leather *et al.* (1993), elucidated that soil is poor conductor of heat and range of daily temperature variation decreases with increasing depth thus providing more stable temperature. The assumption is thus despite the external temperature variation, there could have been soil with less variation in temperature, at the centers of the pots, where most of the pupal cases were found formed.

Moisture showed a significant negative correlation ($P< 0.05$) with depth of pupation sites. As moisture decreased depth of pupation increased and in higher moisture levels pupation was formed at relatively shallower depths. The relation of pupation to soil moisture could be attributed to the importance of moisture (water) to construct the earthen cocoon. Donaldson (1985) and Seneshaw Aysheshim and Mulugeta Negeri (2000), indicated that when the larva is ready to pupate, it forms an oval cocoon made from soils cemented with larval saliva. This supports, the result in the present study for the experimental beetles went deeper and deeper, to find the soil water when scarce in the upper soil surfaces. Moisture as indicated in (Tables 9 and 10) of the present work, has influential effect on life cycle of *P. interrupta*.

Grunshaw (1992), used the term quiescent to express, overwintering in *P. interrupta*. In the present study however diapause was preferred, following the definitions given by Leather *et al* (1993) who explained diapause as most highly evolved system of dormancy for overwintering cyclic, long-term, extremes in environmental conditions. It was also believed that, unlike most other insects, diapause in *P. interrupta* was not initiated by abiotic factors, but by biotic factors such as nutrition. Both environmental and laboratory observations were the bases for this conclusion. In the field, the beetles disappeared when the host was maturing or scarce. This was not related to changes in physical conditions. In the laboratory, all the

experimental beetles died when denied food for 15 days and continued to survive for more than 3 months without diapausing when they were provided with food every day, at intervals of 4 days or every week (Table 13). This agrees with that of Blossey and Hunt (1999) that newly emerged adults require a feeding period to accumulate fat reserves to overwinter successfully.

The new generation, emerging directly from pupae, fed actively (so become worst pest), store sufficient amounts of nutrient and enters in to the soil for diapausing. In Ethiopia the natural environment for breeding as well as diapausing areas are very hot because of the latitude (around 9^0N) and mainly because of low altitudes usually below 1800 masl., particularly the diapausing season from November to end of May is known as dry season. Months from February to May are especially very hot.

Concerning soils as physical factors, *P. interrupta* adults were found diapausing in the depth of soils ranging from 10-21 cm and mean temperature of 23 ^{0}C around Shewa-Robit and 50-60 cms depth and temperature of 25-25.5 ^{0}C around Melka-worer, while maximum environmental temperatures were 30 and 35 ^{0}C, respectively. This was possible because according to Leather *et al.* (1993), by locating suitable overwintering site before on set of harsh conditions, insects can mediate the adverse effects. Conditions can be modified by local effects such as inclinations and aspects of slopes, vegetation, the nature of ground surface *etc.* (Flohn, 1969). Solid ground surfaces absorb all the energy in their top few centimeters. Heat transfer in the soil is by conduction and soil is poor conductor of heat. The range of daily temperature variation decreases with increasing depth, thus providing more stable temperature environment (Leather *et al.* 1993).

The depths at which the beetles were found in the soil around Melka-Worer and Shewa-Robit

were different. This is in agreement with that by Danks, (1978), in which he explained that the increased costs of burrowing, the deeper they go down and the fact that improved conditions effectively come latter, to deeper layers, insects can not simply burrow as deeply as they need, to escape, the cold /hot. Instead they have to balance the advantages of escaping the harsh winter conditions with the disadvantages of burrowing well in the soil, so migrate down wards to keep just ahead the advance of the adverse conditions (Benham and Farror, 1976).

As far as vegetation is concerned, in the present work all the diapausing adults were found under plant shades. This is in agreement with Barry and Chorleys (1976), who elucidates that the thermal environment above ground is further modified by vegetation. In forests, shelter from the sun, heat loss by evaporation blanketing at night, reduction of wind speed and the impeding of vertical air movement, all influence the temperature effects.

Before a successful overwintering can occur, insects must prepare themselves for the potentially dangerous conditions that lie ahead; these biochemical changes associated with cold hardness are often substantial e.g 25 percent of the fresh weight of overwintering *Bracon cephi* (Hymenoptera, Braconidae) is glycerol (Salt 1959). Cryoprotectants are usually manufactured only as winter approaches (Miller 1969). Abdominal lipid contents are vital to the overwintering survival of adult Lepidoptera (Pullin, 1987).

The death of all insects in the group that were not fed for 15 days in the present work (Table 13) agrees with statements mentioned above. That is unless they are pre-fed and prepared for the coming harsh conditions, the beetles could not undergo diapause successfully. At the same time the persistently increasing of lean dry weight, or size of the beetle and fat weight both in females and males obtained for prediapausing adults (days 1-3) (Figures 3 and 4) of the present work indicates that they were preparing themselves for diapausing successfully. This is

in agreement with Pullins (1987), who demonstrated that the feeding time allowed to the adult butterflies prior to diapause was significantly correlated with the weight of lipids present in the abdomen. The longer the adult butterflies fed before diapause, the longer they were able to survive over the winter. These could serve as an indications that the short prediapause period was used for fast growing and accumulation of food reserves, the absence of which led to death of all the experimental insects (Table 13). This finding however disagrees with that of Grunshaw (1992) in which he indicated that *P. interrupta* larvae hatching from eggs laid much later in the season and probably survived the dry season as adults or pupae. This is because unless they are pre-fed, the beetles cannot under go diapause successfully.

According to Wigglesworth (1972) cited in Wolda and Delinger (1984), the major obstacle to be surmounted by insects in diapause is obtaining sufficient energy. This problem is especially acute on adults, as these require more energy than larvae, pupae or eggs. During diapause, the metabolic activity is lower than when the insect is active but some energy is still needed for maintenance and this is drawn from fat body reserves. As indicated in (Fig. 3 and 4), the amount of fat continued decreasing particularly by day 5 and finally the least was recorded by day 6. This extremely least amount of fat was besides its utilization to maintain metabolic activity; more fat was also needed to support energy for newly regenerating muscle tissues that occur at the end of diapause. And this agrees with the findings by Wolda and Delinger (1984), in which they observed samples taken for one full season from diapausing tropical beetle known as *Stenotarsus rotrundus*. Variations were observed, in phase I and phase III (last phase) where amount of lean dry weight and fat weight were seen decreasing and this was associated to flight muscles which were not degenerated in phase I and in phase III (last phase), when flight muscles were developing. There was no clear general decrease in lean dry weight and this was an indication that non-lipid reserve was not used. During phase I, where

degeneration and during phase III, when the flight muscles and ovaries were developing the decrease in fat content, that is fat utilization was larger than phase II (long period of diapause).

6. CONCLUSION AND RECOMMENDATION

6.1 Conclusion

In Ethiopia, for the last nearly 10 years, the condition on sorghum has worsen due to the impact of the less familiar insect pest, the sorghum chafer (*Pachnoda interrupta*) which at times had forced farmers of the infested areas to abandon sorghum cultivation.

In the present study, an attempt was made to study the life cycle, the physical factors and soil types contributing to development and extended diapause, in order to look in to ways of developing potential control mechanisms. It was observed that in the laboratory (at temperature of 25 ^{0}C and moisture of 17%), the F1 generation laid 0. 58 eggs/ female/ day for about 25 days. The mean number of days for egg incubation was 9.63; for larval development was 59.69; for pupae to stay in pupal case was 24 and 93.79 days for adult emergence (Tables 1-4).

Addition of 25-50% manure soil to different soil types has significantly improved all soils for larval growth. When the amount of manure was increased exponentially, larval growth and survival decreased, but shorten the total time to complete the life cycle. In the absence of cow-dung, egg hatching was not affected but larval development was not completed (Tables 5-7).

At moisture 9% eggs were hatched and larval growth occurred, but no larva developed to

pupal stage as a result no adults emerged. Soil moisture levels of 17 and 23% were found to be suitable for larval development, pupal formation and emergence of adults.

Among the four temperature regimes tested, better hatching of eggs occurred in all, but larval development took extended number of days and pupation was not successful and no adult emerged at temperature 20 ^{0}C. Temperatures between 25 and 30 ^{0}C were found to be very suitable for completion of life cycle. At temperature 35 ^{0}C, the developmental rate was very high, but only very few of the experimental insects were able to complete their life cycle while most died at the early larval stages (Tables 8-11).

When soil moisture was less, the larvae went down into the soil and when it was high, they remained in the upper layer of the soil for pupation. Soil temperature how ever did not show significant variation on pupation depth (Fig 2).

Among the 8 food substances tested as bait, ripe banana was preferred significantly ($P<0.05$) followed by ripe guava. All residues of 'katikala', 'tej', and local beer and flours of roasted corn and sorghum were selected 3rd with out significant difference in comparisons between them. Non- roasted sorghum flour was found to be the least preferred (Table 12).

Only few *P. interrupta* adults were found to have survived the long dry seasons of the regions, through diapausing. Topography of the land and vegetation cover, which were able to create temperature situation in the soil less harsh than that of atmospheric temperature are considered to contribute for the successful diapause. Another important factor is the voracious feeding habit of the experimental animal which enables the first phase adults to accumulate sufficient amount of fat utilized for very low metabolic activity during diapausing period (Fig.3 and 4).

6.2 Recommendations

General and comprehensive studies are very essential and timely, giving more attention on control methods.

To be more specific and limit our selves only on gaps, which has became apparent during or at the end of the present study, the following are relevant.

- Extended and comprehensive field based study should be made on the biology and life cycle in the natural physical conditions and in natural environment but with widely varying soil moistures
- The importance of different dung, such as goat, sheep and camel and also different plant debris to complete the life cycle of sorghum chafer must be further studied.
- The study on effects of soil types on the depth of pupation should be investigated extensively.
- To obtain a clearer picture on factors contributing for successful diapause, environmental survey, accompanied with laboratory analysis should be made exactly at the breeding and out breaking sites, at least every week (when the pest is in the air) and every month (when the pest is in the soil).
- Composition of food substances as bait should be identified from already identified food. Study on baits should also continue in the field incorporating other food substances which are fresh.
- Possible control methods should consider factors influencing pupation depth and diapausing sites.
- *P. interrupta* can be successfully bred at temperatures of around 30^{0} C, soil moisture of 17- 23% soil (preferably sandy) provided with cow dung as food for larvae. Reproductive adults should be nourished with variety of food especially with amino acids to obtain sufficient amount of eggs for rearing.

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Appendices

Appendix 1 : Table showing soil sources and classification

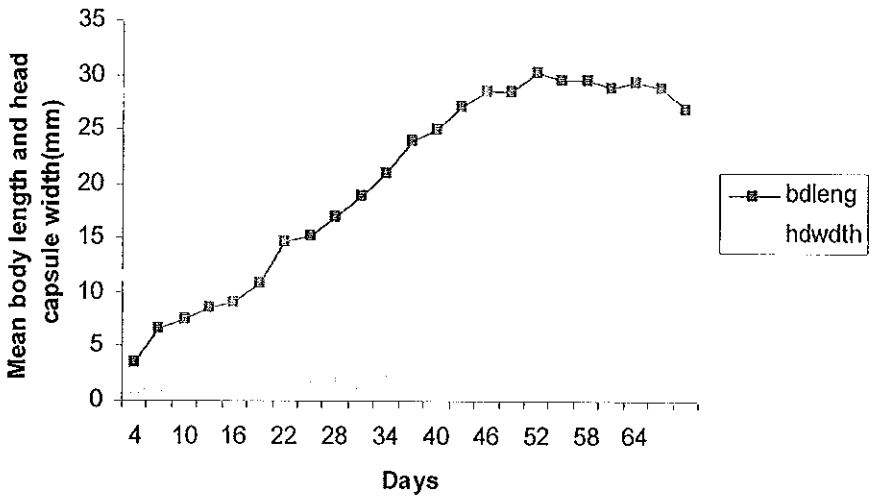
Soil			Sand	Silt	Clay	Class	OrganicCarbon
No.	Source	Ph	%	%	%		
1	Afar	7.96	32	44	24	L	2.21
2	Tikur inchini	5.64	42	50	8	SIL	7.99
3	Sandy (Guder river)	7.55	96	2	2	S	0.15
4	Afar+25%Manure	7.63	48	35	18	L	4.34
5	Tikur nchini+25%Man.	5.89	47.5	43.5	9	L	8.67
6	Sandy+25%Manure	7.33	88	7.5	4.5	S	2.79
7	Afar+50% Manure	7.31	64	23	13	SL	6.47
8	T.inchini+50%Manure	6.15	53	37	10	SL	9.39
9	Sandy+50%Manure	7.1	80	13	7	LS	5.43
10	Afar-burned	6.38	36.58	40.5	18	L	1.16
11	T.inchini-burned	4.48	48	46	6	SL	7.81
12	Sandy-burned	6.04	97	1.5	1.5	S	0.14
13	100%Manure	6.65	64	24	12	SL	10.72

*Soil classification as made by National soil laboratory of Ethiopia.

Appendix 2: ANOVA table Showing body length and head capsule width of larvae of *P. interrupta*

	Sum of square	Degree of freedom	Mean square	F	P-value
Body length b/n groups	50227.77	12	4185.65	98.58	.000
Head capsule width b/n groups.	491.04	12	40.92	67.39	.000

Appendix 3: Body length and head capsule width increments of larvae of *P. interrupta*



Appendix 4: ANOVA table showing differences in body length and head width of larvae reared in different temperature and moisture (from two ways Anova)

Moisture	Sum of squares	Degree of freedom	Mean square	F	P value
Body length	5624.48	3	1874.83	30.195	.000
Head capsule width	51.44	3	17.15	26.451	.000
Temperature					
Body length	1533.26	3	511.09	7.862	.000
Head capsule width	23.03	3	7.68	11.481	.000

Appendix 5: ANOVA-Showing days required for the immature forms to change and for the adult to emerge

Stage	Physical factors	Sum of squares	Degree of freedom	Mean square	F-value	P-value
Larvae	Temperature	5390.56	3	1796.85	15.79	0.000
	Moisture	873.56	3	291.19	1.22	0.318
Pupae	Temperature	479.14	3	159.71	5.03	0.007
	Moisture	40.07	2	20.03	0.433	0.651
Adults	Temperature	1226.13	2	613.06	14.73	0.001
	Moisture	417.43	2	208.72	1.91	0.190

Appendix 6: (Mean ± S.E) depth (cm) for pupation cites of *P. iterrupta* in different soil moisture and temperature

Soil moisture	Mean±s.error of depth
9%	26.79±0.46a
17%	23.5±0.22b
23%	10.04±.64c
29%	7.83±.98c
Temperature	
20°C	14.86±1.88a
30°C	18.5±1.22a
35°C	17.75±1.4a

Means within columns followed by the same letter are not significantly different from each other; P<0.05, DMRT.

Appendix 7: ANOVA table showing differences in depth of pupation cites of *P. interrupta* for different moisture and temperature

	S.S	D.F	M.S	F	P-value
Moisture	6493.58	3	2164.53	225.20	.000
Temperature	234.33	2	117.17	1.53	0.000

Appendix 8: ANOVA showing differences in numbers of insects selecting a different food sample

S.S	D.F	M.S	F	P-value
7761.19	7	108.74	70.07	0.000

Appendix 9: Anova table showing the number of survivals and the mean weight of *P. interrupta* female and male beetles fed for 45 days on different intervals of feeding days.

	S.S	D.F	M.S	F	P-value
Female					
Number	957.71	6	159.62	186.22	0.000
Weight	93.74	6	15.62	110.74	0.000
Male					
Number	1035.6	6	172.5	1207.5	0.000
Weight	103.2	6	17.2	295.999	0.000

Appendix 110 : Mean ± S.E of physiological conditions of *P. interrupta* in pre (1-3) and during (4-6) diapause conditions

		Female	Male
	Day	Weight(mg) Mean ±SE	Weight(mg) Mean ±SE
Dry wt.	1	.111±0.001a	.115±0.001 a
	2	.171±0.001b	.166±0.0005b
	3	.168±0.002b	.170±0.0005b
	4	.127±0.005a	.119±0.001a
	5	.214±0.006c	.184±0.006c
	6	.171±0.01b	.192±0.014c
Fat wt	1	.008±0.0008a	.008±0.0006a
	2	.053±0.0004b	.047±0.0006b
	3	.043±0.0024b	.046±0.0008b
	4	.008±0.004a	.0106± ±0.011a
	5	.006±0.01a	.006±+0.001a
	6	.006±0.023a	.003± 0.015a
Fresh wt	1	.266±0.0015b	.268±0.017b
	2	.325±0.002d	.328±0.014d
	3	.305±0.03c	.320±0.0012d
	4	.237±0.01a	.212±0.009a
	5	.301±0.006c	.288±0.007c
	6	.268±0+0.01b	.271±0.015b
Leandry wt	1	.101±0.001a	.107±0.001a
	2	.118±0.001b	.120±0.0003ab
	3	.126±0.001b	.124±0.0005b
	4	.119±0.004b	.112±0.004ab
	5	.208±0.008d	.178±0.008c
	6	0.182±0.015c	.192±0.016c
Water wt	1	.162±0.001d	.165±0.0014c
	2	.153±0.001cd	.164±0.001c
	3	.137±0.001c	.150±0.001c
	4	.112±0.006b	.09±0.005b
	5	.086±0.009a	.098±0.01b
	6	.104±0.012b	0.059±0.03a

Means within columns followed by the same letter are not significantly different from each other; $P<0.05$, DMRT.

Appendix 11: ANOVA showing differences in physiological analysis of *P. interrupta* females in pre- and during diapause conditions

Sources of variation	Sum of squares	Degree of freedom	Mean squares	F-fest	p-value
Dry wt	.281	5	0.056	93.2	0.000
Fat wt	.01	5	0.02	11.85	0.000
Fresh wt.	.172	5	0.034	39.2	0.000
Leandrywt	.358	5	0.07	73.46	0.000
Water wt	.187	5	0.04	36.65	0.000

Appendix 12: ANOVA showing differences in physiological analysis of *P. interrupta* males in pre- and during diapause conditions

Sources of variation	Sum of squares	Degree of freedom	Mean squares	F-test	P-value
Dry wt	.182	5	.036	50.57	0.000
Fat wt	.088	5	0.018	14.56	0.000
Fresh wt.	.271	5	0.054	63.57	0.000
Leandrywt	.199	5	0.04	51.53	0.000
Water wt	.296	5	0.059	26.75	0.000