INSECT POLLINATORS OF OIL PALM IN KERALA

By

S. SAMBATH KUMAR
(2008 - 11 - 118)

THESIS

Submitted in partial fulfilment of the
requirement for the degree of

Master of Science in Agriculture

(AGRICULTURAL ENTOMOLOGY)

Faculty of Agriculture
Kerala Agricultural University, Thrissur

Department of Agricultural Entomology

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR - 680 656
KERALA, INDIA

2010

DECLARATION

I, **S. Sambath Kumar** (2008-11-118) hereby declare that this thesis entitled **"Insect pollinators of oil palm in Kerala"** is a bonafide record of research work done by me during the course of research and this thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Vellanikkara,

17-07-2010.

S. Sambath Kumar

CERTIFICATE

Certified that this thesis, entitled **"Insect pollinators of oil palm in Kerala"** is a record of research work done independently by **Mr. S. Sambath Kumar** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

17/7/10

Dr. A.M. RANJITH
(Chairperson, Advisory Committee)
Professor
Department of Agricultural Entomology
College of Horticulture
Kerala Agricultural University
Thrissur, Kerala

Vellanikkara
17/7/10

CERTIFICATE

We, the undersigned members of the advisory committee of **Mr. S. Sambath Kumar,** a candidate for the degree of **Master of Science in Agriculture**, with major field in **Agricultural Entomology**, agree that the thesis entitled **"Insect pollinators of oil palm in Kerala"** may be submitted by him in partial fulfillment of the requirement for the degree.

17/7/10

Dr. A.M. Ranjith
(Chairperson, Advisory Committee)
Professor
Department of Agricultural Entomology
College of Horticulture
Vellanikkara

17/07/10

Dr. Sosamma Jacob
(Member, Advisory committee)
Professor and Head
Department of Agrl. Entomology
College of Horticulture
Vellanikkara

17/7/10

Dr. R. Ushakumari
(Member, Advisory committee)
Associate Professor
Department of Agrl. Entomology
College of Horticulture
Vellanikkara

22/7/10

Shri. S. Krishnan
(Member, Advisory committee)
Associate Professor
Department of Agricultural Statistics
College of Horticulture
Vellanikkara

ACKNOWLEDGEMENT

And so comes the time to look back on the path traversed during the endeavour and to remember the faces behind the action with a sense of gratitude. Nothing of significance can be accomplished without the acts of assistance, words of encouragement and gestures of helpfulness from others.

The foremost in my heart is Dr. A.M. Ranjith, Professor, Department of Agricultural Entomology and chairperson of my Advisory Committee for his inspiring guidance, meticulous care, untiring help, extreme patience, encouragement, constructive criticism, valuable suggestions, painstaking scrutiny of the manuscript and affection throughout the course of investigation and in preparation of this thesis. I feel greatly honoured by getting a chance to work under his guidance. It was a great experience to work under his personified with personal attributes. My sincere and heartfelt gratitude ever remains with him.

I would like to exploit this opportunity to extend my profound sense of gratitude and sincere thanks to Dr. Sosamma Jacob, Professor & Head, Department of Agricultural Entomology and member of my advisory committee for her ardent interest, expert advice, critical scrutiny of the manuscript and ever willing help, which has helped a lot in the improvement of the thesis.

I consider it as my privilege to express my deep felt gratitude to Dr. R. Usha kumari, Professor, Department of Agricultural Entomology and member of my advisory committee who helped me in the identification of insects and also thank for her invaluable help, suggestions and constant encouragement throughout the period of the work. I thank her for all the help and co-operation extended to me.

Words are inadequate to express my sincere gratitude to Shri. S. Krishnan, Associate Professor, Department of Agricultural Statistics and member of my advisory committee for the valuable suggestions, criticisms, critical scrutiny, well timed support and whole hearted support extended throughout the course of study.

I profusely thank Dr. Jim Thomas Professor and Dr. Mani Chellappan, Associate Professor, Department of Agricultural entomology who has spent their valuable time to some valuable suggestions for my research programme.

I also avail this opportunity to pay my sincere obligations and heartfelt thanks to my teachers of the Department of Agricultural Entomology Dr. Susannamma Kurien, Dr. Haseena Bhasker, Dr. Babu M. Philip, Dr. K.R. Lyla, and Dr. Maicykutty P. Mathew and Dr. Dijie Bastein, Associate Professor, Dept. of Plant Breeding and Genetics for their moral support, friendly approach and affection helped to complete this venture successfully.

I wish to express my gratitude to Mr. Jacob, Manager, Plantation Corporation of Kerala, Athirappilly, Mr. Wilson, Mr. Vinoth and Mr. Babu for their timely help in identification of oil palm trees and weevil in oil palm plantation. I wish to thank Professors of Agronomic Research Station, Chalakkudy for their timely help in getting the weather data.

I am genuinely indebted to Dr. Ilangovan, Associate Professor, RARS, Pattambi for his valuable assistance and guidance during the entire period of my research and I also thank Dr. Karthikeyan, RARS, Pattambi.

I also thank my inspirants Dr. P. Lakshmanan, Professor, Department of Plant Pathology, Dr. S.V. Krishna Murthi, Professor, Department of Agricultural Entomology and Mr. Murugeshan, Assistant Professor, Department of Sericulture, TNAU for their precious suggestions during my entire period of research.

My heartfelt thanks are due to my seniors Saranya and Dhinesh for their constant support, ever-willing help all through the course of my study which gave me enough mental strength to get through all tedious circumstances.

I also thank my seniors Dr. Deepthi, Hemalatha, Jyothi Sara Jacob, and Jaba Jegdesh for their whole hearted support, encouragement and relentless help through out this research work. Also, I wish to express my thanks to my seniors Senthil Kumar, Sujay Anand, Vaitheesvaran, Thiyagarajan, Sivaji, Rathish, Manikandan, Madusudhanan, Kiran, Alex and Vijith.

My heartfelt gratitude to my dear friends, Rathish and Sakthivel for their constant encouragement.

Words cannot really express the true friendship that I realished from Navaneetha Krishnan and Thamari Thuvasan for their timely suggestions, patient listening and constant *encouragement all through the course of study. I am happy to place on record my sincere thanks to my batch mates and friends, Sangeetha, Randip, Thondatharya, Sunil, Gajanan, Prathamesh, Prakash, Sumalatha, Shabna, Lakshmi, and Shijini.*

I have no words to express my deep sense of gratitude to my juniors Kannan and Elavarasn for their sincere help, support in taking observations and encouragement and also I thank my juniors Amritha, Jyothi and Lini.

I express my deep sense of gratitude to Mr. Mohan, Mr. Binish, Mr. Jain, Mr. Rathish Mrs. Omna, Mrs. Sindhu, Mrs. Nisha, Mr. George, Mrs. Sally and Mrs. Bindhu, and all the members of the Department of Entomology, Agricultural Ornithology and BCCP for their help and their support during the entire course of research. I thankfully acknowledge Mr. Santhosh and Mr. Arvind for his valuable help in computer work.

The award of Junior Research Fellowship (ICAR) is deeply acknowledged.

I am deeply indebted to My Father, Mother, my brothers Sathish Kumar and Senthil Kumar, My sister Raja Lakshmi and all my family members for their constant prayers, unbound love, moral support and unfailing inspiration without them it would have been impossible to complete. Last but not least, my soulful gratitude to Lord Vinayaga.

S. Sambath Kumar

Dedicated to

My Family,

My Department

and ICAR

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDIX

Introduction

1. INTRODUCTION

Oil palm, *Elaeis guineensis* (Jacq.) (Arecaceae) is one of the most commonly available and extensively cultivated perennial trees in many parts of the world. It is native to West Africa and recently it has been introduced to India and it is widely grown in Kerala. It has higher dietary and nutritional values with a high oil content of 40-50% (Purseglove, 1975). The fibrous mesocarp is the source of oil and the seed yields high quality palm kernel oil (Rethinam, 1992). Palm oil is one of the important edible oils of many people through out the world.

In olden days, oil palms were grown as wild trees in forests. A purposeful introduction to different areas and recent scientific, innovative research activities led to the introduction of scientific and commercial method of oil palm cultivation. In the cultivation of oil palm, pollination is one of the most important processes which ensure the quality of harvested fruit and oil content.

Previously pollination was considered as a serious constraint in oil palm, so manual pollination was often carried out, to sustain the yield (Tandon *et al.*, 2001).

The high productivity of oil palm is mainly dependent on adequate level of pollination and permanent production of bunches, which can be achieved by means of suitable pollinating agents. Wind plays an important role in pollination of many crops. Even in a strictly anemophilous crop, considerable level of insect pollination will be occurring. Additionally, bees play a vital role in pollination of majority of the crops. But in young oil palm plantations, due to high density of crop canopy and short nature of plants, chance of wind pollination is very less (Hardon and Turner, 1967). Also, in the absence of a large number of well placed male and female inflorescences, wind alone can not give adequate level of pollination, particularly during the rainy season.

In Malaysia, oil palm was effectively pollinated by an introduced weevil, *Elaeidobius kamerunicus* Faust (Coleoptera: Curculionidae) (Syed *et al.*, 1982). It is the natural pollinator of oil palm and was introduced from West Africa to Malaysia for pollination, which significantly improved the fruit set and oil yield to a great extent (Chowdhury, 2005). When the oil palm was introduced to South East Asia, where the *Elaeidobius* weevils were absent, the plants were hand pollinated to obtain fruit set (Free, 1993). Later on the *Elaeidobius* weevils were introduced to India also.

Apart from *Elaeidobius* weevils, some other insects are also known to visit both male and female inflorescence at the time of anthesis. In West Malaysia thrips are the main pollinators (Syed, 1981). Additionally, frequent movement of small moths and earwigs are also noticed on inflorescences (Basri, 1985). So it is evident that, role of insects is very important in oil palm pollination and it can be an ideal pollinating agent rather than wind and other means.

In India, very little work has been carried out on insect pollination in oil palm. Hence, the present study was undertaken with the following objectives.

1. Survey for the collection, classification and identification of insect pollinators in oil palm.
2. To identify the mechanism of pollination by dominant insect species, by no choice trials.
3. To study the biology of the predominant insect species.
4. Explore the role of any other agents like birds and wind in pollination of oil palm.

Review of literature

2. REVIEW OF LITERATURE

A comprehensive review of literature on the investigation entitled "Insect pollinators of oil palm in Kerala" is presented in this chapter. Though oil palm is grown in many parts of the world, not much emphasis is given on its enhanced productivity. In recent years pollination in oil palm is becoming a serious issue. Therefore, literature on pollination and other related aspects of oil palm is included here.

Though wind pollination is prevalent in oil palm, some other way of enhanced pollination is necessary to achieve adequate pollination and to solve the problem of poor fruit set. Insects act as very good pollinators in oil palm. African oil palm weevil, *Elaeidobius* spp. is one such genus having very close association with oil palm and involved in pollination (Syed, 1979).

2.1 Oil palm

The oil palm is monoecious (i.e. male and female flowers occur separately but on the same plant), but male flowers mature earlier than female flowers (protandry). So, both inflorescences are not simultaneously receptive in the same plant and hence make them an obligatory cross-pollinated crop (Uhl and Dransfield, 1987; Kee *et al.*, 2000).

2.1.1 Floral biology of oil palm

According to Beirnaert (1935), each inflorescence is a compound spike carried on a stout peduncle and enclosed in a woody spathe. The spikelets are arranged spirally on a central axis. About a month after the inflorescence emerges above the base of the petiole, the outer spathe splits open. Two to three weeks later, the inner spathe splits and the flowers, more or less embedded in the spikes, are exposed.

2.1.1.1 Male flower

The male inflorescence is borne on a long peduncle and consists of long finger–like cylindrical spikelets, each comprising 700-1200 male flowers. Each flower may approximately yield 80 g of pollen over a period of five days. The male flower is composed of a perianth of six minute segments and a tubular androecium with six stamens. Flowers begin to open from the base of the spikelet (Kee *et al.*, 2000).

2.1.1.2 Female flower

The female flower consists of a perianth of six segments in two whorls, a tricarpellate ovary and a trifid stigma. There may be 100–300 spikelets and over 2,000 individual flowers in each female inflorescence (Kee *et al.*, 2000).

2.2 Pollination by insects in oil palm

Until late 1970s, oil palm was widely thought to be pollinated by anemophilous mode rather than entomophilous (Turner and Gillbanks, 1974; Hardon and Corley, 1976; Caudel *et al.*, 2005). This was substantiated by the high atmospheric pollen densities observed at considerable distances from male inflorescences. However, Hardon and Turner (1967) found that the onset of rains caused an immediate reduction in atmospheric pollen density and some other agents should be involved in pollination.

Turner (1981) reported that inadequate pollination is one of the major reasons to cause bunch failure and poor fruit set in oil palm. It was attributed to absence of suitable pollinating fauna, poor sanitation and thick canopy of the palms which restrict the wind pollination.

Nevertheless, the participation of another agent in pollen dispersion was suspected, even though in humid season with more rainfall everyday, pollination was efficient. When checking the inflorescences, more number of insects was found in male inflorescences during anthesis and in females during their receptivity periods (Labarca *et al.*, 2007).

Similarly, Syed (1979) also found that large number of insects were present on the male inflorescence during anthesis and on the female flowers, during the first few days of stigma receptivity. He also reported that *E. kamerunicus* Faust (Coleoptera: Curculionidae) was the most abundant species in both dry and wet weather conditions and it could carry more pollen grains than any other insect species. He also stated that *E. kamerunicus* had a high reproductive rate and good host searching capacity with high host specificity.

Elaeidobius genus included *E. kamerunicus, E. plagiatus* Faust and *E. subvittatus* Faust (Syed, 1979). Although various arthropods have been found to be associated with oil palm inflorescences, only *E. subvittatus* (Coleoptera: Curculionidae) and *Mystrops costaricensis* Gillogly (Coleoptera: Nitidulidae) were reported to be principal pollinators in tropical America and Mexico. This was even before the introduction of the species *E. kamerunicus* from Africa (Genty *et al.*, 1986; Sanchez *et al.,* 1998).

In West Africa and South America, natural fruit set in oil palm was achieved due to effective pollination by native insect pollinators (Wood, 1983; Corrado, 1985).

Kevan (1999) reported that oil palm was primarily pollinated by various insect species. In Africa, weevils (*Elaeidobius* spp.) and in Latin America, *M. costaricensis* and *Elaeidobius* spp. act as principal pollinators.

Mariau and Genty (1988) reported that *E. kamerunicus* and *E. singularis* Faust were involved in pollination of oil palm trees in Columbia and Brazil respectively. Ming (1999) reported that low weevil populations were associated with the direct or indirect effects of weather and parasitism by different entomopathogenic nematodes. He also stated that another pollinator, *E. subvittatus* could be able to overcome this hurdle and hence complement the pollination by *E. kamerunicus*.

Among the different insect species present on male inflorescences of oil palm, *Elaeidobius* spp. and *Atheta* spp. were most abundant and they were found in the female inflorescences in large numbers. They normally visited the female inflorescences during the daytime, and tended to arrive in intermittent storms throughout the period of their receptivity (Syed, 1979).

2.3 Pollination by *Elaeidobius* spp. in oil palm

According to Veera (1996) and Chairani *et al.* (1989) where ever the oil palm was grown as an introduced crop, no other insects were available for pollination except the African oil palm weevil, *E. kamerunicus.* Obviously this led to the introduction of *Elaeidobius* weevils into various oil palm growing regions around the world.

Introduction of the pollinating weevil, *E. kamerunicus* in the 1970's ended the costly and inefficient process of hand pollination and resulted in sharp increase in yield in many oil palm growing regions in the world (Fairhurst and Mutert, 1999).

According to PNGOPRA report (2004), the African pollinating weevil *E. kamerunicus* was introduced into Papua New Guinea during 1982 and resulted in significant improvements to oil palm pollination, level of fruit set and oil extraction ratios and which ultimately increased the yield.

After the introduction of *E. kamerunicus* into Costa Rica many changes were observed in fruit set and populations of the introduced and native pollinators (Chinchilla and Richardson, 1991). According to Kevan *et al.* (1986), the careful introduction of the oil palm pollinating weevil, *E. kamerunicus* into Malaysia, with appropriate quarantine studies and risk assessments, led to cheaper supply of palm oil from tropical Asia to other parts of the world. He also introduced the idea of a critical pollinator force, which means the minimum level of population required for adequate pollination.

Dhileepan (1992) reported that the pollen collecting ability of the weevil, *E. kamerunicus* in male inflorescences was increasing from the beginning of anthesis and reaching a maximum level, between the third and fifth day of anthesis. The viability of pollen carried by the weevils in the male inflorescence is 83.1%, but it will be decreased to 81%, when the weevils start leaving from the male flowers. It was also reported that the pollen carrying capacity of male weevil was significantly higher than the female.

Dhileepan (1994) found that the critical pollinator force was always above 5,000 weevils per hectare per day to get adequate pollination. But Donough *et al.* (1996) reported that about 20000 weevils per hectare would be required for a fruit set of 55%.

Genty *et al.* (1978) reported that during the dry season *E. subvitattus* populations were plenty in oil palm growing regions of South America and they act as principal pollinators.

2.3.1 Species abundance

Labarca *et al.* (2007) reported that 4,278 insects were captured during the survey of oil palm pollinating fauna and out of which 71.86% were *E. kamerunicus* and 17.63% of *M. costaricensis*, 6.55% of *E. subvittatus*, 2.1% of *Smicrips* sp. (Coleoptera: Smicripidae) and 1.87% *Thrips hawaiiensis* Morgan (Thysanoptera: Thripidae) were collected.

Similarly, results of survey conducted in anthesising male inflorescence of three oil palm plantations by Bulgarelli *et al.* (2002a) revealed that, 92.57% of total collected species was *E. kamerunicus*, followed by 6.66% of *M. costaricensis* and the rest was shared by *E. subvittatus* and other insects identified such as *T. hawaiiensis* and *Smicrips* sp.

Garcia (1994) reported that the population of *E. kamerunicus* was higher in anthesising male inflorescence than rest of insect species found. Because, male inflorescence is highly suitable to *E. kamerunicus*, in completion of its life cycle.

Survey report of Prada *et al.* (1998) showed that, more activity of insect pollinators was observed between 9.00 a.m. and 2.00 p.m. during 12 months of total survey.

2.3.2 Species adaptation

Research report of Zenner and Posada (1992) indicated that, after the introduction of *E. kamerunicus* in the main oil palm plantations of Venezuela for improving pollination, they established at a faster rate by occupying the existing ecological niche of *E. subvittatus*, without causing much harm to other related insect species.

2.3.3 Pollination efficiency

Weevil species such as *E. kamerunicus, E. plagiatus,* and *E. subvittatus* were found to visit female inflorescences and usually land with more pollen grains. Out of these *E. kamerunicus* was found to carry the largest number of pollen grains (Syed, 1979).

Caudel *et al.* (2005) reported that insect species of *E. kamerunicus, E. subvittatus* and *E. plagiatus* were able to move in large quantities to female inflorescences along with abundant pollen grains over their body with the pollen viability upto 68.5%.

Results of the experiment conducted by Prada *et al.* (1998) revealed that 31318 individuals of *E. kamerunicus* and 578 of *E. subvittatus* visited the female inflorescence during a day of anthesis. The average pollen carrying capacity by female and male insect of *E. kamerunicus* was 446 and 985 respectively. But it was 116 and 246 for female and male insects of *E. subvitattus.*

The pollination efficiency of *E. kamerunicus* was greater, when the weevil population per spikelet was very low (18.7 weevils per spikelet) resulting in higher fruit set (84.9%). But higher weevil population (99.2 weevils per spikelet) resulted in reduced pollination efficiency (72.9%) which was presumably associated with intra specific competition among weevils for the pollen resource (Dhileepan, 1992).

2.3.4 Mechanism of pollination

Continuous observations of Syed (1979) on female inflorescences throughout the period of their receptivity showed that, a large number of insects were visiting the female inflorescence during the day time and tended to arrive in intermittent storms.

Ponnamma *et al.* (1986) reported that the adult weevils chew the anther filaments of opened male flowers and when they crawl on the spikelets, the pollen grains get adhered to their body, subsequently when they visit the female inflorescence the pollen grains were deposited on the stigma of female flowers. This results in pollination.

2.3.5 Impact of climate on weevil population

Population and pollination efficiency of *E. kamerunicus* was more when compared to all other species of *Elaeidobius*, due to the interference of temperature and rainfall with the flight activity of adults (Moura *et al.*, 2008).

In many oil palm plantations of Central America, the number of *E. kamerunicus* per male spikelet was higher at the end of the dry season but dropped drastically during the rainy months of every year, because, they are highly adapted to warm humid conditions (Chinchilla *et al.,* 1990). But the results of experiment on impact of variation in climatic factors on pollination, conducted by Dhileepan and Nampoothiri (1989) confirmed that, in oil palm plantations of India, total population of *E. kamerunicus* was high during humid months (July to October) and comparatively low in dry months (January to April). They also stated that wherever dry season would remain for more than four months, higher fluctuation in population of *E. kamerunicus* was noted with poor activity.

Similarly Bulgarelli *et al.* (2002b) reported that during dry season (maximum temperature = 32.3°C, minimum temperature = 22.8°C and 8.7 hours of sunshine a day) a marked reduction in the number of anthesising male inflorescences was observed in young oil palm plantations, which was associated with a reduction in the population of the pollinator *E. kamerunicus*. Consequently, pollination of female inflorescences in anthesis was much reduced, which caused a marked drop in fruit set and an increase in bunch failure.

Studies conducted by Ponnamma (1999) on diurnal variation in the population of *E. kamerunicus* on the anthesising male inflorescences of oil palm plantations of Kerala revealed that, the maximum number of *E. kamerunicus* was congregating on the male inflorescence on the third day of anthesis and its population was less on the male inflorescences during noon time of rainy months.

2.4 Pollination in India

In order to solve the problem of low productivity of oil palm in India, *E. kamerunicus* was introduced during 1970s by Dr. Abraham, after visiting oil palm growing regions of Malaysia and this has aided in achieving adequate pollination and fruit set (Anon., 2008).

Ponnamma *et al.* (2004) reported that weevils of *E. kamerunicus* were introduced in to the oil palm plantations of National Research Centre for Oil Palm, Palode (Kerala) during 1985. The weevils multiplied themselves and established in all the plantations, under various agro-climatic conditions and enhanced the fruit set of oil palm.

2.5 Biology of predominant insect species

Syed (1984) found that, though many insects are visiting the oil palm, *E. guineensis* and involved in pollen transfer, it is highly suitable to *E. kamerunicus* for its feeding, oviposition and development but not suitable for any other insects.

2.5.1 *Elaeidobius kamerunicus*

According to the research conducted by Jagore (1934), the main pupating site of *E. kamerunicus* was post-anthesis male spikelets. Hussein and Rahman (1991) worked out various biological parameters of *E. kamerunicus*. The mean total life cycle was 15.4 days with net reproductive rate of 3.46. The mean number of eggs produced per female was 35 and the sex ratio was observed as 1 : 2 (male : female).

Ponnamma and Pillai (2002) worked out the life history of *E. kamerunicus* under laboratory conditions, using spent male spikelets. It was observed that white coloured eggs were laid on the male flowers and the total larval period ranged from five to eight days. The larvae pupated within male flower itself with the pupal period of three days.

Ponnamma *et al.* (2006) reported that adult weevil emergence per spikelet ranged from 25.86 to 134.02 and the sex ratio (♂ : ♀) ranged from 1 : 1.13 to 1 : 1.94. A strong positive correlation was observed between the number of weevils that emerged under laboratory conditions and the length of spikelets. Maximum progeny emergence was observed at 26^0C and 27^0C.

2.5.1.1 Host specificity

Syed (1981) reported that laboratory studies on biology of *Elaeidobius* spp. confirmed their host specificity. They did not oviposit on the flowers of any other plant except oil palms. They breed on spent male inflorescences and adult weevil visit the female inflorescence due to specific odour attraction. *Elaeidobius* species are highly specific to the oil palm and entirely depend on the male inflorescences for their growth and development (Syed, 1984).

According to Hussein *et al.* (1991), the adult weevil of *E. kamerunicus* was only specific to the oil palm, *E. guineensis* and locate its host *via* a plant chemical called estragole (5,4 - allylanisole) and the adult weevils showed more response to 4-methoxystyrene analogues. Similarly, Mayfield and Margaret (2005) also stated that male flowers of oil palm produce a strong anise- seed like odour to attract pollen-collecting insects. Similarly female flowers were also producing a similar but weaker smell and do not provide any floral rewards to weevils.

Proctor *et al.* (1996) reported that adult beetles of *E. kamerunicus* breed on spent male inflorescences, attracted by a specific anise seed like scent (estragole 5,4-allylanisole). During stigma receptive stage, they are attracted to the female inflorescences by short pulses of a similar, sharper and more penetrating scent. Since these offer nothing to the weevils, they soon return to the male inflorescences. They feed (on the filament tubes of spent florets), mate and oviposit. The larvae feed and develop only on the decomposing flowers and they will not cause any harm to the male flowers (Chee and Chiu, 1998).

The adults of *E. kamerunicus* are lured to male flowers by a strong anise seed scent released when the flowers begin to release pollen at the time of anthesis, where they feed and complete their life cycle and which persists for 2 - 5 days. Female flowers also produced an anise seed scent at anthesis (which lasts for 36 - 48 hours) and weevils carrying pollen from male flowers are thus attracted to receptive female flowers on neighboring palms (Kee *et al.*, 2000).

2.6 Other insect species involved in oil palm pollination

Pardede (1990) reported that *Thrips hawaiiensis* Morgan and a lepidopteran moth *Pyroderces* spp. acted as indigenous insect pollinators in South Banten region of Brazil.

These insects transferred the viable pollen grains from male to female inflorescences of oil palm and they breed on banana plants during off season.

According to Kang and Zam (1982), many of the native pollinators of oil palm were displaced by the newly introduced weevil, *E. kamerunicus* which led to various levels of interspecific competition.

Price (1984) stated that weevils of *Elaeidobius, T. hawaiiensis* Morgan and *Pyroderces* could co-exist indefinitely in a number of ways, including differing patterns of resource availability, creation of new empty habitats for colonization through natural catastrophes and the occurrence of several generations in a year, whereby each generation might be exposed to different environmental conditions.

2.6.1 *T. hawaiiensis* (Thysanoptera: Thripidae)

According to Syed (1981), in West Malaysia, *T. hawaiiensis* are the main pollinators of oil palm plantations. But unlike African weevils, they were not much better adapted to oil palm due to absence of specialized structures around the body. So it was easily affected by adverse weather and soil conditions. On the contrary, Basri and Kamarudin. (1997) stated that *T. hawaiiensis* could thrive better than *E. kamerunicus* during dry months and rainy season and get involved in pollination.

Syed (1980) reported that each thrips could carry 4.8 pollen grains to the anthesising female inflorescence. They had the capability of spreading the pollen grains within each anthesising female inflorescence by entering deep into the female inflorescence and staying within them.

2.6.2 *Pyroderces* spp. (Lepidoptera: Cosmopterigidae)

Tan and Basri (1985) stated that cosmopterigid moth, *Pyroderces* spp. was a frequent visitor of oil palm, involved in pollination. The moths visited the anthesising female flower regularly, after two or three hours of sunset (Basri and Kamarudin, 1997).

Tan and Basri (1985) reported that the activity of *Pyroderces* spp. in oil palm inflorescence resulted in achieving the fruit set of 31% as compared with 62% by the weevil.

Garraway *et al.* (2007) reported that development of *Pyroderces* spp. from egg to adult took an average of 37 days and they complete their breeding cycle with in the spent male inflorescence itself.

2.7 Other modes of pollination in oil palm

Though insects are playing the main role in oil palm pollination, other pollinating agents are also contributing to a considerable level. Wind pollination is necessary to get adequate fruit set in young oil palm plantations and sufficient male flowers are required for the establishment and effective introduction of pollinating insects. (Veera, 1996).

2.7.1 Wind pollination

Oil palm is a highly cross-pollinated crop and pollination is assisted by wind and insects (DOPR, 2009).

Hardon and Turner (1967) described that oil palm is pollinated by wind, by the way of producing large amount of pollen grains and they could be distributed at least 55 feet from their original source during heavy wind blowing periods.

According to Sparnaaij (1969), both insects and wind contributed to pollen transfer in oil palm and in Africa, the principal pollinating agent was insect whereas in Asia, wind pollination was considered as the most important way of pollination.

Speldewinde and Pereira (1974) stated that assisted pollination was necessary to achieve the optimum level of fruit set and was accomplished by blowing hand-collected pollen mixed with talc or any another diluent onto the receptive female flowers.

Wind-pollination was also involved in oil palm due to high atmospheric pollen densities at considerable distances from male inflorescences leading to effective pollen dissemination to female inflorescences (Turner and Gillbanks, 1974; Hardon and Corley, 1976).

According to Gerridsma and Wessel (1997), wind pollination occurred in oil palm and assisted pollination was done during poor fruit set conditions through artificial means or by insects.

Ponnamma *et al.* (1986) found that when the weevils of *E. kamerunicus* moved on the male inflorescences, a large amount of pollen grains were disbursed and carried by wind especially during dry conditions.

Mayfield and Margaret (2005) reported that in West Africa, the oil palm was originally pollinated by wind and through wind considerable amount of pollen grains was transferred to female flowers, but this mode of pollen transfer was effective only in dry conditions. This was also aided by *E. kamerunicus*, which considerably disturb the anthers while feeding, so that the pollen could become wind-borne.

Bulgarelli *et al.* (2002a) observed that, when the population of pollinating weevils was very less during dry period, effective fruit set could be achieved by wind. Wind plays an important role as a pollen carrier when the palms became taller.

2.7.2 Role of birds

Chenon and Susanto (2006) reported that birds did not have any significant role in oil palm pollination. The avian species such as ashy tailor bird, *Orthotomus ruficeps* (Sylvidae) and Yellow-Bellied Prinia, *Prinia flaviventris* (Sylvidae) which were commonly present in oil palm plantations, has modified its feeding behaviour by preying on *E. kamerunicus* and reduced the population of weevils. This might have resulted in reduction of the population of insect pollinator with the consequence of decreasing the fruit set percentage.

2.8 Inflorescence production

Continuous production of both male and female inflorescence will give sustainable yield. But inflorescence production is mainly dependent on genetic factors, existing management practices and external climatic factors.

Bulgarelli *et al.* (2002a) found that better distributed rain caused an increase in female inflorescences and larger proportions of male inflorescences were produced when level and distribution of rainfall was poor in oil palm growing regions of Costa Rica.

Bulgarelli *et al.* (2002b) reported that the number of male and female inflorescence production was highly varied during different months, in oil palm plantations of Costa Rica. During February and March, there were complete absence of male inflorescence and again they appeared in April with the maximum production during September and October. This continuous availability of male inflorescence in the oil palm plantations aided in maintaining the normal level of weevil population. But more production of female inflorescence was observed in May, while the lowest was recorded in December and for the rest of the months considerable number of female inflorescences was observed.

2.9 Influence of insect population on fruit set

The introduction of the pollinating weevil, *E. kamerunicus*, to Malaysia, reduced the problem of poor pollination and increased the fruit set over hand pollination by about 20% (Basri *et al.,* 1983).

Introduction of *E. kamerunicus* has helped the oil palm growers to increase the yield and reduce their production cost by eliminating the need for assisted pollination (Chan *et al.*, 1987).

The results of experiments carried out by Rao *et al.* (1990) confirmed that the incidence of bunch failure was reduced from 50% to zero after 18 months of introduction of *E. kamerunicus*.

According to Harun and Noor (2002), insect pollinated bunches recorded a mean fruit set of 80% when compared to hand pollinated bunches. These had the range of fruit set from 2% to 76% in major oil palm growing regions of Malaysia.

After the introduction of *E. kamerunicus* to Malaysia, increase in bunch weight was recorded up to 50% in most of the oil palm plantations of Malaysia (Syed 1979; Syed and Corley, 1982). Pollination by *E. kamerunicus* led to 19% increase in normal fruit set when compared to palms pollinated only by *E. subvittatus* (Moura *et al.*, 2008).

Syed and Salleh (1987) reported that 1500 adults of *E. kamerunicus* weevils could pollinate a female inflorescence to an acceptable minimum level of pollination (about 50 per cent fruit set). In order to obtain an optimum fruit set level of about 70 per cent, nearly 3000 adult weevils per female inflorescence were required.

According to Basri (1984), the multi level introductions of *E. kamerunicus* to Malaysia, promoted the significant improvement in fruit set from an average of 52% to 71%, increase in fruit to bunch ratio from an average of 57.7 to 64.7%, increase in mean bunch weight from 14.6 to 18.7kg and increase in kernel to bunch ratio from 4.6 to 6.6%.

Dhileepan and Nampoothiri (1989) found that introduction of oil palm pollinating weevil to India increased the fruit set from 36.87% to 56.10% and resulted in 40% increase in bunch weight and 11% increase in fruit: bunch ratio.

Materials and Methods

3. MATERIALS AND METHODS

The present study entitled "Insect pollinators of oil palm in Kerala" was conducted in oil palm plantations of Plantation Corporation of Kerala, Athirappilly and the Department of Agricultural Entomology, College of Horticulture, Vellanikkara during 2009 to 2010. The details of the materials used and the techniques adopted for the investigation are described below.

3.1 COLLECTION AND IDENTIFICATION OF POLLINATING INSECTS ON INFLORESCENCE OF OIL PALM

Insects that visit male and female inflorescences of oil palm during the period of their anthesis were collected and identified separately.

3.1.1 Selection of oil palm trees

Ten numbers of shorter, eight years old, oil palm trees were selected randomly for the study in one acre area of the estate of Plantation Corporation of Kerala, Athirappilly. The trees were marked separately and each tree was considered as one replication. They were maintained with normal management practices.

3.1.1.1 Selection of female flowers

From each tree one unopened female inflorescence was selected and covered with a paper bag (30 x 60 cm) until flower opening to avoid error while taking observations. At the time of flower opening in female inflorescence, after removing the paper bag, observations on population of different insect visitors was taken at two hours interval from 8.00 a.m. to 4.00 p.m. The time of maximum anthesis occurred in female inflorescence between 10.00 a.m. to 2.00 p.m.

3.1.1.2 Selection of male flowers

Among the 10 selected palms that were considered as 10 replications, male inflorescence emerged from only three replications (R_1, R_6 and R_8). So, observation on different insect visitors was made only on these three trees at the time of anthesis of their female flowers.

3.1.2 Collection and identification of pollinating insects from male and female inflorescences

During the peak period of anthesis of male inflorescence, it was cut at the peduncle from the tree and brought to the laboratory. Different insects present on the cut inflorescence were collected and identified.

Insect visitors on the female inflorescence were collected by tapping it gently and visual observation was also made. The collected insects were identified upto family level at the Department of Agricultural Entomology, College of Horticulture, Vellanikkara.

3.1.3 Population of different insect visitors on inflorescence of oil palm

Population of insect visitors was observed at two hours interval from both male and female inflorescences during the period of anthesis and stigma receptivity respectively (which were previously covered by paper bags) from the 10 selected palms. In female inflorescence, the stigma receptivity period was detected by an anise seed like odour that emitted from the flowers. Observation was taken by gentle tapping of the inflorescence and insects were collected in a non odorous vaseline coated plastic tray and also by visual observation. The observation on population of different insect visitors was taken at two hours interval between 8.00 a.m. to 4.00 p.m. during the 1st and 2nd day of anthesis. Based on the population counts of different insects, the insect species was identified.

3.1.4 Population of predominant insect species (*E. kamerunicus*) during peak period of anthesis on inflorescence of oil palm

Based on the previously described observations (3.1.3), *E. kamerunicus* was found to be the most predominant insect species. Population of *E. kamerunicus* was recorded during the 1st and 2nd day of anthesis (peak period) at two hours interval starting from 8.00 a.m. to 4.00 p.m. and the mean population was calculated.

3.1.5 Relationship between population of *E. kamerunicus* and per cent pollination in oil palm

Correlation relationship was computed between the population of predominant species (*E. kamerunicus*) on 1st and 2nd days of anthesis of female inflorescence and the per cent pollination.

3.1.6 Population of *E. kamerunicus* at different positions on male inflorescence

A preliminary study was conducted to find out the duration of anthesis in male inflorescence and the population of *E. kamerunicus* was observed during the time of anthesis.

Three spikelets from top, middle and bottom portions of seven different male inflorescences during the peak stage of anthesis were selected and observations on the number of weevils were recorded during rainy (August to September) and summer (January to February) months.

3.2 MECHANISM OF POLLINATION

Continuous observations on population of different insect visitors (particularly on *E. kamerunicus*) on both male and female inflorescences during the time of anthesis were taken. Based on these observations mechanism of pollination was studied.

3.3 BIOLOGY OF PREDOMINANT INSECT SPECIES

Since the population of *E. kamerunicus* was predominant on inflorescence, biology study was restricted only on this insect species.

3.3.1 Biology of African oil palm weevil, *E. kamerunicus*

Biological studies on *E. kamerunicus* were carried out in the Aluminium cage (32 x 32 x 42 cm) at Department of Agricultural Entomology, College of Horticulture, Vellanikkara, during both rainy and summer seasons during 2009 - 2010.

3.3.1.1 Site of oviposition, fecundity and oviposition period

Three spent male spikelets were inoculated along with adult weevils of both the sexes. Different sex ratios such as 1 : 1, 1 : 2, 1 : 3 and 1 : 4 of male and female weevils were maintained with five replications each. Observations on site of oviposition, total fecundity, total period of oviposition and difference in fecundity with respect to total oviposition period were recorded and their maximum, minimum, mean and standard deviation values were worked out.

3.3.1.2 Life cycle

Spent male inflorescences were collected from the field and eggs were identified and kept in net cage. Ten eggs were maintained in each replication. Observation on biological parameters like duration of eggs, number of larval instars, duration of each larval instar, total larval period, pupal period and total life cycle from egg to adult emergence were taken from 10 replications and their mean and standard deviation values were worked out.

3.3.1.3 Adult longevity

The freshly emerged 10 adult weevils of both sexes were released separately on spikelets of anthesising male inflorescence and covered with polyester cages. The longevity of the adult weevils was recorded until death of the weevils and their mean and standard deviation values were calculated.

3.3.1.4 Sex ratio

Adult weevils were collected randomly during the peak period of anthesis of male inflorescences. Totally 10 replications were maintained with 100 individuals in each replication. Finally their sex ratio (♂ : ♀) and mean was worked out.

3.3.2 Morphology and morphometric study of *E. kamerunicus*

Shape, colour and size of different stages of *E. kamerunicus* were examined and measurements on diameter of eggs and length and width of eggs, larvae, pupae and adults (males and females) were taken using image analyser (Model 2 EISS STEML 2000-C) for describing the different stages of the insect.

3.3.2.1 Egg

Eggs were collected from spent male inflorescences and diameter of 10 eggs was taken and their maximum, minimum and standard deviation values were worked out.

3.3.2.2 Larva

Grubs of different larval instars were collected and the length and width of head capsule and body were measured. Measurements were recorded in 10 grubs to work out the maximum, minimum and standard deviation values.

3.3.2.3 Pupa

Length and width of freshly formed 10 pupae were measured and the maximum, minimum and standard deviation values were worked out.

3.3.2.4 Adult male and female weevils

Length and width of 10 male and female weevils were measured and the maximum, minimum and standard deviation values were worked out.

3.4 INFLORESCENCE PRODUCTION

Observation on number of male and female inflorescence production and number of bunch set during every month was taken separately from 10 randomly selected oil palm trees up to eight months.

Duration of anthesis of male and female inflorescences and stigma receptivity of female inflorescence were found based on continuous monitoring on inflorescences during the time of observation on population of insect visitors.

3.4.1 Influence of abiotic factors on inflorescence production and bunch set

The changes in the production of both male and female inflorescences and bunch set in relation to various abiotic factors were studied from July '09 to Feb '10 in the oil palm plantations of Plantation Corporation of Kerala, Athirappilly at monthly interval. Data on prevailing meteorological parameters *viz.,* maximum and minimum temperature, relative humidity, rain fall and sunshine hours during the entire study period were collected from Agronomic Research Station (ARS), Chalakudy. Correlation coefficient of inflorescence production and bunch set with various meteorological parameters was computed.

3.5 ROLE OF OTHER AGENTS IN OIL PALM POLLINATION

Apart from insect pollination, role of other agents such as wind and birds were identified by adopting the following methods.

3.5.1 Wind pollination

Three unopened female inflorescences were covered with polythene bag (30 x 60 cm) to identify the role of wind pollination. The lower side of the polythene bag was open, to allow for the entry of pollinating weevils from bottom. Care was taken while covering bunches to ensure that the bags were not torn due to the thorns of the spikelets. After five months they were opened and level of pollination and fruit set were examined.

3.5.2 Bird pollination

Similarly, three unopened female inflorescences were covered with nylon net (3 cm diameter) to identify the inflorescence visitors of bird species.

3.6 YIELD CHARACTERS

Observations on yield characters such as number of flowers per inflorescence, number of fruits per bunch, number of partially developed fruits, fruit set percentage, days to fruit set from anthesis, total bunch weight and mean fruit weight per bunch from different trees were recorded separately and calculations were done with different statistical tools.

3.6.1 Per cent pollination

Per cent pollination was worked out based on observations such as initial number of flowers in female inflorescence, and number of complete and partially developed fruits from each inflorescence.

$$\text{Per cent pollination} = \frac{\text{Number of completely and partially developed fruits}}{\text{Number of flowers in the female inflorescences}} \times 100$$

3.7 STATISTICAL ANALYSIS

All collected data during the entire period of observations are interpreted with appropriate summary statistics. Results are given based on mean, standard deviation, range and mode values. The original data are given in the Appendix.

Results

4. RESULTS

The results obtained from the present study "Insect pollinators of oil palm in Kerala" are presented in this chapter.

4.1 COLLECTION AND IDENTIFICATION OF POLLINATING INSECTS ON INFLORESCENCE OF OIL PALM

A total of fifteen different species of insects were observed and collected from both male and female inflorescence during the period of observation (Table 1). Insect species such as, the African oil palm weevil, *Elaeidobius kamerunicus* (Coleoptera: Curculionidae); earwig, *Forficula* sp.? (Dermaptera: Forficulidae); moth, *Pyroderces* sp.? (Lepidoptera: Cosmopterigidae) and Indian honey bees, *Apis çerana indica* (Hymenoptera: Apidae) were identified from the collection (Plate 1). Other hymenopteran insects included dammer bee, *Trigona iridipennis* (Meliponidae), black ant, *Camponotus* sp. (Formicidae), leaf cutter bee, *Megachile* sp. (Megachilidae), cuckoo wasp, *Chrysis* sp.? (Chrysididae), carpenter bee, *Xylocopa* sp. (Xylocopidae) and giant hornet, *Vespa* sp. (Vespidae). Three lepidopteran insects *viz.,* leaf caterpillar, *Elymnias* sp. (Nymphalidae), citrus butter fly, *Papilio* sp. (Papilionidae) and Yellows, *Eurema hecabe* (Pieridae) and a hemipteran mealy bug, *Paracoccus marginatus* (Pseudococcidae) and a dipteran hover fly, *Syrphus* sp.? (Syrphidae) were also found to be visiting the inflorescence of oil palm.

4.1.1 Population of different insect visitors on inflorescence of oil palm

Results of the population of different insect visitors in the female inflorescence (Table 2 and 3) indicated that *E. kamerunicus* was dominating both male and female inflorescence during the time of anthesis. Though other insects *viz.,* earwig, moth and Indian honey bees were present, their population was very less.

African oil palm weevil

Elaeidobius kamerunicus (x 20X)

(Coleoptera: Curculionidae)

Earwig

Forficula sp.? (x 2X)

(Dermaptera: Forficulidae)

Moth

Pyroderces sp.? (x 6X)

(Lepidoptera: Cosmopterigidae)

Indian honeybee

Apis cerana indica (x 5X)

(Hymenoptera: Apidae)

Plate 1. Different insects collected from inflorescence of oil palm

Table 1. Insect visitors on oil palm inflorescence

S. No.	Insect	Scientific name	Family	Order
1.	African oil palm weevil	*Elaeidobius kamerunicus*	Curculionidae	Coleoptera
2.	Earwig	*Forficula* sp.?	Forficulidae	Dermaptera
3.	Moth	*Pyroderces* sp.?	Cosmopterigidae	Lepidoptera
4.	Leaf caterpillar	*Elymnias* sp.	Nymphalidae	Lepidoptera
5.	Citrus butterfly	*Papilio* sp.	Papilionidae	Lepidoptera
6.	Butterfly - Yellows	*Eurema hecabe*	Pieridae	Lepidoptera
7.	Indian honey bee	*Apis cerana indica*	Apidae	Hymenoptera
8.	Dammer bee	*Trigona iridipennis*	Meliponidae	Hymenoptera
9.	Black ant	*Camponotus* sp.	Formicidae	Hymenoptera
10.	Leaf cutter bee	*Megachile* sp.	Megachilidae	Hymenoptera
11.	Cuckoo wasp	*Chrysis* sp.?	Chrysididae	Hymenoptera
12.	Carpenter bee	*Xylocopa* sp.	Xylocopidae	Hymenoptera
13.	Giant hornet	*Vespa* sp.	Vespidae	Hymenoptera
14.	Mealy bug	*Paracoccus marginatus*	Pseudococcidae	Hemiptera
15.	Hover fly	*Syrphus* sp.?	Syrphidae	Diptera

4.1.2 Population of *E. kamerunicus* during peak period of anthesis on female inflorescence of oil palm

Population of *E. kamerunicus* was highest on female inflorescence during 1st and 2nd day of anthesis and it was highly varied from 8.00 a.m. to 4.00 p.m. (Table 2). During the 1st day of anthesis at 8.00 p.m. the population was lowest (0.5) and highest at 12.00 noon (30.2). At 4.00 p.m. the count was 1.5. On 2nd day of anthesis, there were no weevils at 8.00 a.m. But there were 12.6 weevils at 10 a.m. At 12.00 noon the population was highest (15.2) and it was further decreased to 10.7 at 2.00 p.m. and no weevils were found at 4.00 p.m. Peak population of *E. kamerunicus* was found at 12.00 noon on both days of anthesis.

4.1.3 Population of *E. kamerunicus* during peak period of anthesis on male inflorescence of oil palm

Population of *E. kamerunicus* was highly varied from 8.00 a.m. to 4.00 p.m. (Table 3). During the 1st day of observation at 8.00 p.m. the population was 41.3 and decreased during 10.00 a.m. (36.3). At 12.00 noon, the count was 39.0 and reached to 52.7 during 2.00 p.m. After 2.00 p.m. population was further increased and at 4.00 p.m. the count was highest (66.7). On 2nd day of observation, 43.0 weevils were present at 8.00 a.m. Thereafter, its count was gradually increased to 44.0 (10.00 a.m.), 46.3 (12.00 noon) and 53.7 during 2.00 p.m. Highest population was observed during 4.00 p.m. (62.7). Population of *E. kamerunicus* was found to be increased after 2.00 p.m. on both days of observation, and reached its peak at 4 .00 p.m. on both days.

Thus *E. kamerunicus* was found to be the predominant insect species on both male and female inflorescence of oil palm. Results on mean population of *E. kamerunicus* (Table 4) on 1st and 2nd day of anthesis of female flowers showed that, high population was found between 10.00 a.m. (16.7) to 2.00 p.m. (14.3) and insect population was very negligible during 8.00 a.m. (0.3) and 4.00 p.m. (0.8) with highest population at 12.00 noon (22.7). Similarly, results of mean population of *E. kamerunicus*

Table 2. Population of different insect visitors on female inflorescence of oil palm

Insect species	Insect population									
	1st day of anthesis of female flowers					2nd day of anthesis of female flowers				
	8.00 a.m.	10.00 a.m.	12.00 noon	2.00 p.m.	4.00 p.m.	8.00 a.m.	10.00 a.m.	12.00 noon	2.00 p.m.	4.00 p.m.
E. kamerunicus	*0.5	20.8	30.2	17.8	1.5	-	12.6	15.2	10.7	-
Earwig	-	0.3	1.3	-	-	-	0.2	0.8	0.2	-
Honeybees	-	0.1	0.1	-	-	-	0.1	0.5	0.1	-
Moth	-	-	0.1	-	-	-	0.2	0.1	0.1	-

*Mean of 10 replications

Table 3. Population of different insect visitors on male inflorescence of oil palm

Insect species	Insect population									
	1st day of observation					2nd day of observation				
	8.00 a.m.	10.00 a.m.	12.00 noon	2.00 p.m.	4.00 p.m.	8.00 a.m.	10.00 a.m.	12.00 noon	2.00 p.m.	4.00 p.m.
E. kamerunicus	*41.3	36.3	39.0	52.7	66.7	43.0	44.0	46.3	53.7	62.7
Earwig	-	1.7	1.7	0.7	0.3	-	0.3	1.7	-	-
Honeybees	-	0.3	0.6	0.3	-	-	1.3	-	-	-
Moth	-	1.3	-	0.3	-	-	2.0	-	-	-

*Mean of 3 replications

Table 4. Mean population of *E. kamerunicus* on inflorescence of oil palm at the time of anthesis

Inflorescence	Mean population *E. kamerunicus* on inflorescence				
	8.00 a.m.	10.00 a.m.	12.00 noon	2.00 p.m.	4.00 p.m.
Male	*42.2	40.2	42.7	53.2	64.7
Female	**0.3	16.7	22.7	14.3	0.8

*Mean population of 3 replications for two days of observation
**Mean population of 10 replications on 1st and 2nd day of anthesis of female inflorescence

Table 5. Correlation between population of *E. kamerunicus* and per cent pollination on two successive days of anthesis of female inflorescence

Maximum population of *E. kamerunicus*						Per cent pollination	
1st day of anthesis			2nd day of anthesis				
Mean	Range	Correlation	Mean	Range	Correlation	Mean	Range
32	19 - 47	0.712**	16	6 - 34	0.199	80.71	60.36 - 88.37

** = Significant at 1% level

on two days of observations in male inflorescence (Table 4) indicated that, high population was recorded at 8.00 a.m. (42.2). At 10.00 a.m. the weevil population was 40.2 and gradually increased to 42.7 and 53.2 during 12.00 noon and 2.00 p.m. respectively. Highest mean population of *E. kamerunicus* (64.7) recorded at 4.00 p.m.

4.1.4 Relationship between population of *E. kamerunicus* and per cent pollination in oil palm

Results of correlation study between the population of *E. kamerunicus* on female inflorescence during two successive days of anthesis and per cent pollination indicated a highly positive correlation (r = 0.712**) between population of *E. kamerunicus* on day 1 of anthesis and percent pollination. Negligible correlation (r = 0.199) was obtained between weevil population on day 2 and per cent pollination (Table 5).

4.1.5 Population of *E. kamerunicus* at different positions on male inflorescence

Weevils of *E. kamerunicus* were congregating on the male inflorescence during the entire period of anthesis. Statistic median weevil population was 48, 76, 80 and 35, 56 and 72 on top, middle and bottom portions of male inflorescence during rainy and summer seasons respectively (Table 6).

4.2 MECHANISM OF POLLINATION

Adult weevils of *E. kamerunicus* were found to feed on anthers of male inflorescence and multiplied there itself. A specific anise seed like odour was perceived from inflorescence. It would attract the weevils towards both male and female inflorescences. During emission of similar kind of odour from female inflorescence between 10.00 a.m. to 2.00 p.m. more number of weevils moved towards the female flowers and shed the pollen grains on the stigma and again they came back to its original place of host (male inflorescence). This has resulted in adequate level of pollination of female flowers.

Table 6. Population of *E. kamerunicus* on male inflorescence during peak period of anthesis in two seasons

Position of spikelets on male inflorescence	Statistical median population of *E. kamerunicus*	
	Rainy season	Summer season
Top	*48	*35
Middle	76	56
Bottom	80	72

[edian of 7 replications

Aluminium cage

Spent spikelets of male inflorescence

Plate 2. Biology of *E. kamerunicus*

Eggs

Single egg

Eggs on spent male inflorescence

Plate 3. Eggs of *E. kamereunicus*

4.3 BIOLOGY OF PREDOMINANT INSECTS

A study on biology was conducted in aluminium cages using spent male spikelets (Plate 2) under laboratory conditions. This study was conducted only on the African oil palm weevil, *E. kamerunicus* because its population was predominant on the inflorescence when compared to other insect species.

4.3.1 Biology of African oil palm weevil, *Elaeidobius kamerunicus*

Different parameters of weevil biology were worked out and the results were interpreted based on their values of range, mode, mean and standard deviation.

4.3.1.1 Site of oviposition, fecundity and oviposition period

The female weevil of *E. kamerunicus* laid eggs singly on the spent male inflorescence (Plate 3).

During rainy season mean fecundity was 31.8, 33.2, 32.2 and 31.6 when weevils were released at sex ratios (♂ : ♀) of 1 : 1, 1 : 2, 1 : 3 and 1 : 4 respectively with an oviposition period of 2, 2, 2 and 1.8 days (Table 7).

During summer season, with an oviposition period of two days, mean fecundity was 34.6, 34.8, 34.6 and 34.2 at released sex ratios (♂ : ♀) of 1:1, 1:2, 1:3 and 1:4 respectively (Table 7).

The median fecundity was 32 and 35 during rainy and summer seasons respectively with respect to different sex ratios. During both seasons only slight difference was observed in fecundity and no significant difference in oviposition period with respect to different sex ratios (Table 7).

Table 7. Fecundity and oviposition period of *E. kamerunicus* with respect to different sex ratios during rainy and summer seasons

Sex ratio (♂ : ♀)	Rainy season			Summer season		
	Fecundity		Mean oviposition period (days)	Fecundity		Mean oviposition period (days)
	*Mean	± SD		*Mean	± SD	
1 : 1	31.8	2.59	2.0	34.6	2.31	2.0
1 : 2	33.2	2.86	2.0	34.8	2.39	2.0
1 : 3	32.2	3.03	2.0	34.6	3.97	2.0
1 : 4	31.6	3.05	1.8	34.2	3.56	2.0
Median fecundity	32		-	35		-

*Mean of 10 replications

4.3.1.2 Duration of different developmental stages

Duration of different life stages such as, egg, larva, pupa and adults was recorded and their results were given based on range and mode values.

4.3.1.2.1 Egg period

Eggs of *E. kamerunicus* hatched into grubs within 1 to 2 days with the mode value of 2 days in rainy and summer seasons respectively (Table 8).

4.3.1.2.2 Larval period

During both rainy and summer seasons, three instars were observed during the grub stage of *E. kamerunicus*. The mode value of larval duration of 1^{st}, 2^{nd} and 3^{rd} instars were found to be 2, 1 and 6 days respectively in rainy season and corresponding values in summer season were 1, 1 and 5 days (Table 8).

The total duration of grubs varied from 8 to 10 days in rainy and 7 to 9 days in summer seasons. The mode vale of grub period was 9 days in rainy and 7 days in summer season respectively.

4.3.1.2.3 Pupal period

The pupal period of *E. kamerunicus* ranged from 3 to 4 days with the mode values of 4 in rainy and 3 in summer seasons respectively (Table 8).

4.3.1.2.4 Total life cycle

The total life cycle of *E. kamerunicus* from egg to adult was completed with in a period of 14 to 16 days (mode = 15 days) in rainy season and it was 11 to 14 days (mode = 13 days) in summer season (Table 8).

Table 8. Duration of different life stages of *E. kamerunicus* during rainy and summer seasons

Life stages		Rainy season		Summer season	
		Range (days)	*Mode	Range (days)	*Mode
Egg		1 - 2	2	1 - 2	*2
Larva	I instar	1 - 2	2	1 - 2	1
	II instar	1 - 2	1	1 - 2	1
	III instar	5 - 7	6	5 - 6	5
	Total duration	8 - 10	9	7 - 9	7
Pupa		3 - 4	4	3 - 4	3
Total life cycle (egg to adult emergence)		14 - 16	15	11 - 14	13
Adult weevils	Male	5 - 7	6	4 - 6	5
	Female	4 - 6	5	4 - 5	5
Total life span	Male weevils	19 - 23	21	15 - 20	18
	Female weevils	18 - 22	20	15 - 19	18

*Mode of 10 replications

4.3.1.2.4 Total life cycle

The total life cycle of *E. kamerunicus* from egg to adult was completed with in a period of 14 to 16 days (mode = 15 days) in rainy season and it was 11 to 14 days (mode = 13 days) in summer season (Table 8).

4.3.1.2.5 Adult longevity

Adult male weevil lived for 5 to 7 days during rainy season and 4 to 6 days during summer (Table 8). The mode value of male weevil life span was 6 and 5 days during rainy and summer seasons respectively.

The longevity of female weevil varied from 4 to 6 days in rainy season and 4 to 5 days in summer season. The mode value of longevity of female weevil was 5 during both the seasons.

The total life span of adult male weevils ranged from 19 to 23 (mode = 21) and 15 to 20 (mode = 18) days during rainy and summer seasons respectively whereas, female weevils were recorded with total life span of 18 to 22 (mode = 20) and 15 to 19 (mode = 18) days on these seasons.

4.3.1.3 Sex ratio

Random collection of adult weevils from three different male inflorescences, during the peak period of anthesis during both rainy and summer seasons revealed that female weevils were found to be more than male (Table 9). The average sex ratio of male to female was 1 : 1.87 (Table 9) and 1 : 1.96 during rainy and summer seasons respectively.

Table 9. Sex ratio of male and female weevils of *E. kamerunicus*

Repl.	Rainy season				Summer season			
	Adult weevils		Total	Sex ratio (♂ : ♀)	Adult weevils		Total	Sex ratio (♂ : ♀)
	Male	Female			Male	Female		
1	32	68	100	1 : 2.13	31	69	100	1 : 2.23
2	38	62	100	1 : 1.63	36	64	100	1 : 1.78
3	34	66	100	1 : 1.94	33	67	100	1 : 2.03
4	33	67	100	1 : 2.03	37	63	100	1 : 1.70
5	30	70	100	1 : 2.33	28	72	100	1 : 2.57
6	42	58	100	1 : 1.38	32	68	100	1 : 2.13
7	29	71	100	1 : 2.45	35	65	100	1 : 1.86
8	36	64	100	1 : 1.78	41	59	100	1 : 1.44
9	40	60	100	1 : 1.50	34	66	100	1 : 1.94
10	33	67	100	1 : 2.03	36	64	100	1 : 1.78
Total	347	653	1000	Mean = 1 : 1.87	343	657	1000	Mean = 1 : 1.96

*Repl. = Replication

4.3.2 Morphology and morphometrics of *E. kamerunicus*

Results of morphology and morphometric characters of *E. kamerunicus* are presented in Table 10.

4.3.2.1 Egg

Minute pale yellow coloured smooth eggs (Plate 3) were laid singly with a small apical projection and they turned yellowish towards hatching.

The diameter of eggs is given in Table 10. Eggs showed a maximum diameter of 0.263 mm and minimum of 0.253 mm with the mean value of 0.258 mm.

4.3.2.2 Larva

The grub of the weevil was yellow in colour with a brown sclerotized head (Plate 4). It has 'C' shaped body with rudimentary prothoracic legs. The grub had three larval instars (Plate 4) with pinkish yellow colour for the first instar grub.

The measurements of length and width of grubs are given in Table 10. The mean body length of 1^{st}, 2^{nd} and 3^{rd} instar was 1.59, 2.73 and 3.84 mm whereas mean body width was 0.52, 0.86 and 1.62 mm respectively.

4.3.2.3 Pupa

The newly formed pupa of *E. kamerunicus* was dark yellow in colour (Plate 5) and was seen inside the individual male flowers. Only one pupa could be seen in each male flower.

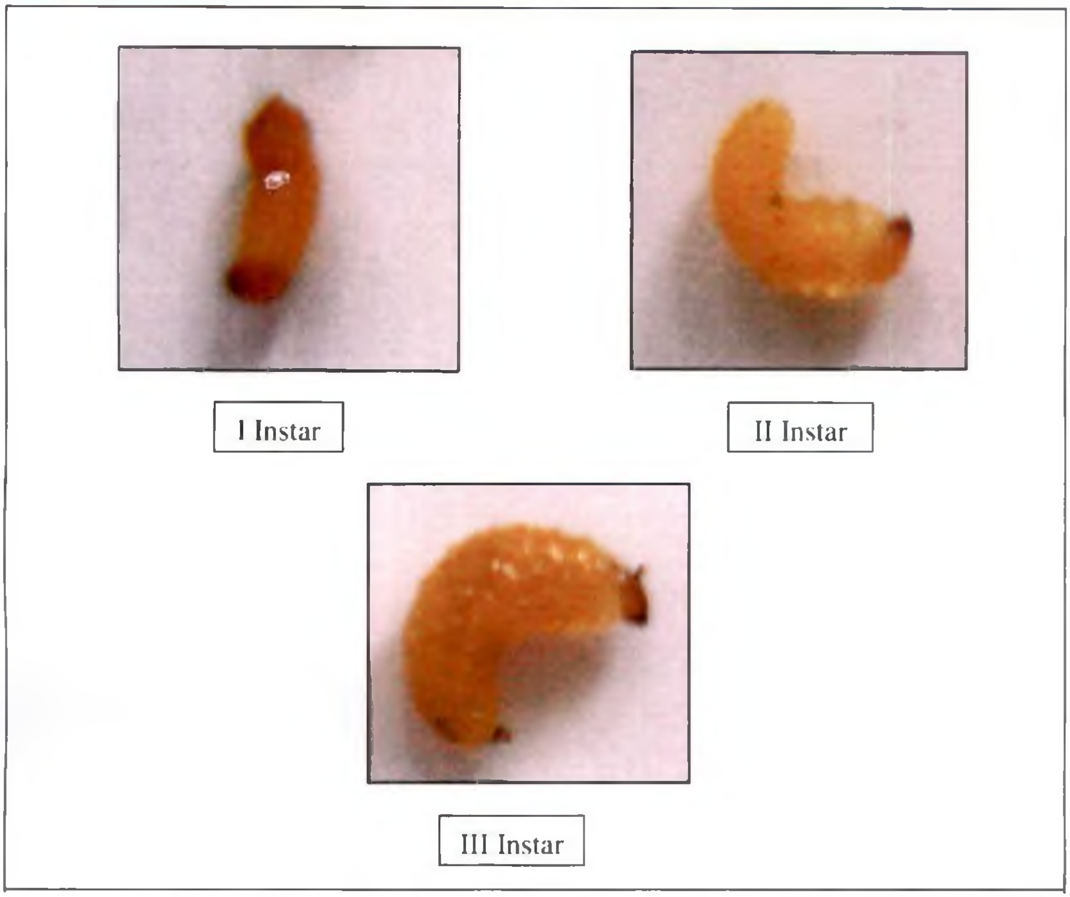


Plate 4. Different larval instars of *E. kamerunicus*

Plate 5. Pupae of *E. kamerunicus*

Table 10. Measurements of different life stages of *E. kamerunicus*

Life stage		Parameters	Range (mm)	*Mean ± SD (mm)
Egg		Diameter	0.253 - 0.263	0.258 ± 0.005
Larva	I instar	Length	1.49 - 1.64	1.59 ± 0.057
		Width	0.47 - 0.58	0.52 ± 0.036
	II instar	Length	2.51 - 2.90	2.73 ± 0.120
		Width	0.74 - 0.94	0.86 ± 0.071
	III instar	Length	3.60 - 4.02	3.84 ± 0.131
		Width	1.32 - 1.90	1.62 ± 0.156
Pupa		Length	3.13 - 3.78	3.53 ± 0.217
		Width	1.32 - 1.92	1.63 ± 0.165
Adult weevils	Male	Length	3.82 - 4.41	4.13 ± 0.189
		Width	1.47 - 1.82	1.54 ± 0.134
	Female	Length	3.61 - 4.02	3.81 ± 0.196
		Width	1.20 - 1.41	1.28 ± 0.086

*Mean of 10 replications

Male
(x 20X)

Female
(x 20X)

Plate 6. Adult weevils of *E. kamerunicus*

The pupa had a maximum length of 3.78 mm and a minimum length of 3.13 mm with a mean value of 3.53 mm (Table 10). The width of the pupa ranged from 1.32 to 1.92 mm with a mean value of 1.63 mm.

4.3.2.4 Adult male and female weevils

Adults are small black, broad elliptical weevils and the sides of prothorax are sharply margined. Adult males are with distinct elytral marginal fringe of long, curved, brownish setae (Plate 6) and additionally some coloured basal marks with dorsal spines are present on the elytra. Adult females are not having these structures (Plate 6).

Male weevils are larger in size with length ranging from 3.82 to 4.41 mm (mean = 4.13 mm), while body length of female weevils ranging from 3.61 to 4.02 mm with a mean value of 3.81 mm (Plate 6) (Table 10). The body width of male ranged from 1.47 to 1.82 mm (mean = 1.54 mm) and that of female was 1.20 to 1.41 mm with a mean value of 1.28 mm (Table 10).

4.4 INFLORESCENCE PRODUCTION

Both male and female inflorescences were produced separately in successive leaf whorls.

4.4.1 Male inflorescence

Monthly production of male inflorescence (Plate 7) ranged from 0 to 2 from 10 different marked palm trees (Table 11). At least one male inflorescence (mode = 1) was observed in each tree from July '09 to Jan '10 except during Sep '09 when, two inflorescences were observed (mode = 2). There was no male inflorescence noted during Feb '10 from 10 palms (mode = 0).

Anthesising male inflorescence

Spent male inflorescence

Plate 7. Male inflorescence of oil palm

Table 11. Monthly inflorescence production and bunch set of oil palm

Month	Male inflorescence			Female inflorescence			Bunch set		
	*Mean	Range	#Mode	*Mean	Range	#Mode	*Mean	Range	#Mode
July '09	0.8	0 - 2	1	0.5	0 - 1	1	0.5	0 - 2	0
Aug '09	1.1	0 - 2	1	2.8	1 - 6	1	1.4	0 - 4	1
Sep '09	1.4	0 - 2	2	0.3	0 - 1	0	4.2	1 - 7	5
Oct '09	1.2	0 - 2	1	0.8	0 - 3	0	4.7	1 - 8	5
Nov '09	1.0	0 - 2	1	0.2	0 - 1	0	4.9	1 - 12	5
Dec '09	1.1	0 - 3	1	0.2	0 - 1	0	4.6	1 - 10	4
Jan '10	1.0	0 - 2	1	0.2	0 - 1	0	4.6	2 - 10	6
Feb '10	0.7	0 - 3	0	0.3	0 - 1	0	2.2	1 - 8	2

*Mean of 10 replications; #Mode of 10 replications

4.4.2 Female inflorescence

Unlike male inflorescence, female inflorescence (Plate 8) production was not uniform. It ranged from 0 to 1 from July '09 to Feb '10 except during Aug '09 (1 to 6) and Oct '09 (0 to 3) (Table 11). The mode value of female inflorescence production was found to be 1 during July '09 and Aug '09 and 0 from the period of Sep '09 to Feb '10.

4.4.3 Period of anthesis and stigma receptivity

Anthesis period of male inflorescence was observed for 10 to 14 days and maximum weevil population was observed between 4th and 7th days which coincided with the maximum odour emission. Stigma receptivity was identified by a similar odour emission. Observations of more insect visits on female inflorescence and colour change of stigma lobe from creamy yellow to deep pink was noticed. The receptivity of stigma lasted for 2 to 3 days but, insect visit was observed for only 2 days.

4.4.4 Bunch set

Results of bunch set in Table 11, revealed that the bunch (Plate 9) development was normal during the entire period of observation except July '09 (mode = 0). But the total number of bunches in each tree was highly varied in different months *viz.,* 0 to 2 (July '09); 0 to 4 (Aug '09); 1 to 7 (Sep '09); 1 to 8 (Oct '09); 1 to 12 (Nov '09); 1 to 10 (Dec '09); 2 to 10 (Jan '10) and 1 to 8 (Feb '10) and their respective mode values are 0, 1, 5, 5, 5, 4, 6 and 2.

4.4.5 Influence of abiotic factors on inflorescence production and bunch set

The maximum male inflorescence production (Table 12) was recorded during Sep' 09 (mode = 2). This coincided with monthly weather parameters of maximum temperature (29.91 ^{o}C), minimum temperature (24.28 ^{o}C), relative humidity (94.37%), rain fall (12.67 mm) and sunshine hours of 0.52 hrs respectively. Thereafter

Anthesising female inflorescence (on 1st day)

Anthesising female inflorescence (on 2nd day)

Plate 8. Female inflorescence of oil palm

Developing fruit bunch

Plate 9. Fruit bunch of oil palm

male inflorescence production started declining and no inflorescence was seen during Feb '10. Monthly values of maximum, minimum temperature, relative humidity, rainfall and sunshine hours were 35.79 °C, 23.48 °C, 83.57%, 0 mm and 9.28 hrs respectively during this period.

Similarly, female inflorescence production (Table 12) was found to be uniform during July '09 and Aug '09 (mode = 1) with monthly weather parameters of maximum temperature (28.4 and 29.94 °C), minimum temperature (23.45 and 24.08 °C), relative humidity (98.38 and 93.52%), rainfall (19.72 and 12.31 mm) and sunshine hours of 2.48 and 3.05 hrs. Thereafter female inflorescence production was very much reduced (mode = 0).

Very poor bunch set was observed in July '09 and gradually it was increased and reached the maximum during Jan '10 (mode = 6). Weather parameters such as, maximum temperature (33.24 °C), minimum temperature (21.7 °C), relative humidity (85.23%), rainfall (0.18 mm) and sunshine hours (8.96 hrs) were recorded during this time. Thereafter, bunch set was gradually reduced (Table 12).

4.4.5.1 Relationship of inflorescence production and bunch set with different weather parameters

Correlation analysis (Table 13) of male and female inflorescence production and various weather parameters showed that there was a significant positive correlation with relative humidity (male = 0.555 and female = 0.643) and rainfall (male = 0.501 and female = 0.724) and significant negative correlation with maximum temperature (male = -0.691 and female = -0.626) and sunshine hours (male = -0.733). On the contrary, results of correlation study (Table 14) between monthly bunch set and various weather parameters revealed that there was a significant negative correlation with relative humidity (-0.522) and very much negligible level of positive correlation with maximum temperature (0.161) and sun shine hours (0.141).

Table 12. Influence of weather parameters on oil palm inflorescence production and bunch set (July '09 to Feb '10)

Month	**Mode values of inflorescence production		**Mode values of bunch set	Monthly weather parameters				
				Temperature (°C)		RH (%)	RF (mm)	Sun shine hours
	Male	Female		Max.	Min.			
July '09	1	1	0	28.40	23.45	98.38	19.72	2.48
Aug '09	1	1	1	29.94	24.08	93.52	12.31	3.05
Sep '09	2	0	5	29.91	24.28	94.37	12.67	0.52
Oct '09	1	0	5	31.76	24.01	93.84	4.51	3.97
Nov '09	1	0	5	30.81	24.65	87.63	9.84	3.11
Dec '09	1	0	4	32.99	23.15	87.71	0.86	6.74
Jan '10	1	0	6	33.24	21.70	85.23	0.18	8.96
Feb '10	0	0	2	35.79	23.48	83.57	0.00	9.28

*Max. = Maximum; Min. = Minimum; RH = Relative humidity; RF = Rainfall

**Mode of 10 replications

Table 13. Correlation of inflorescence production and bunch set in oil palm with monthly weather parameters (July '09 to Feb '10)

Components	Monthly weather parameters				
	Maximum temperature	Minimum temperature	Relative humidity	Rainfall	Sunshine hours
Male inflorescence	- 0.691**	0.235	0.555**	0.501**	- 0.733**
Female inflorescence	- 0.626**	0.112	0.643**	0.724**	- 0.386
Bunch set	0.161	- 0.409	- 0.522**	- 0.224	0.141

**= Significant at 1% level

4.5 ROLE OF OTHER AGENTS IN OIL PALM POLLINATION

Role of other pollinating agents such as wind and birds were observed.

4.5.1 Wind pollination

Level of pollination and fruit set were found to be normal in those inflorescences, covered with polythene bags and also uncovered bunches.

4.5.2 Bird pollination

No bird species was observed and trapped in nylon nets on developing female bunches during the time of pollination. Fruit production of female inflorescences was normal, even in those bunches that were covered with nylon nets and the weevils of *E. kamerunicus* could easily land on the female inflorescences during anthesis.

4.6 YIELD ATTRIBUTES

Results on different yield parameters based on their mean and standard deviation are presented in Table 14.

Number of female flowers ranged from 336 to 800 flowers in a female inflorescence with a mean value of 596.4. Number of fruits per bunch ranged from 186 to 583 (mean = 393). The number of partially developed fruits varied from 27 to 132 with the mean value of 73.8 fruits per bunch. Pollination was ranged from 60.36 to 88.37 with the mean level of 77.13%. Fruit set was completed within 145 to 161 days and bunches were ready to harvest with a mean = 153.3 days. The maximum value of bunch weight was 29 kg and minimum value was 5 kg with a mean value of 17.13 kg. A fruit in a bunch weighed from 24.29 to 41.71 g and showed a mean weight of 32.52 g.

Table 14. Yield attributes of oil palm

Yield attributes	Range	*Mean ± SD
Number of female flowers/ inflorescence	336 - 800	596.4 ± 177.11
Number of completely developed fruits/ bunch	186 - 583	393.00 ± 142.62
Number of partially developed fruits/ bunch	27 - 132	73.8 ± 35.37
Per cent pollination	60.36 - 88.37	77.13 ± 8.63
Days to fruit set	145 - 161	153.3 ± 4.88
Bunch weight (kg)	5 - 29	17.13 ± 8.6
Mean fruit weight/ bunch (g)	24.29 - 41.71	32.52 ± 6.11

* Mean of 10 replications

Discussion

5. DISCUSSION

The results of the investigation on "Insect pollinators of oil palm in Kerala" are discussed herein based on earlier literature and relevant conclusions are presented. The study was conducted with the following objectives.

1. Survey for the collection, classification and identification of insect pollinators in oil palm.
2. To identify the mechanism of pollination, by dominant insect species by no choice trials.
3. To study the biology of the predominant insect species involved in pollination.
4. To explore the role of any other agents like birds and wind in pollination.

5.1 COLLECTION AND IDENTIFICATION OF POLLINATING INSECTS ON OIL PALM INFLORESCENCE

Totally 15 insect species were observed from the oil palm inflorescence. The African oil palm weevil, *Elaeidobius kamerunicus* (Coleoptera: Curculionidae); earwig, *Forficula* sp.? (Dermaptera: Forficulidae); a small moth, *Pyroderces* sp.? (Lepidoptera: Cosmopterigidae) and Indian honey bees, *Apis cerana indica* (Hymenoptera: Apidae) were present in the collection. These observations were also made by Kevan *et al.* (1986) and Franz and Valente (2005) who mentioned that adult weevils of *E. kamerunicus* are specialized and more efficient pollinators of African oil palm and are able to transfer pollen from male to female inflorescences of many adjacent palms. Similarly Pardede (1990) observed that, a cosmopterigid moth was acting as indigenous insect pollinators and transferred the pollen grains from male to female inflorescences of oil palm in South Banten region of Brazil.

Apart from these, black ant colonies were also observed on female inflorescences. These are basically visitors of ripening bunches and nest builders below the fronds and they also get honey dew from mealy bugs, developing on the ripening bunch. So it is assumed that black ants were not having any significant role in oil palm pollination. Similarly, mealy bugs are also not having any role in oil palm pollination since, they will infest only on the developing fruit bunch of oil palm.

All insect visitors are not seen to have significance with regard to pollination in oil palm. They were only casual visitors on oil palm inflorescence.

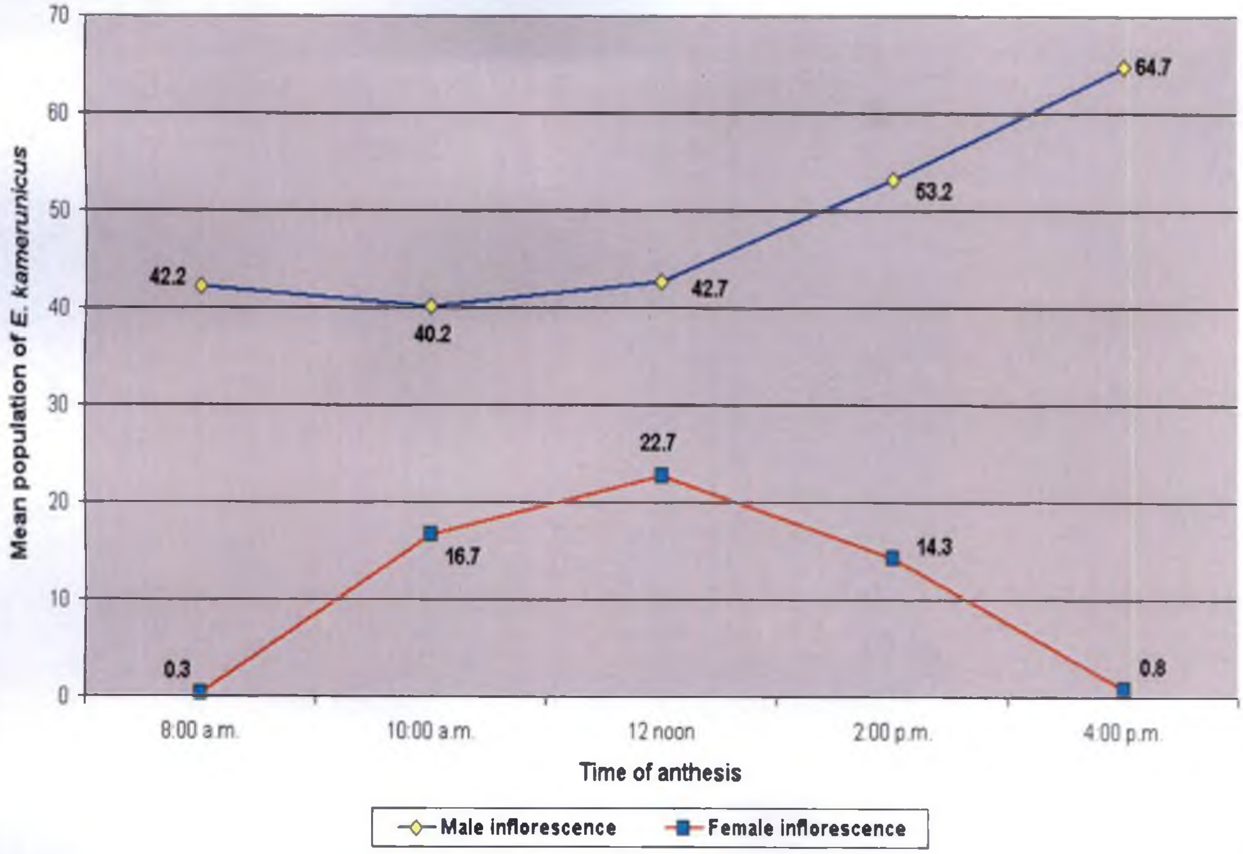
Earlier findings of Pardede (1990) indicated that thrips and cosmopterigid moth were breeding on banana plants during off season. But, in Kerala banana is a widely cultivated crop. Hence, it is not possible to enhance the population of these insects as it may lead to the introduction of these pests on banana. Most of the other insects observed were only occasional visitors of oil palm. Additionally, *E. kamerunicus* can fly to a larger distance than thrips and moth, and will aid in pollination effectively.

The number of insect pollinators depends on the number of anthesising male and female inflorescences in the field as these insects will feed on the pollen from the inflorescences. Similarly, Syed (1978) reported that the lack of anthesising male inflorescences has drastically reduced the population of *E. kamerunicus*, since the weevil completes its life cycle only by feeding pollen grains from male inflorescences of oil palm.

5.1.1 Population of different insect visitors on inflorescence of oil palm

The normal time of visit of insects on female inflorescence was found to be between 10.00 a.m. to 2.00 p.m. and maximum number of insects was seen around 12.00 noon. This was perceived with maximum emission of anise seed odour which was similar as that of male inflorescence. This observation in the present study is in consonance with the findings of Ponnamma *et al.* (1986) who concluded that insect visit towards the female inflorescences was promoted by a specific odour emission. Carlos *et al.* (1991) observed that adult weevils visited the female inflorescence during the hot sunny hours of the day and the more frequent activity was noted between 10.00 a.m. to 1.00 p.m., which

Fig. 1 Population of *E. kamerunicus* on male and female inflorescence of oil palm



coincided with 83% and 71% of the total of the insect visits on the first and second day of anthesis respectively in the oil palm plantations of Central America. Prada *et al.* (1998) reported that mid day of hot sunny period was highly conducive for insect dispersion to female flowers.

5.1.2 Population of *E. kamerunicus* during peak period of anthesis on female inflorescence of oil palm

Among all the insect visitors, population of *E. kamerunicus* were found to be more than that of all other insect species, because, it is permanently invading the male inflorescence of oil palm for their growth and development. Similar observations were made by Syed (1984) who reported that, *E. kamerunicus* is highly specific to the oil palm and breed on spent male inflorescences. The adult weevils visit the female inflorescence due to specific anise seed like odour attraction. Similarly, Kevan *et al.* (1986) indicated that the total number of insects that visited a female inflorescence was approximately 1/15 of those who frequent the male inflorescences.

It is clearly revealed that (Fig. 1) very low population of weevils was recorded on female inflorescence at 8.00 a.m. and 4.00 p.m. This showed that population of weevils between 10.00 a.m. to 2.00 p.m. on the female inflorescence would give valid information on pollination. During this time, higher amount of anise seed like odour was perceived from female flowers. This odour is perceptible to humans.

5.1.2 Population of *E. kamerunicus* during peak period of anthesis on male inflorescence of oil palm

It was found that, more insects were visiting and harbouring the male inflorescence than female inflorescence because, it is the male flower that contains food source (pollen) and is thus more attractive to insects. Both male and female inflorescence contains similar kind of anise seed odour. This is in agreement with the findings of

Kee *et al.* (2000), who found that pollen grains of male inflorescence act as food for many insect visitors.

Results of population of *E. kamerunicus* on male inflorescence clearly revealed that (Fig. 1) more number of weevils was recorded at 8.00 a.m. whereas, between 10.00 a.m. to 2.00 p.m., it was less. This is because of attraction of weevils towards female flowers due to emission of similar kind of odour (anise seed like odour). After 2.00 p.m. the count of *E. kamerunicus* on male flowers was found to be increased and highest was at 4.00 p.m. because, emission of attractive odour from female inflorescence will be gradually reduced which lead to attraction of weevils towards male inflorescence. This is also due to absence of food source (pollen grains) of weevils on female inflorescence.

5.1.3 Relationship of population of *E. kamerunicus* and per cent pollination

Highly significant positive correlation (r = 0.712**) was found between maximum number of *E. kamerunicus* on day 1 of anthesis of female flowers and per cent pollination and non significant correlation (r = 0.199) was obtained between maximum population on day 2 of anthesis of female flowers and per cent pollination (Table 5). This indicated that maximum amount of pollination occurred in the first day of anthesis of female inflorescence itself, which coincided with maximum emission of attractive odour when compared to second day of anthesis.

5.1.4 Population of *E. kamerunicus* at different positions on male inflorescence

The population dynamics of *E. kamerunicus* was estimated by monitoring the population in different inflorescences in order to understand the abundant nature of weevil population and spatial or seasonal distribution in the field as influenced by the different meteorological factors.

Results of studies (Table 6) on weevil population showed that, it was more in the bottom portion of male inflorescence during both rainy and summer seasons. Median weevil population was 48, 76, 80 and 35, 56 and 72 on top, middle and bottom portions of male inflorescence during rainy and summer seasons respectively.

Anthesis of male flower starts from base to top (acropetal). So, weevil population was observed to gradually increase from bottom to top (Table 6). More weevil population in the bottom of male inflorescence was due to the acropetal nature of flower opening and frequent movement of weevils on spikelets cause continuous shedding of pollen grains which leads to accumulation of pollen grains at the base. So, weevils can freely feed on it. The peak population coincided with the peak anthesis time. Similar finding was also observed by Syed (1978). The peak population density was observed with the medium temperature, rainfall and high relative humidity in oil palm plantations. Similar findings were given by Chinchilla *et al.* (1990).

5.2 MECHANISM OF POLLINATION

Adult weevils of *E. kamerunicus* solely depend on male inflorescence and feed on anther (main part of male flowers, containing pollen grains) and multiply there itself. The host specificity is due to presence of some anise seed like odour. Hussein *et al.* (1991) found that, the host specificity of *E. kamerunicus* was due to presence of estragole (5, 4 - allylanisole), a plant chemical in male flowers of oil palm. But, at the time of observation, similar kind of odour was felt from female inflorescence also during its peak stigma receptivity period (between 10.00 a.m. to 2.00 p.m.). The time specificity is due to sedentary nature of weevils during other times and immigration of newly emerged weevils from spent to newly anthesising male inflorescences. Mayfield and Margaret (2005) reported that female flowers were also producing a similar and weaker smell as that of male flowers and does not provide any food rewards to weevils. Intermittent visit of weevils was observed from one palm to the nearby female inflorescence of another palm. This may be due to overcrowding of weevils on the same male inflorescence and their genetic makeup. Due to absence of food materials in the female flower and loss of similar kind of odour, the weevils would shed the pollens adhered over their body on the stigma of female flowers and come back to male inflorescence. Presence of specialized hair like structures of weevils (on the periphery of abdomen) and their frequent visit to female inflorescence could make them an ideal pollinating agent in oil palm. Similar conclusions were also given by Ponnamma *et al.* (1986), Proctor *et al.* (1996) and Mayfield and Margaret (2005).

A sex ratio of 1 : 2 of male and female weevils did not cause any negative effect on oil palm pollination. Though the population of male weevils is less, presence of specialized setae on the periphery of abdomen and elytral spines aid them to carry more amounts of pollen grains to the female flowers when compared to female weevils. Hence the presence of more number of male weevils will be good in view of pollination. Also, abundance of female weevils will not cause any harm to the male weevils and pollination. But, in nature, there is no warranty of availability of equal proportion of male and female weevils on oil palm inflorescence. So, with the prevailing sex ratio of male and female weevils (1 : 1.87 in rainy and 1 : 1.96 in summer seasons) adequate pollination could be achieved.

5.3 BIOLOGY OF PREDOMINANT INSECTS

The study of life cycle of an insect helps to understand the strong and weak points in its life stage and thereby it provides important clues for its effective exploitation and utilization in the research activities with respect to pollination.

5.3.1 Biology of African oil palm weevil, *E. kamerunicus*

Though, many insects visited the inflorescence, the African oil palm weevil, *E. kamerunicus* gave the maximum count because they are completely dependent on male inflorescence of oil palm for their breeding cycle. So, biology study was conducted only on *E. kamerunicus.*

5.3.1.1 Site of oviposition, fecundity and ovipositional period

Results of fecundity studies in the laboratory showed that the female weevils laid the eggs singly on the spent male inflorescence on all the sides, thus indicating no preference to any surface of inflorescence. There was no significant difference observed in the site of oviposition in both the seasons. Similar report was also given by Jagore (1934). Adult female weevils showed mean fecundity of 31.8, 33.2, 32.2 and 31.6 eggs with corresponding sex ratios (♂ : ♀) of 1 : 1, 1 : 2, 1 : 3 and 1 : 4 respectively on rainy season with the median fecundity of 32. Similarly the mean fecundity was 34.6, 34.8, 34.6 and 34.2 with corresponding sex ratios (♂ : ♀) of 1 : 1, 1 : 2, 1 : 3 and 1 : 4 respectively on summer season (median fecundity = 35) (Table 7, Fig. 2).

Fecundity was continued upto two days during both rainy and summer seasons. There is an indication of slight rise in the fecundity during summer season (mean = 34.8) when compared to rainy months (Fig. 2). This is in consonance with the observations of Hussein and Rahman (1991), who claimed that, the mean number of eggs laid per female was 35 in Malaysia under laboratory conditions. But the small variation in the fecundity might be due to higher temperature during summer season. This is because, generally the rate of fecundity will be increased with a moderate hike in the temperature up to a certain limit in order to maintain the generation for compensating the mortality rate.

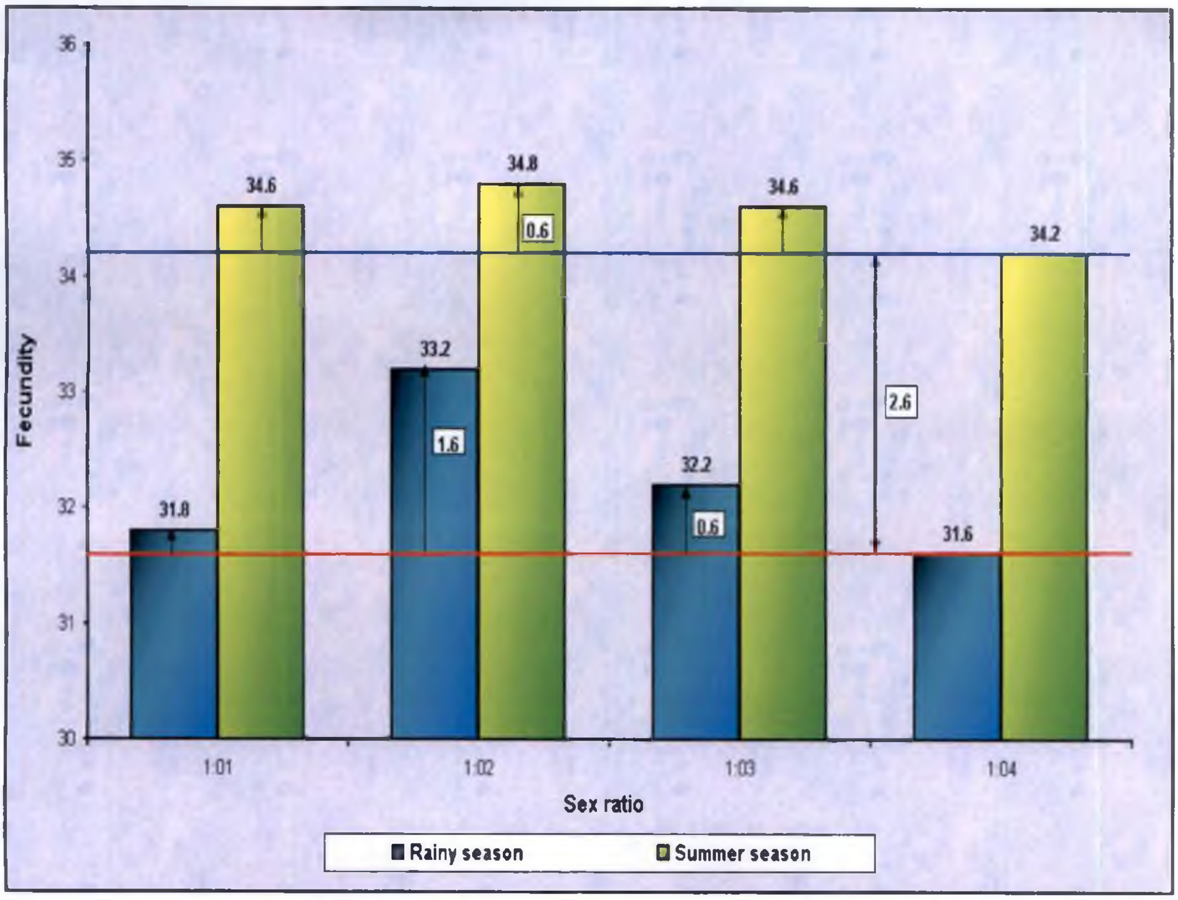
5.3.1.2 Duration of different developmental stages

Duration of different life stages such as egg, larva, pupa and adults are important and it is known that it highly varied with the habitat and the quality and quantity of available food materials (Syed, 1979).

5.3.1.2.1 Egg period

The incubation period of eggs of *E. kamerunicus* was found to be 1 to 2 days during both rainy (mode = 2) and summer seasons (mode = 1) (Fig. 3 to 6). The present

Fig. 2 Fecundity of *E. kamerunicus* during rainy and summer seasons with respect to different sex ratios (♂ : ♀)



result is in agreement with the findings of Ponnamma and Pillai (2002) who reported that, the total egg incubation period of *E. kamerunicus* is 1 to 2 days at the room temperature of 27 °C to 28 °C in Malaysia.

5.3.1.2.2 Larval period

The grub period of *E. kamerunicus* was found to be 9 days in rainy season and 7 days in summer season. This is in partial agreement with the findings of Ponnamma and Pillai (2002) who reported that larva of *E. kamerunicus* was fully developed in 6 to 8 days under room temperature.

Three instars, each with duration of 2, 1 and 6 days in rainy (Fig. 3 and 4) and 1, 1 and 5 days in summer seasons (Fig. 5 and 6) respectively were found to be completed during the larval stage. Similar results were observed by Ponnamma and Pillai (2002) in Malaysia, who found that mean larval duration of 1st, 2nd and 3rd instars were 1, 1 and 5 to 8 days respectively during the period of February to October.

5.3.1.2.3 Pupal period

The pupal period lasted for 3 to 4 days with mode values of 4 in rainy (Fig. 3 and 4) and 5 in summer seasons (Fig. 5 and 6) respectively. Ponnamma and Pillai (2002) also reported that pupal period of *E. kamerunicus* was about 3 days, which is in consonance with the present finding.

5.3.1.2.4 Total life cycle

E. kamerunicus completed its life cycle (egg to adult emergence) within 14 to 16 days (mode = 15) and 11 to 14 days (mode = 13) in rainy and summer seasons respectively (Table 8). There was only 2 days difference in the total life cycle (egg to adult emergence) of *E. kamerunicus* between rainy and summer seasons, thus indicating only slight difference in the duration of life cycle between seasons. The result is in conformity with the findings of Hussein and Rahman (1991), who reported that *E. kamerunicus* completed its life cycle with in 15 days. The short duration of life cycle during the summer season obtained in the present study might be due to the difference in the weather conditions in the two regions. But, some earlier findings showed that the total life-cycle of *E. kamerunicus* was completed within 11 to 13 days in different seasons at Eluru, Andra Pradesh, where the summer temperature was very high (Anon., 2008). This supports the present result. High temperature during the summer season would increase the physiological processes of insect, which resulted in reducing the developmental period of some important life stages. But this might reduce the effectiveness of pollination by the weevils.

5.3.1.2.5 Adult longevity

Longevity of any pollinating insect is important not only on its influence on demographics but also it determines how long the insect is active and exerts some positive influence on crops. The longevity of adult weevil varied with the sex. Males lived longer than the females. Adult males of *E. kamerunicus* lived for 5 to 7 days (mode = 6) in rainy season (Fig. 3) and from 4 to 6 days (mode = 5) in summer season (Fig. 5). The female longevity was equal during both summer and rainy seasons (mode = 5 days) (Fig. 4 and 6). They lived from 4 to 6 days in rainy season and 4 to 5 days in summer seasons thus indicating a shorter life for female weevils than male insects. This is in agreement with the observations in oil palm plantations of Eluru, Andra Pradesh where longevity of adult weevils ranged from 4 to 5 days (Anon., 2008).

Among the duration of different stages *viz.*, egg, larva, pupa and adult of *E. kamerunicus*, the period of larval stage (7 to 9 days) was found to be longest followed by adult (male = 5 to 6 days; female = 5 days), pupa (3 to 4 days) and egg (1 to 2 days) during both rainy and summer seasons (Fig. 3 to 6). The longer duration of larval stages would not cause any damage to the palms, as it is feeding only on anther grains of spent male flowers and the feeding of pollen grains by adult weevils, would result in higher degree of pollen transfer to female inflorescences. Hence this finding is of considerable

Fig. 3 Duration of different life stages of *E. kamerunicus* (Male) during rainy season (mode values)

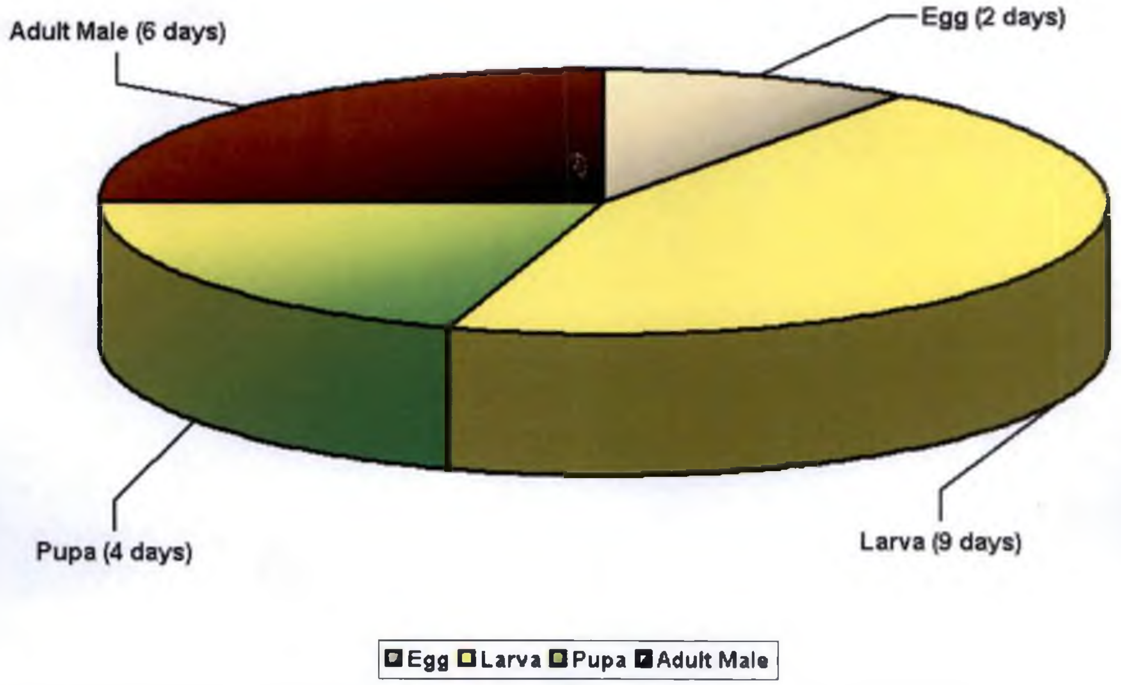


Fig. 4 Duration of different life stages of *E. kamerunicus* (Female) during rainy season (mode values)

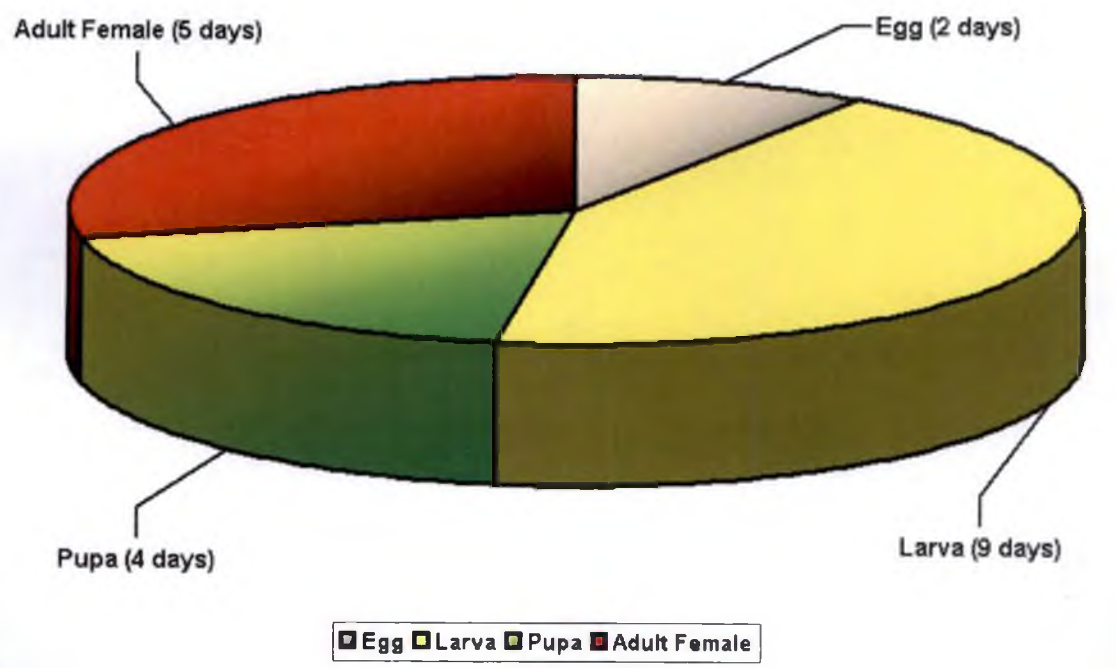


Fig. 5 Duration of different life stages of *E. kamerunicus* (Male) on summer season (mode values)

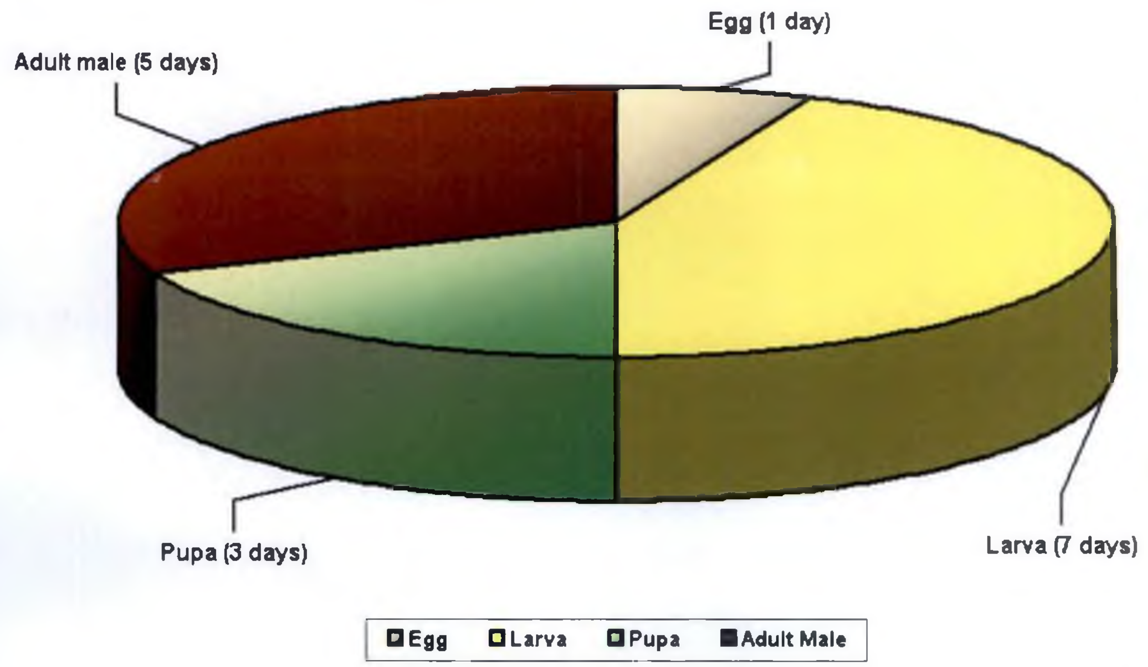
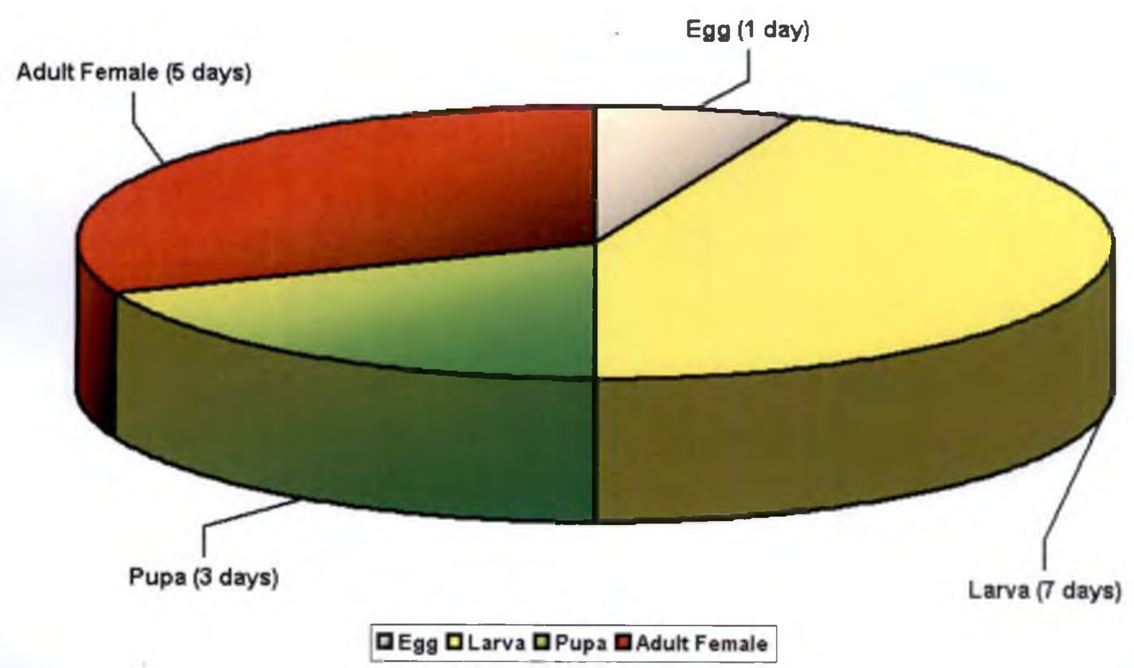


Fig. 6 Duration of different life stages of *E. kamerunicus* (Female) during summer season (mode values)



importance from the angle of management and exploiting the productive role of the insect.

The total life span of adult male weevils ranged from 19 to 23 (mode = 21) and 15 to 20 (mode = 18) days during rainy and summer seasons respectively whereas female weevils were recorded with total life span of 18 to 22 (mode = 20) and 15 to 19 (mode = 18) days on these seasons (Table 8).

5.3.1.3 Sex ratio

The male and female weevils collected from oil palm inflorescences during peak period of anthesis indicated that the number of female weevils were more compared to male (mean sex ratio (♂ : ♀) on rainy season = 1 : 1.87 and mean sex ratio (♂ : ♀) of summer season = 1 : 1.96) during both the seasons (Table 9, Fig. 7 and 8). This is in consonance with the results of Hussein and Rahman (1991) who reported a similar sex ratio (♂ : ♀) of 1 : 2 in Malaysia and Brazil. Similar result was also given by Ponnamma *et al.* (2006). When compared to rainy season, slight reduction in the population of male weevils was observed during summer. Though the population of male weevils is lesser than that of female weevils, the presence of some hairs around the body make them to collect more amount of pollen grains and act as effective pollinators. However, this will not be sufficient to surpass the effectiveness of females in pollination due to their numerical abundance (sex ratio favours 1 : 2). Highest population of insect was observed during peak period of anthesis and before and after this period, weevil population was less.

5.3.2 Morphology and morphometrics

Observations on various morphological and morphometric characters of different life stages will give a correct identification of a particular insect species and helps in further detailed taxonomic studies.

Fig. 7 Male and female weevil population (sex ratio) of *E. kamerunicus* on male inflorescence during rainy season for 10 replications

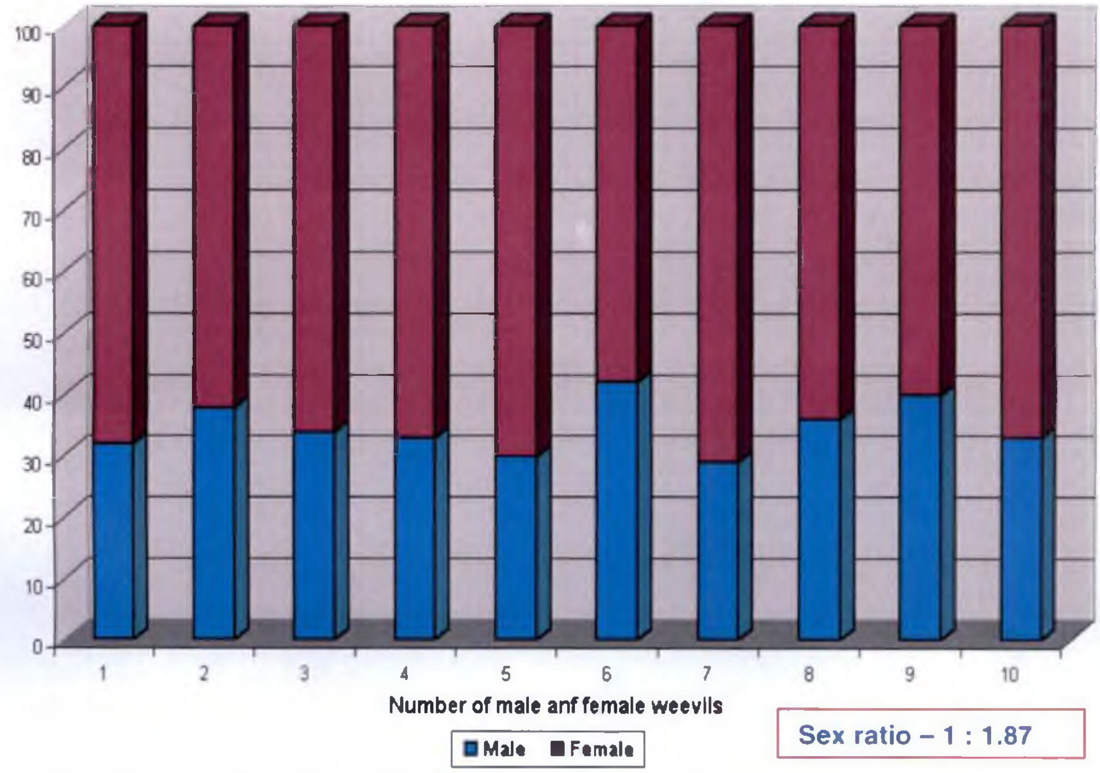
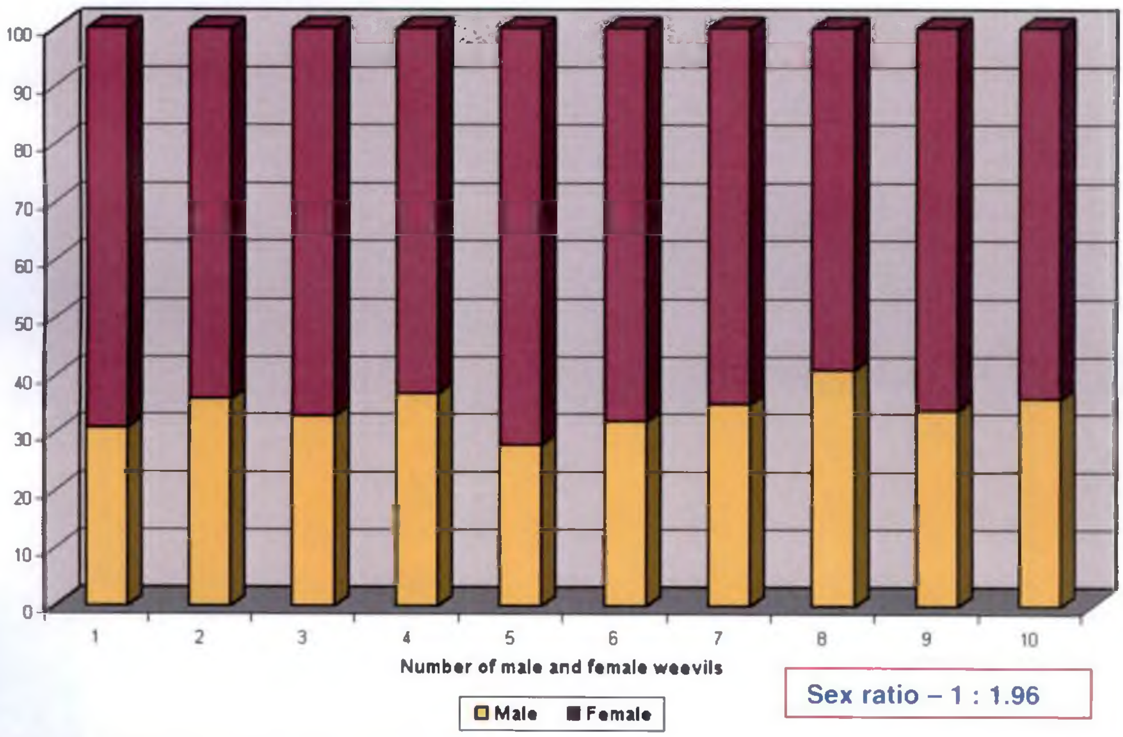


Fig. 8 Male and female weevil population (sex ratio) of *E. kamerunicus* on male inflorescence during summer season for 10 replications



5.3.2.1 Egg

Adult weevils of *E. kamerunicus* laid white coloured round smooth eggs on male inflorescences (Plate 3). This result is in agreement with the findings of Ponnamma and Pillai (2002) who observed that adult female weevils laid white coloured eggs on post anthesis spikelets of male inflorescences. The diameter of egg was 0.263 mm and minimum value was 0.253 mm with the mean value of 0.258 mm.

5.3.2.2 Larva

The grubs of *E. kamerunicus* were yellow in colour with dark brown head. It showed a small head capsule and 'C' shaped body with rudimentary legs (Plate 4). Similar observations was made by Ponnamma and Pillai (2002) who found that newly emerged larva was pinkish yellow in colour and later on it changed to yellow.

5.3.2.2.1 First instar

Newly emerged 1st instar grub was pinkish yellow in colour with small brown head (Plate 4). The average length and width of 1st instar grub was found to be 1.59 mm and 0.52 mm respectively.

5.3.2.2.2 Second instar

The 2nd grub showed the pure yellow colour with a brown head capsule and average length and width of larval body was 2.73 and 0.86 mm respectively (Plate 4).

5.3.2.2.3 Third instar

There was no colour change observed between 2nd and 3rd instar larvae (Plate 4). It measured an average length of 3.84 mm and width of 1.62 mm.

The total length of grub increased from 1.59 mm in first instar to 3.84 mm in 3rd instar. The width also increased from 0.52 mm in 1st instar to 1.62 mm in the 3rd instar.

5.3.2.3 Pupa

Freshly formed pupa was dark yellow in colour and seen inside the flowers (Plate 5). It measured a maximum length of 3.71 mm and minimum length of 3.13 mm with a mean value of 3.53 mm. Its width varied from 1.51 to 1.92 mm with the mean value of 1.63 mm. The colour of pupal skin remains same even before and after the adult emergence (Plate 4).

5.3.2.4 Adult

The newly emerged adult weevil was brownish and later on changed to dark colour. The male and female weevils could be differentiated based on larger body size, presence of specialized, distinct elytral marginal fringe of long, curved, brownish setae and some coloured basal marks with dorsal spines on the elytra (Plate 6). Similar identifications were made by Marshall (1958).

The male weevils are bigger than female in size. The body length (4.13 mm) and width (1.54 mm) of male weevil was larger than that of the female (length = 3.81 mm; width = 1.28mm). The males are having more setae around the peripheral side of elytra with dorsal spines where as the female weevils are bare (Plate 6). But there are no significant difference with respect to antenna and legs.

The present finding of larger body size and hairy structure of male of insect is in agreement with the findings of O'Brien and Woodruff (1986).

5.4 INFLORESCENCE PRODUCTION

Production of male and female inflorescences was not found to be normal and they were produced separately in successive leaf whorls. This is in agreement with the findings of Kee *et al.* (2000). They also mentioned that the bunch production was strongly related to the rate of leaf and inflorescence production, which in turn was affected by various environmental conditions. The fruit set was not found to be uniform in each month and its count was varying irrespective of age and height of different marked trees.

5.4.1 Male inflorescence

Male inflorescence production was found to be uniform in all the months and it ranged from 0 to 2. Only one male inflorescence (mode = 1) was observed in each tree from July '09 to Jan '10 except during Sep '09 (mode = 2) and during Feb '10, when male inflorescence was not observed (mode = 0) from the 10 palm trees (Fig. 9).

The fluctuation in the number of male inflorescences in anthesis would cause major variations in weevil population in commercial plantations. But high rain fall is very much inimical to weevil movement to different trees. Bulgarelli (2002a) reported that high concentration of weevils in a few inflorescences during only a particular season due to availability of more pollen grains. This might be negative for the species, since it may lead to an increase in the mortality rate and to a greater risk of disease transmission.

5.4.2 Female inflorescence

The female inflorescence production was not uniform and it ranged from 0 to 1 from July '09 to Feb '10 except during Aug '09 (1 to 6) and Oct '09 (0 to 3). The mode value found to be 1 during July '09 and Aug '09 and it was 0 from Sep '09 to Feb '10 (Fig. 10). High fluctuation of the female inflorescence production will directly influence the bunch count and its development.

Fig. 9 Monthly production of male inflorescence (July '09 - Feb '10)

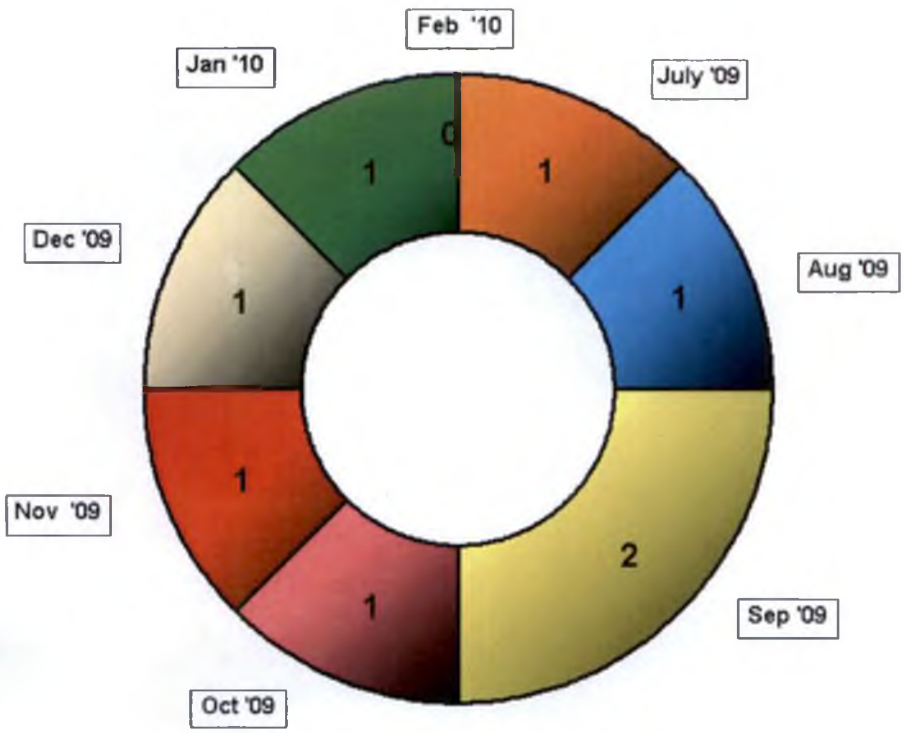
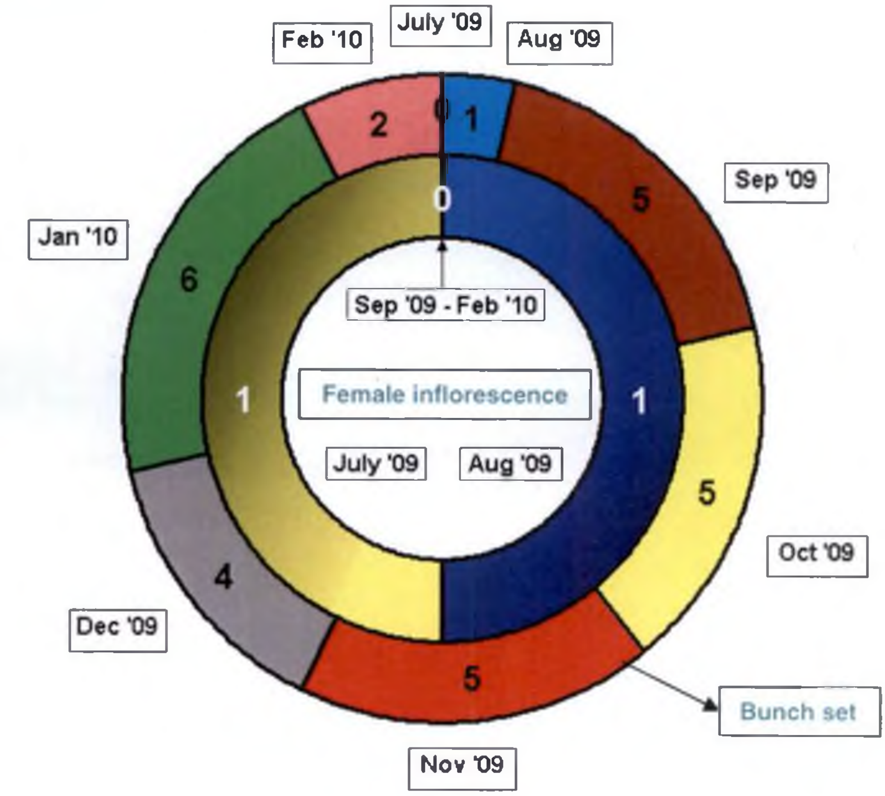


Fig. 10 Female inflorescence production and bunch set during every month (July '09 – Feb '10)



5.4.3 Period of anthesis and stigma receptivity

Anthesis of male inflorescence was completed within 10 to 14 days (Plate 7) and more weevil population was noted for around 3 to 4 days (between 4^{th} to 7^{th} days) which coincided with the maximum emission of specific odour. This is in consonance with the observations of Ponnamma (1999). Emission of similar odour, maximum number of insect visit and colour change of stigma lobe from creamy yellow to deep pink confirmed the stigma receptivity of female inflorescence which lasted for 2 to 3 days with insect visit of only 2 days (Plate 8). The present observation is in agreement with the findings of Kee *et al*. (2000).

5.4.4 Bunch set

Bunch development was normal during the entire period of observation except July '09 (Fig 10). The range of bunch production was highly varied in different months such as 0 to 2, 0 to 4, 1 to 7, 1 to 8, 1 to 12, 1 to 10, 2 to 10 and 1 to 8 from the months of July '09 to Feb '10 respectively and their corresponding mode values are 0, 1, 5, 5, 5, 4, 6 and 2 (Fig. 10). The fruit set was not found to be uniform in each month and its count was varying irrespective of age and height of different marked trees. This showed that the normal bunch development requires warm humid climate.

5.4.5 Influence of abiotic factors on inflorescence production and bunch set

The dynamics of inflorescence production and bunch set of oil palm was estimated in different months in order to understand the production pattern as influenced by different climatic factors and period of supporting the pollinating insects.

5.4.5.1 Influence on male inflorescence production

Production pattern of male inflorescence indicated the increasing trend from July '09 to Sep '09 and decreased production from Oct '09 to Feb '10. But every month at least one male inflorescence was produced (mean = 1.04). This is mainly to sustain the production cycle and also aids in the population maintenance of pollinating weevils. The maximum male inflorescence production was recorded during Sep '09 (mode = 2) which coincided with monthly weather parameters of lower maximum (29.91 °C) and higher minimum temperature (24.28 °C), higher relative humidity (94.37%), medium rainfall (12.67 mm) and low sunshine hours of 0.52 hrs respectively. There after male inflorescence production started declining and no inflorescence was observed during Feb '10 with maximum, minimum temperature, relative humidity, rainfall and sun shine hours of 35.79 °C, 23.48 °C, 83.57%, 0 mm and 9.28 hrs respectively during this period (Fig. 11 and 12). This coincides with the earlier findings of Bulgarelli *et al.* (2002b) who mentioned that the number of male inflorescences in anthesis dropped gradually between Oct 1994 and Jan 1995 in oil palm plantations of Costa Rica. When the weather factors were not congenial, a poor flight activity was observed particularly during rainy period though it favours the male inflorescence production. The poor flight activity would ultimately reduce the level of pollination and fruit set which might be due to a nuisance factor of the lashing rain drops. Similar findings were made by Bulgarelli *et al.* (2002b) and Moura *et al.* (2008). They reported that poor flight activity of weevils was observed during rainy months in oil palm plantations of Costa Rica.

5.4.5.2 Influence on female inflorescence production

Female inflorescence production was found to be uniform during July '09 and Aug '09 (mode = 1) with recorded monthly climatic parameters of medium maximum (28.4 and 29.94 °C) and higher minimum temperature (23.45 and 24.08 °C), higher relative humidity (98.38 and 93.52%), higher rainfall (19.72 and 12.31 mm) and low sunshine hours of 2.48 and 3.05 hrs (Fig. 11 and 12). Thereafter it was very much reduced (mode =0). This showed that, medium temperature, high rainfall and relative humidity would enhance the female inflorescence production. Broekmans (1957) found that higher and even distribution of rainfall caused an increase in sex ratio (more female inflorescences). But, monthly mean of female inflorescence production was 0.7 which indicated that at least one inflorescence could be produced in every month.

5.4.5.3 Influence on bunch set

Very poor bunch set was observed in July '09 which is associated with a reduction in the inflorescence production and pollinating weevil population that occurred about five months earlier. The bunch set reached its maximum during Jan '10 (mode = 6) which was characterized by higher maximum (32.24 ^{o}C), lower minimum temperature (21.7 ^{o}C), medium level of relative humidity (85.23%), low rainfall (0.18 mm) and higher sunshine hours (8.96 hrs). Thereafter bunch set was gradually reduced (Fig. 11 and 12). The high bunch set also coincided with reasonably good weevil population and good weather (maximum temperature = 35.79 ^{o}C, minimum temperature = 23.48 ^{o}C, relative humidity = 83.57%, rainfall = 0 mm and sunshine hours = 9.28) during harvest ie. five months when the fruit set occurred. Monthly mean of bunch set was 3.4 which shows, around 3 developing bunches were seen during every month by compensating all kind of stress.

Generally inflorescence production was more during onset of monsoon and later on it was gradually reduced. The present finding confirmed that medium rain fall, temperature and high relative humidity are highly congenial for production of both male and female inflorescences and rapid multiplication of weevils. Rainfall is the main source of water for the oil palm plantation. However, during the dry season, only some amount of water is available for the trees that cause poor production of inflorescences and bunch set. Similar kind of conclusions were made by Chinchilla *et al.* (1990) and Bulgarelli *et al.* (2002b) reported that the number of male inflorescences in anthesis was found to be low during the dry season due to high water deficit in the soil and unfavourable climatic conditions in major oil palm growing regions of Costa Rica.

5.4.5.4 Relationship of inflorescence production and bunch set with different weather parameters

Male and female inflorescence production showed significant positive correlation with weather parameters, like relative humidity (male = 0.555 and female = 0.643) and

Fig. 11 Monthly inflorescence production and bunch set with their corresponding maximum, minimum temperature and relative humidity

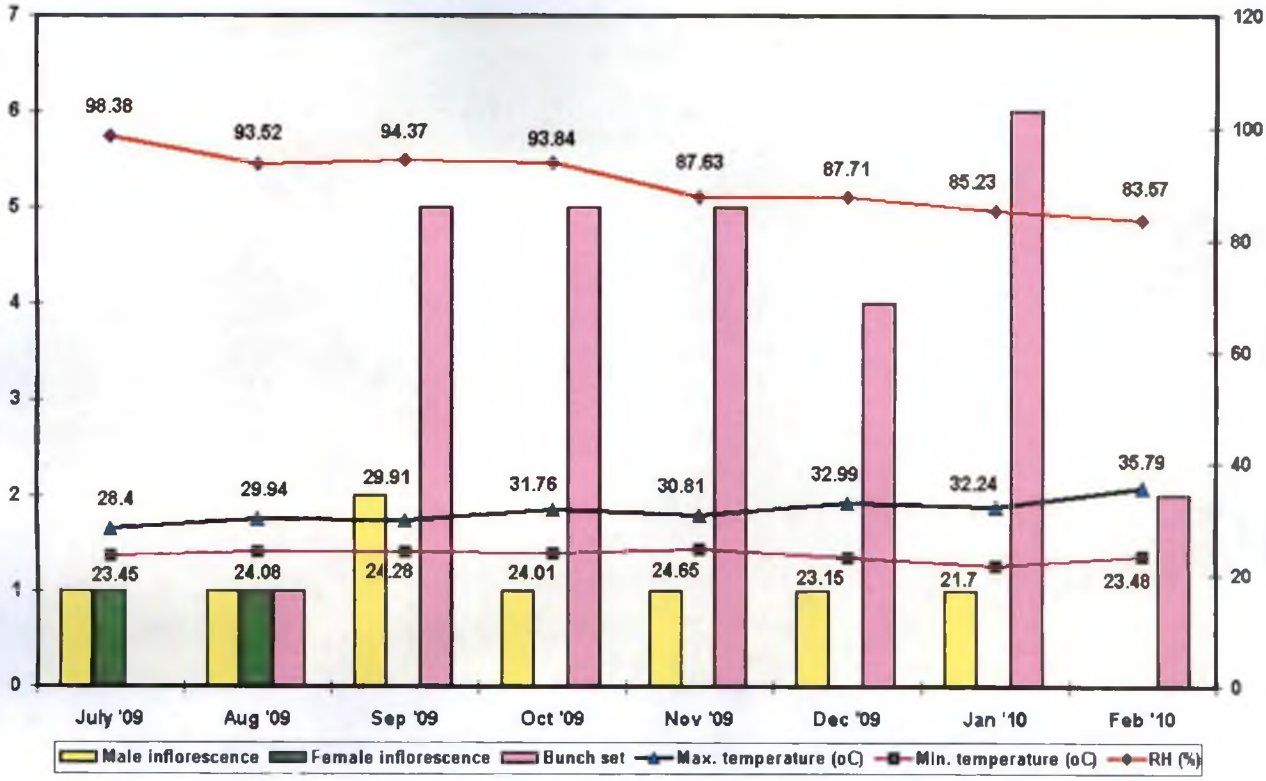
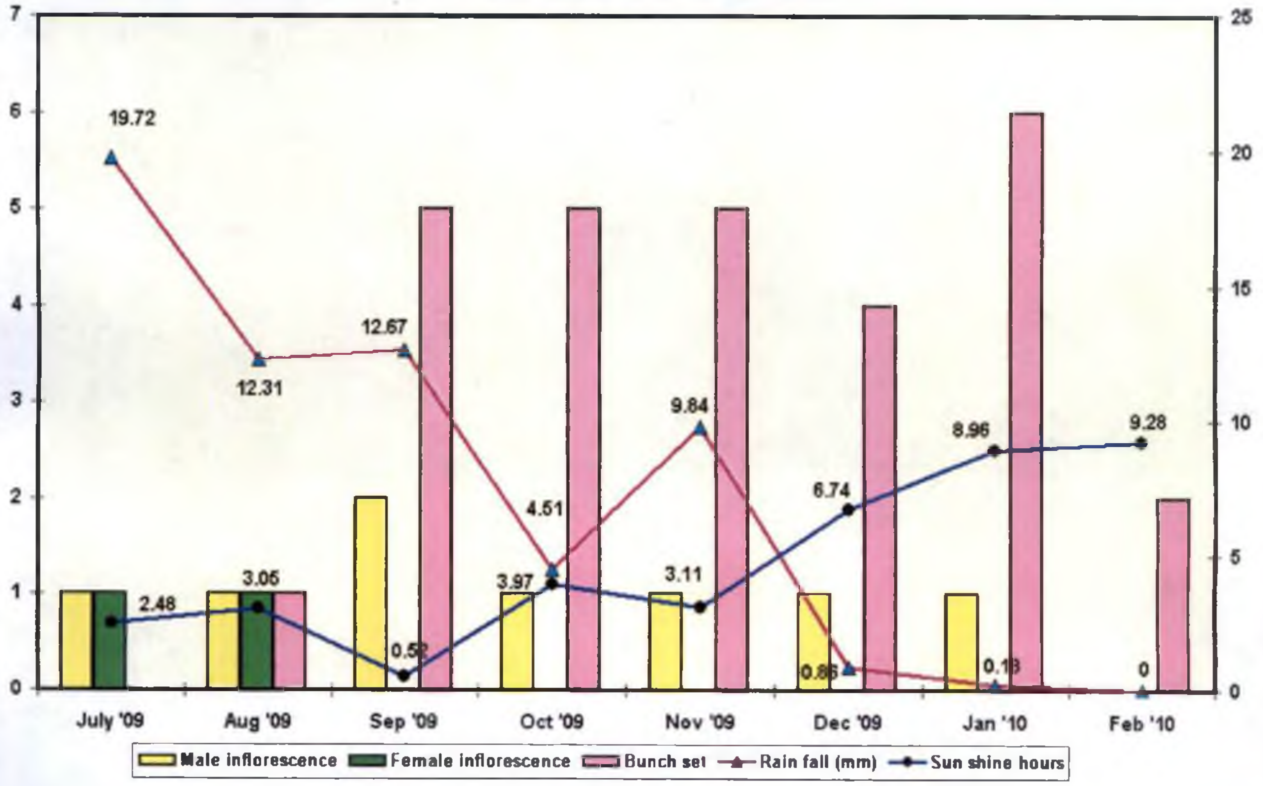


Fig. 12 Monthly inflorescence production and bunch set with their corresponding rainfall and sunshine hours



rainfall (male = 0.501 and female = 0.724) and significant negative correlation with maximum temperature (male = -0.691 and female = -0.626) and sun shine hours (male = -0.733) (Table 13). In contrast to this, bunch set showed a significant negative correlation with relative humidity (-0.522) and very much negligible level of positive correlation with maximum temperature (0.161) and sun shine hours (0.141) (Table 13).

This showed that weather factors such as minimum temperature, relative humidity and rainfall are having favourable role on both male and female inflorescence production with negative effect from maximum temperature and sunshine hours. But bunch set was highly favoured by maximum temperature and sunshine hours. Hence the present study indicated that, optimum inflorescence production requires lower maximum, higher minimum temperature and relative humidity with low sunshine hours and medium level of rainfall. In contrast to this, normal bunch set will be promoted by higher maximum temperature, sun shine hours with medium level of relative humidity and also by low minimum temperature and rainfall. So, some level of balance will be maintained with these weather parameters to obtain sustainable production of inflorescences and bunch set.

5.5 ROLE OF OTHER AGENTS IN OIL PALM POLLINATION

Generally, in nature there won't be a single pollinating agent for a particular crop. Even in a strictly cross pollinated crop, some level of self pollination can be observed. Obviously, though the weevils of *E. kamerunicus* act as a principal pollinating agent in oil palm, some other agents like wind and rodents might also contribute to some extent in the pollination and their role is to be explored.

5.5.1 Wind pollination

Level of pollination and fruit set were found to be normal in those inflorescences covered with polythene bags and that of uncovered bunches in shorter palms. It is assumed that the height of tree plays a vital role in the disbursement of pollen. The contribution of wind might be very less in shorter palms due to thick canopy of palm. Similar reports were also given by Syed (1978) that thick canopy and high pollen density of oil palms would not support the effective pollen transfer. These showed insects are the main pollinating agent in oil palm.

5.5.2 Bird pollination

There were no bird species observed and trapped on developing female bunches during pollination. Even in female inflorescences covered with nylon nets, the fruit production was normal. Any pollinator bird should frequently visit both male and female inflorescences and should have some kind of association with them. So birds might be occasional visitors of oil palm to collect the mature fruits and also larvae of *E. kamerunicus.* Similarly, Chenon and Susanto (2006) also reported that birds were not involved in any significant role in oil palm pollination, instead, they are preying up on *E. kamerunicus* and thereby reduce the population of weevils.

5.6 YIELD ATTRIBUTES

Different yield parameters have to be worked out, mainly to understand the productive role of the crop and predicting the efficiency of source to sink conversion.

5.6.1 Number of flowers per female inflorescence

Flower production ranged from 336 to 800 per inflorescence with the mean value of 596.4. But the present result is contrary to the observations of Beirnaert (1935) who reported that more than 2,000 individual flowers could be seen in each female inflorescence of well grown oil palm tree. The deviation might be due to age of the tree and difference in the prevailing climatic conditions and management practices.

5.6.2 Number of fruits per bunch

Number of fruits per bunch ranged from 186 to 583 (mean = 467.57). But the present result is contrary to the findings of Teoh-Cheng-Hai (2002) who reported that a well maintained mature oil palm tree can yield around 1000 to 1300 fruits per bunch. The low number of fruits per bunch from the present observation might be due to difference in the age, management practices and prevailing climatic and stress factors. But this can be compensated by obtaining fruits with more weight and oil content.

5.6.3 Number of partially developed or sterile fruits

Number of partially developed fruits varied from 27 (12.8 %) to 132 (28.7 %) with the mean value of 73.8 fruits per bunch. Dhileepan and Nampoothiri (1989) also got similar result and obtained up to 23.60 per cent partially developed fruits during the research in oil palm plantations of Kerala. But development of more number of partially developed fruits will not contribute to yield which ultimately reduces the quality of bunches. Sterile fruits were considered as non pollinated flowers in this study.

5.6.4 Per cent pollination

The rate of pollination ranged from 60.36 to 88.37 per cent with the mean value of 77.13 % which would give optimum level of fruit set. Similar results were attained by Syed and Salleh (1987) who reported that around 70 per cent of fruit set will give economic yield. Success of pollination is mainly decided by the duration of transfer and viability of pollen during the peak anthesis time.

5.6.5 Days to fruit set from anthesis

The fruit set was completed within 145 to 161 days and bunches were ready to harvest (mean = 153.3 days). This is in agreement with the findings of Beirnaert (1935) who reported that, the period from anthesis to bunch harvest is about 5 months.

5.6.6 Total bunch weight

The total bunch weight varied from 5 to 29 kg with the mean value of 20.86 kg. Dhileepan and Nampoothiri (1989) mentioned that average weight of bunches pollinated by wind and weevils was 16.93 kg in 10 year old commercial plantations of Kerala. Similarly Kee *et al.* (2000) and DOPR (2009) reported that 8 to 10 years old palms would give 10 to 25 kg of bunches through weevil pollination and this was considered to be economical.

5.6.7 Mean fruit weight per bunch

The mean fruit weight ranged from 24.29 to 41.71 g in each bunch (mean = 32.52 g). Much variation was noted in the fruits with respect to its size and individual weight. The results of DOPR (2009) indicated that mean weight of fruit is 30 g.

In general, oil palm trees containing bunches with medium weighing fruits and more oil content is very much suited for large scale commercial oil palm plantations rather than the high weighed and sterile fruits.

5.7 SALIENT FINDINGS AND RECOMMENDATIONS

Observations on period of stigma receptivity of female inflorescence and time of weevil visit to female flowers may be helpful to the farmers when they would need assisted pollination through manual pollination or artificial means by using *E. kamerunicus.* During that time, they can restrict the pollination just for 2 days, which will ultimately save labour, money and time spent on this.

Since there is very poor inflorescence production during summer season, the weevil population should be maintained artificially. Otherwise, this will reflect in the yield of forth coming months. So artificial attractive para pheromones can be employed to capture large amount of weevils and release them when considerable level of male inflorescence are available. Otherwise it can be maintained in laboratory.

In order to conserve the weevil population in the oil palm plantations, the male inflorescence should be retained at least for one month after anthesis. This will help for multiplication of weevils and lead to sufficient population build up. During heavy rainy months, retaining of spent male inflorescence for more than 40 to 45 days will cause unnecessary fungal invasion on inflorescence and on the weevils which obviously affect future generation of weevil population. Hence during the rainy period, the spent male inflorescence should be removed between 40 to 45 days.

A good yield is also dependent on proper fertilizer management. Uniform flower production of both male and female inflorescence will be achieved by good management practices of plantation.

Summary

6. SUMMARY

Oil palm is one of the major oil yielding crops in the world. In olden days it was grown in the wild and hand pollinated to get adequate yield. Until now, pollination is considered as a vivid issue in the cultivation of oil palm and it has been reported to have an ideal pollinating agent to obtain sustainable yield. Hence the present study entitled "Insect pollinators of oil palm in Kerala" was undertaken in the oil palm plantations of Plantation Corporation of Kerala, Athirappilly and further laboratory studies in the Department of Agricultural Entomology, College of Horticulture, Vellanikkara during 2009 to 2010. The results of the study are summarized here under.

Totally 15 different insect species were observed on oil palm inflorescence and among them the African oil palm weevil, *Elaeidobius kamerunicus* (Coleoptera: Curculionidae); earwig, *Forficula* sp.? (Dermaptera: Forficulidae); moth, *Pyroderces* sp.? (Lepidoptera: Cosmopterigidae) and Indian honey bee, *Apis cerana indica* (Hymenoptera: Apidae) were main species from the collection on male and female inflorescences. Along with these, some other hymenopteran insects included dammer bee, *Trigona iridipennis (Meliponidae)*, black ant, *Camponotus* sp. (Formicidae), leaf cutter bee, *Megachile* sp. (Megachilidae), cuckoo wasp, *Chrysis* sp.? (Chrysididae), carpenter bee, *Xylocopa* sp. (Xylocopidae) and giant hornet, *Vespa* sp. (Vespidae) and three lepidopteran insects *viz.,* leaf caterpillar, *Elymnias* sp. (Nymphalidae), citrus butter fly, *Papilio* sp. (Papilionidae) and Yellows, *Eurema hecabe* (Pieridae) and a hemipteran mealy bug, *Paracoccus marginatus* (Pseudococcidae) and a dipteran hover fly, *Syrphus* sp.? (Syrphidae) were also found to be visiting the inflorescence of oil palm.

Population of different insect visitors on marked anthesising female inflorescence was highly varied and the African oil palm weevil, *E. kamerunicus* was found to be more, among all insect species. High population of *E. kamerunicus* was found between 10.00 a.m. to 2.00 p.m. and it was very less during 8.00 a.m. and 4.00 p.m. Though other insects *viz.,* earwig, moth and Indian honey bees were present, their population was very less.

Population of *E. kamerunicus* was highest on female inflorescence during 1st and 2nd day of anthesis. During the 1st day of anthesis at 8.00 p.m. the population was lowest (0.5) and highest at 12.00 noon (30.2). At 4.00 p.m. the count was 1.5. On 2nd day of anthesis, no weevils were found at 8.00 a.m. At 12.00 noon the population was highest (15.2) and it was decreased to 10.7 at 2.00 p.m. and no weevils were found at 4.00 p.m. Peak weevil population was observed around 12.00 noon on both 1st and 2nd day of anthesis of female inflorescence.

But, on the 1st day of observation on male inflorescence, at 8.00 p.m. the population was 41.3 and decreased during 10.00 a.m. (36.3). It reached to 39.0 and 52.7 at 12.00 noon and 2.00 p.m. respectively. After 2.00 p.m. population was further increased and at 4.00 p.m. the count was highest (66.7). Similarly, on 2nd day of observation, 43.0 weevils were present at 8.00 a.m. Thereafter, its count was gradually increased to 44.0 (10.00 a.m.), 46.3 (12.00 noon) and 53.7 during 2.00 p.m. and at 4.00 p.m. the population was 62.7. Population of *E. kamerunicus* was found to be increased after 2.00 p.m. on both days of observation.

Correlation between population of *E. kamerunicus* on day 1 of anthesis of female flowers and percent pollination was highly significant (r = 0.712**) and it was not significant (r = 0.199) on the 2nd day of anthesis which indicates that the maximum amount of pollination occurred in the first day of anthesis.

Weevils of *E. kamerunicus* were congregating on the male inflorescence during the entire period of anthesis and their population was varied with the position of spikelet. Statistical median weevil population was 48, 76, 80 and 35, 56 and 72 on top, middle and bottom portions of male inflorescence during rainy and summer seasons respectively.

Adult weevils of *E. kamerunicus* feed on anthers of male inflorescence and multiply there itself. Weevils are attracted towards both male and female inflorescence due to a specific anise seed like odour. During emission of similar odour from female inflorescence (between 10.00 a.m. to 2.00 p.m.) more weevils moved towards the female flowers and shed the pollen grains. Due to absence of food source (pollen) and low persistence of odour, weevils came back to its original place of host (male inflorescence).

In oil palm, the population of *E. kamerunicus,* was found to be more when compared to all other insect species so, biology studies were only conducted on this species. There was a marked difference noticed in the biology of *E. kamerunicus* during both rainy and summer seasons. Eggs were laid singly on the spent male inflorescences. The fecundity ranged from 31.6 to 33.2 eggs in rainy and 34.2 to 34.8 eggs in summer seasons with an oviposition period of 2 days.

Eggs are hatched into grubs with in 1 to 2 days during both the seasons and grubs feed on anthers of spent male inflorescences. They completed development with 3 larval instars in 8 to 10 days in rainy and 7 to 9 days in summer seasons. Grubs pupated with in the spent male flowers for 3 to 4 days during both rainy and summer seasons. Male weevils had a longer life than females (5 to 7 days in rainy and 4 to 6 days in summer seasons). The emerged out adult female weevils lived for 4 to 6 and 4 to 5 days in rainy and summer seasons respectively. The total life cycle of *E. kamerunicus* from egg to adult stage was completed with in a period of 14 to 16 days in rainy and 11 to 14 days in summer seasons.

In the field generally female weevils were found to be more than male with the mean sex ratio of 1 : 1.87 and 1 : 1.96 during rainy and summer seasons respectively. The peak population was observed during the peak period of anthesis of male inflorescence *viz.,* 4^{th} to 7^{th} day.

Freshly laid eggs were round shaped and yellow coloured. They had diameter of 0.258 mm. The grub of *E. kamerunicus* was creamy yellow with brown head. The length of grub increased from 1.59 to 3.84 mm from 1^{st} to 3^{rd} instar. Similarly the width also increased from 0.52 to 1.62 mm during these instars. The freshly formed pupa was yellow in colour and seen loosely present inside the spent male flowers. It measured an average length of 3.53 mm and width of 1.63 mm. The freshly emerged weevil was light brown and later changed to dark brown colour. The adult male weevil was longer than female with 4.13 mm length and 1.54 mm width. Female weevil was brownish 3.81 mm length and 1.28 mm width. Male and female weevils could be differentiated by the size and additional structures of the body. Male weevils showed larger body size. The additional structures are the presence of setae on the peripheral side of elytra with dorsal spines. Female had smaller body and absence of the above mentioned structures over its body.

Both male and female inflorescences were produced separately in successive leaf whorls. Production of male inflorescence ranged from 0 to 2 from 10 different marked palm trees and at least one male inflorescence (mode = 1) was observed in each tree from July '09 to Jan '10 except during Sep '09 when, 2 inflorescences were observed (mode = 2). Female inflorescence production was not uniform and it ranged from 0 to 1 during July '09 to Feb '10 except during Aug '09 (1 to 6) and Oct '09 (0 to 3). The mode value of female inflorescence production was found to be 1 during July '09 and Aug '09 and mode value of zero was recorded from the period of Sep '09 to Feb '10. Anthesis period of male inflorescence accounted for 10 to 14 days and more weevil population was observed between 4^{th} to 7^{th} days which coincided with the maximum odour emission from the flowers. Stigma receptivity lasted for 2 to 3 days but, insect visit was observed for only 2 days.

The bunch set was not found to be uniform in each month and its count was varying irrespective of age and height of different marked trees. Bunch development was normal during the entire period of observation except July '09. But the mode value of bunch set was highly varied in different months like 0 (July '09), 1 (Aug '09), 5 (Sep '09), 5 (Oct '09), 5 (Nov '09), 4 (Dec '09), 6 (Jan '10) and 2 (Feb '10).

Male and female inflorescence production dynamics with respect to different climatic factors was recorded from July '09 to Feb '10. Male inflorescence production was found to be increasing from July '09 to Sep '09 and later on uniform production was noticed up to Jan '10 and no inflorescence was seen on Feb '10. This coincided with the maximum and minimum temperature of 21.91 and 24.98 °C, relative humidity of 94.37 %, rain fall of 12.67 mm and sun shine hours of 0.52 hrs. Similarly female inflorescence production was found to be uniform during July '09 and Aug '09 (mode = 1) with recorded monthly climatic parameters of maximum temperature (28.4 and 29.94 °C), minimum temperature (23.45 and 24.08 °C), relative humidity (98.38 and 93.52 %), rain fall (19.72 and 12.31 mm) and sun shine hours of 2.48 and 3.05 hrs. There after it was very much reduced (mode =0).

Bunch set was low in July' 09 and gradually showed increasing trend and reached the maximum during Jan '10 (mode = 6). Weather parameters such as, maximum (32.24 °C), minimum temperature (21.7 °C), relative humidity (85.23 %), rain fall (0.18 mm) and sun shine hours (8.96 hrs) were recorded at this time. There after bunch set was gradually reduced.

Correlation study of inflorescence production and various weather parameters showed that there was a significant positive correlation with relative humidity (male = 0.555 and female = 0.643) and rainfall (male = 0.501 and female = 0.724) and high significant negative correlation with maximum temperature (male = -0.691 and female = -0.626) and sunshine hours (male = -0.733). But, monthly bunch set showed a significant negative correlation with relative humidity (-0.522) and less positive correlation with maximum temperature (0.224) and sunshine hours (0.141).

Pollination and fruit set were found to be normal in those inflorescences covered with polythene bags and which was similar, as that of uncovered bunches. This showed that, wind could be offered only less level of contribution to pollination of oil palm. There were no bird species observed and trapped on developing female bunches covered by nylon nets during pollination which showed that birds were not a pollinating agent in oil palm.

Around 336 to 800 flowers were seen on marked female inflorescences with the mean value of 596.4. Fruit count ranged from 186 to 583 (mean = 393) with 27 to 132 partially developed fruits with the mean value of 73.8 fruits per bunch. Per cent pollination ranged from 60.36 to 88.37 (mean = 77.13 %). Totally 145 to 161 days were taken for the complete development of fruits from anthesis with the mean duration of 153.3 days. The maximum bunch weight was 29 kg and minimum value was 5 kg with a mean value of 17.13 kg and mean fruit weight per bunch was 32.52 g with the range of 24.29 to 41.71 g.

References

7. REFERENCES

Anonymous, 2008. *Elaeidobius kamerunicus*- pollinating weevil of oil palm. *Plant Hort. Technol.* 7(6): 30-32

Anonymous, 2008. Oil Palm (*Elaeis guineensis*) [online]. Available: http://agritech.tnau.ac.in/horticulture/horti_plantation%20crops_oilpalm.html. [Accessed on: 18 Dec, 2009, 2.25 p.m.]

Basri, M.W. 1985. Developments of the oil palm pollinator *Elaeidobius kamerunicus* in Malaysia. *Palm Oil Rev.* 2: 1-3

Basri, M.W., Halim, H.A., and Ahmad, H. 1983. Current status of *Elaeidobius kamerunicus* Faust and its effects on the oil palm industry in Malaysia. *PORIM Occasional Paper.* Palm Oil Research Institute of Malaysia, No. 6, p.24

Basri, M. and Kamarudin, N.H.J. 1997. Role and effectiveness of *Elaeidobius kamerunicus*, *Thrips hawaiiensis* and *Pyroderces* sp. in pollination of mature oil palm in peninsular Malaysia. *Elaeis* 9(1): 1-16

Beirnaert, A. 1935. Introduction to floral Biology of oil palm (*Elaeis guineensis* Jacq.). National Agricultural Institute of Belgium. *Scient. Ser.* 5: 3-42

*Broekmans, A. 1957. Growth, flowering and yield of the oil palm in Nigeria. *J. W. Afr. Oil Palm Res.* 2(7): 187-220

*Bulgarelli, J., Chinchilla, C., and Rodriguez, R. 2002a. Population of *Elaeidobius kamerunicus* (Coleoptera: Curculionidae) and quality of pollination in commercial oil palm plantations of Costa Rica. *ASD Oil Palm Papers*, No. 2, pp.1-18

Bulgarelli, J., Chinchilla, C., and Rodriguez, R. 2002b. Male inflorescences, population of *Elaeidobius kamerunicus* and pollination in a young commercial oil palm plantation in a dry area of Costa Rica. *ASD Oil Palm Papers*, No. 24, pp.32-37

Carlos, M., Chinchilla, C., and Richardson, D.L. 1991. Pollinating insects and the pollination of oil palms in Central America. *ASD Oil Palm Papers*, No. 2, pp. 1-18

Caudel, R.D., Hunt, D., Reid, A., Mesah, B.A., and Chinchilla, C. 2005. Insect pollination of oil palm: a comparison of the viability and long-term sustainability of *Elaeidobius kamerunicus* in Papua New Guinea, Indonesia, Costa Rica and Ghana. *ASD Oil Palm Papers*, No. 25, pp.1-16

Chairani, M., Taniputra, B., and Subronto, K. 1989. The effect of introduction of the *E. kamerunicus* Faust on the bunch components of the oil palm during 1983-1988. *Bull. Plantn* 20(2): 67-75

Chan, K.W.Y.Y., Yong, A., Ahmad. K., and Goh, K.H.M. 1987. Comparison of the yield, bunch and oil characteristics and their heritability before and after the introduction of oil palm pollinating weevils (*E. kamerunicus*) in the oil palm plantations(*E. guineensis*) of Malaysia. In: Pushparajah, E. and Chin, S.L. (eds.), *Proceedings of the International Oil Palm/ Palm Oil Conference-Progress and Prospects.* June 23-26, 1987. Kuala Lumpur, Malaysia, pp.23-36

Chee, K.H. and Chiu, S.B. 1998. A study of *Elaeidobius kamerunicus* in West Kalimantan oil palm plantations. *Planter* 74: 587–595

Chenon, R.D. and Susanto, A. 2006. Ecological observations on diurnal birds in Indonesian oil palm plantations. *J. Oil Palm Res.* 6(Special): 122-143

*Chinchilla, L., Manuel, C., and Richardson, D.L. 1990. Pollination of oil palm in Central America. I. Insect populations and their efficiency as pollinators. *Turrialba* (Costa Rica) 40(4): 452-460

Chinchilla, C.M. and Richardson, D.L. 1991. Pollinating insects and pollination of oil palm in Central America. *ASD Oil Palm Papers of Costa Rica.* No. 2 (Special), pp.23-45

Chowdhury, A.R. 2005, Dec 06. Pollinating agent. *The Hindu.* P.9

Corrado, F. 1985. Conformation of oil palm bunches (*Elaeis guineensis* Jacq.) in certain Columbian plantations. *Oleagineaux* (French) 40(4): 173-187

DOPR [Directorate of Oil Palm Research]. 2009. Details on Recommended Varieties, Fertilizer Doses, Agronomical Practices, Application of Pesticide, Yield and Productivity of Oil Palm [online]. Available: http://dopr.gov.in/The%20Oil %20Palm_files/Detail%20on%20Oil%20Palm%20Cultivation.pdf. [Accessed on: 18 March, 2009, 3.25 p.m.]

Dhileepan, K. and Nampoothiri, K.U.K. 1989. Pollination potential of introduced weevil *Elaeidobius kamerunicus* on oil palm *(Elaeis guineensis)* plantations. *Indian J. Agric. Sci.* 59(8): 517-521

Dhileepan, K. 1992. Pollen carrying capacity, pollen load and pollen transferring ability of the oil palm pollinating weevil, *Elaeidobius kamerunicus* Faust in India. *Oleagineux* (French) 47(2): 55-61

Dhileepan, K. 1994. Variations in populations of the introduced pollinating weevil, *Elaeidobius kamerunicus* (Coleoptera: Curculionidae) and its impact on fruit set of oil palm (*Elaeis guineensis*) in India. *Bull. Ent. Res.* 84: 477-485

Donough, C.R., Chew, K.W., and Law, I.H. 1996. Effect of fruit set on oil extraction rate (OER) and kernel extraction rate (KER): results from studies at oil palm estates (Sabah), Kuala Lumpur, Malaysia. *Planter* 72: 203-209

Fairhurst, T.H. and Mutert, E. 1999. Introduction to oil palm production. *Bett. Crops Int.* 13(1): 1-6

Franz, M.N. and Valente, M.R. 2005. Evolutionary trends in derelomine flower weevils (Coleoptera: Curculionidae): from associations to homology. *Invertebrate Syst.* 19: 499-530

*Free, J.B. 1993. *Insect Pollination of Crops* (2nd ed.). London, Academic Press, London, 684p.

*Garcia, L. 1994. Evaluation of some factors affecting fertilization and fruit formation in oil palm (*Elaeis guineensis* Jacq.) Santa Cruz, Venezuela. UG Thesis. National University Experimental Sur del Lago. TG-0081 ING Cota, 85p.

Garraway, E., Henry, D.C., and Critchley, B.R. 2007. The biology, ecology and economic importance of the pink scavenger caterpillar *Pyroderces rileyi* (Lepidoptera: Cosmopterigidae) on banana in Jamaica. *Trop. Sci.* 47(4): 231-243

Genty, P., Desmier, D.C.R., and Morin, J.P. 1978. The ravages of oil palm in Latin America. *Oleagineux* (French) 33(7): 324-420

Genty, P., Garzon, A., Luchini, F., and Delvare, G. 1986. Entomophilous pollination of oil palm in tropical America. *Oleagineux* (French) 41(3): 99-112

Gerridsma, W. and Wessel, M. 1997. Oil palm- domestication achieved? *Neth. J. Agric. Sci.* 45: 463-475

Hardon, J.J. and Corley, R.H.V. 1976. Pollination. In: Corley, R.H.V., Hardon, J.J. and Wood, B.J. (eds.), *Developments in Crop Science*. Elsevier, Amsterdam, 532p.

Hardon, J.J. and Turner, P.D. 1967. Observations on natural pollination in commercial plantings of oil palm (*Elaeis guineensis*) in Malaya. *Expt. Agric.* 3(2): 105-116

Harun, M.H. and Noor, M.D.M.R. 2002. Fruit set and oil palm bunch components. *J. Oil Palm Res.* 14(2): 24-33

Hussein, M.Y., Lajis, N.H., and Ali, J.H. 1991. Biological and chemical factors associated with the successful introduction of *Elaeidobius kamerunicus* Faust, the oil palm pollinator in Malaysia. *Acta Hort.* 288: 81–86

*Hussein, M.Y. and Rahman, W.H.A. 1991. Life tables for *Elaeidobius kamerunicus* Faust (Coleoptera: Curculionidae) in oil palm. *Planter* 67(778): 3-8

*Jagore, R.B. 1934. Observations and experiments in connection with pollination of oil palm. *Malay. Agric. J.* 22: 598-606

Kang, S.M. and Zam, A.K. 1982. Quarantine Aspects of the Introduction into Malaysia of an Oil Palm Insect Pollinator. In: Hoeng, K.L., Lee, B.S., Lim, T.M., Teoh, C.H., and Yusof, I. (eds.), *Proceedings of the First International Conference on Plant Protection in the Tropics,* 1 - 4 March, 1982, Malaysian Plant Protection Society, Kula Lumpur, pp.615- 626

Kee, N.S., Uexkull, H.V., and Hardter, R. 2000. Botanical Aspects of the Oil Palm Relevant to Crop Management [online]. Available: http://www.klonsawitagro. com/Botany%20of%20Oil%20Palm.pdf. [Accessed on: 27 July, 2009, 12.45 p.m.]

Kevan, P.G. 1999. Pollinators as bioindicators of the state of the environment: species, activity and diversity. *Agric. Ecosyst. Environ.* 74: 373-393

Kevan, P.G., Hussein, N.Y., Hussey, N., and Wahid, M.B. 1986. The use of *Elaeidobius kamerunicus* for pollination of oil palm. *Planter* 62: 89-99

Labarca, M.V., Portillo, E., and Narváez, Y.Z. 2007. Relationship between inflorescences, climate and the pollinating in oil palm (*Elaeis guineensis* Jacq.) plantations located in south Lake of Maracaibo, Zulia State. *J. Fac. Agron.* 24(2): 32-47

*Mariau, D. and Genty, P. 1988. IRHO contribution to the study of oil palm insect pollinators in Africa, South America and Indonesia. *Oleagineux* (French) 43 (6): 233-240

Marshall, G.A.K. 1958. Curculionidae (Coleoptera) of Angola. II. *Publ. Cult. Comp. Diam. Angola.* 38: 111-154

Mayfield, T. and Margaret, M. 2005. The importance of nearby forest to known and potential pollinators of oil palm (*Elaeis guineensis* Jacq.) (Arecaceae) in Southern Costa Rica. *Econ. Bot.* 59(2): 190-196

Ming, K.S. 1999. The *Elaeidobious kamerunicus* story. *Planter* 75 (876): 143-150

Moura, T., Lacerda, J.I., Cividanes, K., Jorge, F., Filho, S., and Pereira, L. 2008. Pollination of oil palm by weevils in southern Bahia of Brazil. *Embrapa Inf. Technol.* 43(3): 289-294

O'Brien, C.W. and Woodruff, R.E. 1986. First records in the United States and South America of the African oil palm weevils, *Elaeidobius subvittatus* (Faust) and *E. kamerunicus* (Faust) (Coleoptera: Curculionidae). *Entomology Circular*, No. 284. Florida Department of Agriculture and Consumer Service. Division of Plant Industry. U.S.A. Florida. 2p.

*Pardede, D. 1990. Indigenous pollinator insects of oil palm at South Banten. *Plantn Newsl.* 21(4): 213-223

PNGOPRA [Papua New Guinea Oil Palm Research Association], 2004. Oil Palm Pollinating Weevil in Malaysia [online]. Available: http://www.pngopra.org. pages/publications/annual_reports.html. [Accessed on: 21 March, 2009, 9.45 a.m.]

*Ponnamma, K.N. 1999. Diurnal variation in the population of *Elaeidobius kamerunicus* on the anthesising male inflorescences of oil palm. *Planter* 75(881): 405-410

*Ponnamma, K.N., Asha, V., and Sajeebkhan, A. 2004. Impact of release of oil palm pollinating weevil, *Elaeidobius kamerunicus* (Faust) (Coleoptera: Curculionidae) and the status of weevil population and fruit set in the various oil palm plantations in India. *J. Plantn Crops.* 32(Supplement): 379-384

*Ponnamma, K.N., Asha, V., and Sajeebkhan, A. 2006. Progeny emergence in *Elaeidobius kamerunicus* [online]. Available: http://www.isp.org.my/files/ May %2006.doc. [Accessed on: 15 Oct, 2008, 11.35 a.m.]

Ponnamma, K.N., Dhileepan, K., and Sasidharan, V.G. 1986. Record of the pollinating weevil *Elaeidobius kamerunicus* (Faust) (Coleoptera: Curculionidae) in oil palm plantations of Kerala. *Curr. Sci.* 55(19): 992-994

Ponnamma, K.N. and Pillai, R.S.N. 2002. Evaluation of the pollination of different bio- types of *Elaeidobius kamerunicus* in the oil palm plantations in different agro ecosystems. *Annual Report 2002-2003.* National Research Centre for Oil Palm, Padvagi, Andra Pradesh, p.50

Prada, M., Molina, D., Villaroel, D., and Dias, R.B.A. 1998. Effectivity of two pollinator species of he genus *Elaeidobius* (Coleoptera: Curculionidae) in oil palm crop. *Bioagro* 10(1): 3-10

*Price, P.W. 1984. *Insect Ecology* (2nd ed.). John Wiley and Sons, p.607

Proctor, M., Yeo, P., and Lack, A. 1996. *The Natural History of Pollination.* Timber Press, Portland, pp.112-118

*Purseglove, J.W. 1975. *Tropical Crops: Monocotyledons: Vol. 1.* Longman Group Ltd London, pp.75-85

Rao, S.C., Babu, M.K., and Nair, R.R. 1990. Effect of the pollinating weevil, *Elaeidobius kamerunicus,* on the incidence of bunch failure in oil palm plantations of Little Andamans. *J. Plantn Crops.* 18(1): 62-65

Rethinam, P. 1992. History of oil palm cultivation and its potential in India. In: Nair, M.K. and Nampoothiri, K.U.K. (eds.), *Oil Palm Production Technology*. Central Plantation Crops Research Institute, Kasargod, pp.7-11

*Sanchez, S.S., Carlos, F., and Ortiz, G. 1998. Oil palm pests and pollinators in Tabasco, Mexico [online]. Available: www.asd-cr.com/ASD-pub/Bol18/Bi8c3 ing.htm-9k. [Accessed on: 26 August, 2008, 12.30 p.m.]

*Sparnaaij, I.D. 1969. Oil palm (*Elaeis guineensis* Jacq.). In: Ferwerda, F.P., and Wit, F. (eds.), *Outlines of Perennial Crop Breeding in the Tropics,* Miscellaneous Papers, Agricultural University, Wageningen. pp.339-387

*Speldewinde, H.V. and Pereira, J.R. 1974. Assisted pollination of oil palm in the Labuk Valley, Sabah. *Planter* 50: 99–109

*Syed, R.A. 1978. Studies on pollination of oil palm in West Africa and Malaysia. *Report of the Commonwealth Institute of Biological Control (CIBC).* 38p.

Syed, R.A. 1979. Studies on the oil palm pollination by insects. *Bull. Ent. Res.* 69: 213-224

Syed, R.A. 1980. Pollinating insects of oil palm. *Report of Commonwealth Institute of Biological Control (CIBC),* June 1980, pp.18-32

Syed, R.A. 1981. Insect pollination of oil palm: feasibility of introducing *Elaeidobius* spp. into Malaysia. In: Pushparajah, E. and Chew, P.S. (eds.), *Proceedings of the International Conference on Oil Palm in Agriculture in the Eighties*, 17-20 June, Kuala Lumpur, Malaysia, pp.263-289

Syed, R.A. 1984. Insect pollinators of African palm. *Palmas* 5: 19-64

Syed, R.A. and Corely, R.H.V. 1982. Insect pollination of oil palm, introduction, establishment and pollinating efficiency of *Elaeidobious kamerunicus* in Malaysia, Kuala Lumpur. *Planter* 58: 547-561

Syed, R.A., Law, I.H., and Corley, R.H.V. 1982. Insect pollination of oil palm: Introduction, establishment, establishment and pollinating efficiency of *Elaeidobius kamerunicus* in Malaysia. *Planter* 58: 547–561

Syed, R.A. and Salleh, A. 1987. Population of *Elaeidobius kamerunicus* in relation to fruit set. In: Pushparajah, E. and Chin, S.L. (eds.), *International Oil Palm/ Palm Oil Conference-Progress and Prospects.* June 23-26, Kuala Lumpur, Malaysia, pp.48-67

Tan, Y.A.P. and Basri, M.W. 1985. Another pollinating insect of oil palm-*Pyroderces* spp. In: Hassan, A.H. (ed.), *Proceedings of the Seminar on Impact of the Pollinating Weevil of Malaysian Palm Oil Industry,* 21-24 February, 1984, Palm Oil Research Institute of Malaysia. Kula Lumpur, pp.50-57

Tandon, R., Manoharaj, T.N., Nijalingappa, B.H.M., and Shivanna, K.R. 2001. Pollination and pollen-pistil interaction in oil palm, *Elaeis guineensis*. *Ann. Bot.* 87: 831-838

Teoh-Cheng-Hai. 2002. *The Palm Oil Industry in Malaysia: From Seed to Frying Pan.* National Annual Corporate Reports Aware Brochure, Malaysia. p.4

Turner, P.D. 1981. *Oil palm Diseases and Disorders.* Incorporated Society of Planters, Kuala Lumpur, 280p.

Turner, P.D. and Gilbanks, R.A. 1974. *Oil Palm Cultivation and Management.* Incorporated Society of Planters, Kuala Lumpur, p.672

Uhl, N.W. and Dransfield, J. 1987. *Genera Palmarum.* Allen Press, Lawrence, pp.23-54

Veera, J. 1996. Insect assisted pollination in young oil palm plantings. *Plantn Res. Dev.* 3(2): 89-96

Wood, B.J. 1983. Note on insect pollination of oil palm in South Central America. *Planter* 59: 167-170

*Zenner, I. and Posada, F. 1992. *Management of Insect Pests and Beneficial Insects of Oil Palm.* Colombian Agricultural Institute. pp.98-105

*Originals not seen

Appendix

APPENDIX - I

Abbreviations used in the thesis

i) Months

- July '09 = July 2009
- Aug '09 = August 2009
- Sep '09 = September 2009
- Oct '09 = October 2009
- Nov '09 = November 2009
- Dec '09 = December 2009
- Jan '10 = January 2010
- Feb '10 = February 2010

ii) Symbols and short forms

- a.m. = Ante Meridiem
- p.m. = Post Meridiem
- % = Per cent
- r = Correlation
- t = Tonne
- Kg = Kilogram
- g = Gram
- °C = Celsius
- hrs = Hours
- mm = Millimeter
- RH = Relative humidity
- Max. = Maximum
- Min. = Minimum
- RF = Rain fall
- R, Repl. = Replication
- S. No. = Serial Number
- Fig. = Figure

- SD = Standard Deviation
- I = Inflorescence production
- B = Bunch set
- Anon. = Anonymous
- spp. = Species
- ♂ = Male
- ♀ = Female
- ± = Plus or Minus
- *Via* = Through
- *Viz.* = Namely, See
- *et al.* = Coworkers

iii) Organizations

ASD = Agricultural Services and Development
ARS = Agronomic Research Station
CIBC = Commonwealth Institute of Biological Control
DOPR = Directorate of Oil Palm Research
NRCO = National Research Center for Oil Palm (former name of DOPR)
PNGOPRA = Papua New Guinea Oil Palm Research Association
PORIM = Palm Oil Research Institute of Malaysia

APPENDIX - II

Population of different insect visitors on female inflorescence of oil palm

Repl.	Day of anthesis	Time of anthesis	Insect species							
			Male inflorescence				Female inflorescence			
			Weevil	Earwig	Honey bee	Moth	Weevil	Earwig	Honey bee	Moth
R_1	1	8 a.m.	63	-	-	-	-	-	-	-
		10 a.m.	68	1	1	-	18	-	-	-
		12 noon	73	-	1	-	39	1	-	-
		2 p.m.	91	-	-	-	28	-	-	-
		4 p.m.	98	-	-	-	3	-	-	-
	2	8 a.m.	58	-	-	-	-	-	-	-
		10 a.m.	51	-	2	-	13	-	-	-
		12 noon	48	-	-	-	21	-	-	-
		2 p.m.	71	-	-	-	20	-	-	-
		4 p.m.	86	-	-	-	-	-		
R_2	1	8 a.m.	-	-	--	-	-	-		
		10 a.m.	-	-	-	-	26	2	-	-
		12 noon	-	-	-	-	45	-	-	-
		2 p.m.	-	-	-	-	44	-	-	-
		4 p.m.	-	-	-	-	3	-	-	-
	2	8 a.m.	-	-	-	-	-	-	-	-
		10 a.m.	-	-	-	-	26	-	-	-
		12 noon	-	-	-	-	31	1	-	1
		2 p.m.	-	-	-	-	34	-	1	-
		4.p.m.	-	-	-	-	2	-	-	-
R_3	1	8 a.m.	-	-	-	-	-	-	-	-
		10 a.m.	-	2	-	-	16	-	-	-
		12 noon	-	1	-	-	26	1	-	-
		2 p.m.	-	-	-	-	20	-	-	-
		4 p.m.	-	-	-	-	-	-	-	-
	2	8 a.m.	-	-	-	-	-	-	-	-
		10 a.m.	-	-	-	2	14	-	-	1
		12 noon	-	-	-	-	18	2	2	-
		2 p.m.	-	-	-	-	16	1	-	-
		4.p.m.	-	-	-	-	-	-	-	-

*Repl. = Replication

Population of different insect visitors on female inflorescence of oil palm

Repl	Day of anthesis	Time of anthesis	Insect species							
			Male inflorescence				Female inflorescence			
			Weevil	Earwig	Honey bee	Moth	Weevil	Earwig	Honey bee	Moth
R4	1	8 a.m.	-	-	-	-	2	-	-	-
		10 a.m.	-	1	-	-	12	-	-	-
		12 noon	-	1	-	-	19	1	-	-
		2 p.m.	-	-	-	-	22	-	-	-
		4 p.m.	-	-	-	--	2	-	-	-
	2	8 a.m.	-	-	-	-	-	-	-	-
		10 a.m.	-	-	-	2	10	-	-	-
		12 noon	-	2	-	-	11	-	-	-
		2 p.m.	-	-	-	-	4	-	-	-
		4 p.m.	-	-	-	-	-	-	-	-
R5	1	8 a.m.	-	-	-	-	-	-	-	-
		10 a.m.	-	1	-	2	36	-	-	-
		12 noon	-	-	-	-	21	3	-	-
		2 p.m.	-	-	-	-	8	-	-	-
		4 p.m.	-	-	-	-	-	-	-	-
	2	8 a.m.	-	-	-	-	-	-	-	-
		10 a.m.	-	-	-	-	14	-	-	-
		12 noon	-	-	-	-	12	-	1	-
		2 p.m.	-	-	-	-	3	-	-	-
		4.p.m.	-	-	-	-	-	-	-	-
R6	1	8 a.m.	34	-	-	-	-	-	-	-
		10 a.m.	29	-	-	-	19	-	1	-
		12 noon	32	2	-	-	9	2	-	-
		2 p.m.	48	-	1	1	7	-	-	-
		4 p.m.	51	-	-	-	-	-	-	-
	2	8 a.m.	73	-	-	-	-	-	-	-
		10 a.m.	65	-	1	-	11	1	-	-
		12 noon	72	-	2	-	12	-	-	-
		2 p.m.	71	-	-	-	4	-	-	1
		4.p.m.	94	-	-	-	-	-	-	-

*Repl. = Replication

Population of different insect visitors on female inflorescence of oil palm

Repl	Day of anthesis	Time of anthesis	Insect species							
			Male inflorescence				Female inflorescence			
			Weevil	Earwig	Honey bee	Moth	Weevil	Earwig	Honey bee	Moth
R_7	1	8 a.m.		-	-	-	-	-	-	-
		10 a.m.	-	-	-	-	9	-	-	-
		12 noon	-	-	1	-	20	1	1	-
		2 p.m.	-	-	-	-	6	-	-	-
		4 p.m.	-	-	-	-	-	-	-	-
	2	8 a.m.	-	-	-	-	-	-	-	-
		10 a.m.	-	-	1	-	9	-	-	1
		12 noon	-	-	-	-	9	2	1	-
		2 p.m.	-	-	-	-	3	-	-	-
		4 p.m.	-	-	-	-	-	-	-	-
R_8	1	8 a.m.	18	-	-	-	-	-	-	-
		10 a.m.	12	-	-	2	19	-	-	-
		12 noon	12	-	-	-	25	-	-	-
		2 p.m.	19	2	-	-	16	-	-	-
		4 p.m.	32	-	-	-	-	-	-	-
	2	8 a.m.	14	-	-	-	-	-	-	-
		10 a.m.	16	-	-	-	16	1	1	-
		12 noon	19	-	-	-	17	1	-	-
		2 p.m.	19	-	-	-	15	1	-	-
		4 p.m.	24	-	-	-	2	-	-	-

*Repl. = Replication

Population of different insect visitors on female inflorescence of oil palm

Repl.	Day of anthesis	Time of anthesis	Insect species							
			Male inflorescence				Female inflorescence			
			Weevil	Earwig	Honey bee	Moth	Weevil	Earwig	Honey bee	Moth
R_9	1	8 a.m.	-	-	-	-	3	-	-	-
		10 a.m.	-	-	-	-	36	-	-	-
		12 noon	-	-	-	-	41	2	-	1
		2 p.m.	-	-	-	-	16	-	-	-
		4.p.m.	-	-	-	-	3	-	-	-
	2	8 a.m.	-	-	-	-	-	-	-	-
		10 a.m.	-	-	-	-	11	-	-	-
		12 noon	-	2	-	-	15	1	1	-
		2 p.m.	-	-	-	-	6	-	-	-
		4 p.m.	-	-	-	-	-	-	-	-
R_{10}	1	8 a.m.	-	-	-	-	-	-	-	-
		10 a.m.	-	-	-	-	16	1	-	-
		12 noon	-	1	1	-	47	2	-	-
		2 p.m.	-	-	-	-	11	-	-	-
		4 p.m.	-	-	-	-	-	-	-	-
	2	8 a.m.	-	-	-	-	-	-	-	-
		10 a.m.	-	1	-	-	2	-	-	-
		12 noon	-	1	-	-	6	1	-	-
		2 p.m.	-	-	-	-	2	-	-	-
		4 p.m.	-	-	-	-	-	-	-	-

*Repl. = Replication

APPENDIX – III

Correlation between maximum count of insect visit and per cent pollination on two successive days of anthesis of female inflorescence

Replication	Maximum number of insect count on 1st day of anthesis	Maximum number of insect count on 2nd day of anthesis	Per cent pollination
R_1	39	21	78.38
R_2	45	34	83.73
R_3	26	18	79.17
R_4	22	11	78.08
R_5	36	14	78.86
R_6	19	12	76.67
R_7	20	9	60.86
R_8	25	17	63.39
R_9	41	15	80.85
R_{10}	47	6	88.37
Mean	32	16	80.71
Range	19 - 47	6 - 34	76.67 - 88.37
Correlation	0.707**	0.178	-

** = Significant at 1% level

APPENDIX – IV

Population of *E. kamerunicus* on male inflorescence during peak period of anthesis

i) Population of *E. kamerunicus* during rainy season

Spikelets		Male inflorescence						
		1	2	3	4	5	6	7
Top portion	1	48	29	47	42	42	50	48
	2	52	38	56	50	46	54	53
	3	45	36	53	52	54	52	49
	Mean	48.3	34.3	52.0	40.0	47.3	52.0	50.0
	Median	48						
Middle portion	1	69	71	77	79	72	86	76
	2	72	68	82	71	83	72	83
	3	78	76	82	78	78	71	68
	Mean	73.0	71.7	80.3	76.0	77.7	76.3	75.7
	Median	76						
Bottom portion	1	68	64	79	82	81	77	85
	2	72	81	83	80	84	79	76
	3	81	78	82	78	81	78	79
	Mean	73.7	74.3	81.3	80.0	82.0	78.0	80.0
	Median	80						

ii) Population of *E. kamerunicus* during summer season

Spikelets		Male inflorescence						
		1	2	3	4	5	6	7
Top portion	1	38	32	49	36	41	35	28
	2	44	38	54	32	30	29	32
	3	36	34	51	35	39	37	24
	Mean	39.3	34.7	51.3	34.3	36.7	33.7	28.0
	Median	35						
Middle portion	1	63	54	71	53	58	53	48
	2	72	48	68	51	56	58	51
	3	68	62	61	64	70	45	43
	Mean	67.7	54.7	66.7	56.0	61.3	52.0	47.0
	Median	56						
Bottom portion	1	78	88	71	87	69	69	58
	2	72	78	70	72	73	68	70
	3	89	91	76	74	62	72	59
	Mean	79.7	85.7	72.3	77.7	68.0	69.7	62.3
	Median	72						

APPENDIX - V

Biology of *E. kamerunicus*

i) Fecundity and oviposition period of *E. kamerunicus* with respect to different sex ratios

Sex ratio (male to female ratio)	Parameters	Seasons	Replication						
			1	2	3	4	5	Mean	± SD
1 : 1	Fecundity	Rainy	35	38	31	28	32	31.8	2.59
		Summer	34	37	35	36	31	34.6	2.31
	Oviposition period	Rainy	2	2	2	2	2	2	-
		Summer	2	2	2	2	2	2	-
1 : 2	Fecundity	Rainy	35	30	33	37	31	33.2	2.86
		Summer	32	35	38	36	33	34.8	2.39
	Oviposition period	Rainy	2	2	2	2	2	2	-
		Summer	2	2	2	2	2	2	-
1 : 3	Fecundity	Rainy	36	31	32	28	34	32.2	3.03
		Summer	38	36	28	34	37	34.6	3.97
	Oviposition period	Rainy	2	2	2	2	2	2	-
		Summer	2	2	2	2	2	2	-
1 : 4	Fecundity	Rainy	32	35	28	34	29	31.6	3.05
		Summer	37	33	34	29	38	34.2	3.56
	Oviposition period	Rainy	2	2	1	2	2	1.8	0.45
		Summer	2	2	2	2	2	2	-

ii) Duration of development stages of *E. kamerunicus* during rainy and summer seasons

Replication	Egg period (days)		Grub period (days)		Pupal period (days)		Days to adult emergence	
	Rainy season	Summer season	Rainy season	Summer season	Rainy season	Summer season	Rainy season	Summer season
1	2	1	9	9	4	3	15	13
2	1	1	10	7	3	4	14	12
3	2	1	8	8	4	4	14	13
4	2	2	10	7	3	3	15	12
5	2	2	10	8	4	4	16	14
6	2	1	9	9	4	3	15	13
7	2	1	8	9	4	4	14	14
8	1	1	10	7	4	3	15	11
9	2	2	9	7	4	3	15	12
10	2	2	9	8	3	3	14	13
Mode	2	1	9	7	4	3	15	13
Range	1 - 2	1-2	8 - 10	7 - 9	3 - 4	3 - 4	14 - 16	11 - 14

iii) Duration of different larval stages of *E. kamerunicus* during rainy and summer seasons

Replication	Duration of different instars of grub (days)							
	I instar		II instar		III instar		Total grub period	
	Rainy season	Summer season	Rainy season	Summer season	Rainy season	Summer season	Rainy season	Summer season
1	2	1	1	2	6	6	9	9
2	2	1	2	1	6	5	10	7
3	1	1	1	1	6	6	8	8
4	2	1	2	1	6	5	10	7
5	2	2	1	1	7	5	10	8
6	2	2	2	1	5	6	9	9
7	1	1	2	2	5	6	8	9
8	2	1	2	1	6	5	10	7
9	2	1	1	1	6	5	9	7
10	1	1	1	2	7	5	9	8
Mode	2	1	1	1	6	5	9	7
Range	1 - 2	1 - 2	1 - 2	1 - 2	5 - 7	5 - 6	8 - 10	7 - 9

iv) Adult longevity of *E. kamerunicus* during rainy and summer seasons

Replication	Adult weevil longevity (Days)			
	Male		Female	
	Rainy season	Summer season	Rainy season	Summer season
1	7	5	5	4
2	6	4	5	5
3	7	5	6	4
4	5	5	5	5
5	6	5	5	4
6	6	4	4	5
7	7	6	5	5
8	7	5	6	5
9	6	6	6	5
10	6	5	5	4
Mode	6	5	5	5
Range	5 - 7	4 - 6	4 - 6	4 - 5

APPENDIX - VI

Monthly inflorescence production and bunch set of oil palm

i) Monthly production of male inflorescence of oil palm (July '09 to Feb '10)

Replication	July '09	Aug '09	Sep '09	Oct '09	Nov '09	Dec '09	Jan '10	Feb '10
R_1	1	1	1	2	2	2	1	3
R_2	0	1	0	1	1	0	2	1
R_3	1	2	2	0	0	1	1	1
R_4	0	1	2	1	1	0	0	0
R_5	1	2	2	1	1	2	1	1
R_6	1	2	2	2	2	1	0	0
R_7	1	0	2	1	1	0	2	0
R_8	0	1	1	2	1	1	0	0
R_9	1	1	2	1	1	3	1	1
R_{10}	2	0	0	1	0	1	2	0
Mean	0.8	1.1	1.4	1.2	1.0	1.1	1.0	0.7
Range	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 3	0 - 2	0 - 3
Mode	1	1	2	1	1	1	1	0

ii) Monthly production of female inflorescence and bunch set of oil palm (July '09 to Feb '10)

Month	Replications																			
	R_1		R_2		R_3		R_4		R_5		R_6		R_7		R_8		R_9		R_{10}	
	I	B	I	B	I	B	I	B	I	B	I	B	I	B	I	B	I	B	I	B
July '09	1	2	0	0	0	0	1	0	1	0	1	0	0	1	0	0	0	2	1	0
Aug '09	2	4	1	1	5	0	2	3	1	1	4	1	6	1	3	0	3	2	1	1
Sep '09	0	5	0	1	0	5	0	3	1	3	0	5	1	7	0	3	1	5	0	5
Oct '09	1	5	0	1	3	5	0	4	0	4	0	6	3	8	0	3	0	6	1	5
Nov '09	0	5	0	1	1	6	0	4	0	3	0	6	1	12	0	2	0	5	0	5
Dec '09	0	4	0	1	0	5	1	4	0	3	0	6	1	10	0	3	0	4	0	6
Jan '10	0	2	0	2	0	6	1	4	0	3	0	6	1	10	0	3	0	4	0	6
Feb '10	0	1	1	2	0	1	1	2	0	1	0	2	0	8	0	1	0	2	1	2

* I = Inflorescence production; B = Bunch set

APPENDIX - VII

Yield attributes of oil palm

Repl.	Number of female flowers/ inflorescence	Number of fruits developed	Number of partially developed fruits	Per cent pollination	Days to fruit set	Bunch weight (kg)	Mean fruit weight (g)
R_1	800	519	108	78.38	161	25	35.87
R_2	510	359	68	83.73	158	13	34.21
R_3	384	268	36	79.17	158	8	25.81
R_4	780	496	113	78.08	153	23	35.76
R_5	700	486	66	78.86	150	23	39.67
R_6	600	328	132	76.67	152	13	27.38
R_7	396	203	38	60.86	154	6	26.58
R_8	336	186	27	63.39	148	5	24.29
R_9	710	502	72	80.85	154	20	33.88
R_{10}	748	583	78	88.37	145	29	41.71
Mean	596.4	393	73.8	77.13	153.3	17.13	32.52
± SD	177.11	142.62	35.37	8.63	4.88	8.6	6.11

*Repl. = Replication

APPENDIX - VIII

Weather parameters collected from Agronomic Research Station, Chalakkudy

i) July '09

Date	Maximum temperature	Minimum temperature	Relative humidity (%)	Rainfall (mm)	Sunshine hours
1-7-09	27.3	22.5	96	96.8	0.0
2-7-09	26.4	23.0	96	16.0	0.0
3-7-09	23.8	22.8	96	46.4	0.0
4-7-09	26.4	22.4	91	47.6	0.0
5-7-09	25.5	23.0	96	34.8	0.0
6-7-09	26.6	23.0	96	4.20	0.6
7-7-09	27.1	23.9	92	31.6	0.0
8-7-09	28.8	23.4	96	3.00	4.1
9-7-09	26.5	23.9	91	21.9	0.0
10-7-09	28.8	23.8	96	46.8	3.5
11-7-09	30.5	23.9	96	16.2	0.0
12-7-09	28.5	23.5	96	6.40	4.6
13-7-09	28.2	23.6	96	5.80	0.0
14-7-09	29.3	22.7	96	39.2	0.0
15-7-09	29.6	24.3	96	20.8	0.2
16-7-09	26.9	23.2	96	31.8	0.1
17-7-09	24.4	21.8	96	2.1	0.0
18-7-09	27.4	22.3	96	19.8	1.0
19-7-09	27.2	23.8	96	19.8	0.0
20-7-09	28.8	23.5	96	9.6	0.0
21-7-09	28.8	25.4	85	3.2	1.0
22-7-09	30.5	24.4	92	13.4	4.5
23-7-09	31.5	24.1	91	11.2	4.1
24-7-09	32.5	22.7	96	10.0	7.6
25-7-09	31.2	23.7	96	2.1	7.0
26-7-09	31.9	24.0	89	1.2	6.5
27-7-09	29.6	22.6	96	22.2	0.0
28-7-09	30.2	23.7	91	16.2	0.0
29-7-09	29.2	23.9	96	1.4	0.0
30-7-09	30.2	23.9	94	9.8	5.1
31-7-09	26.9	24.2	94	0	26.9

ii) August '09

Date	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Rainfall (mm)	Sunshine hours
1-8-09	31.0	23.2	91	56.8	0.0
2-8-09	31.0	24.4	86	3.2	6.5
3-8-09	30.3	23.9	96	0.0	3.8
4-8-09	27.5	24.4	92	8.0	3.3
5-8-09	30.4	23.9	96	1.2	4.8
6-8-09	25.2	23.2	91	0.6	2.0
7-8-09	31.1	23.8	96	7.1	7.5
8-8-09	29.7	23.8	96	0.0	5.2
9-8-09	30.3	24.0	86	1.0	0.0
10-8-09	28.3	24.7	96	1.2	0.7
11-8-09	31.3	23.8	96	6.4	2.8
12-8-09	31.4	24.1	96	1.2	7.5
13-8-09	31.8	25.4	96	0.8	7.7
14-8-09	32.3	25.7	96	1.3	5.3
15-8-09	30.9	24.1	91	11.4	0.1
16-8-09	31.4	25.5	86	0.0	3.1
17-8-09	29.9	22.9	91	69.4	0.0
18-8-09	29.6	23.4	91	0.0	0.0
19-8-09	32.1	24.3	96	0.0	0.0
20-8-09	32.1	24.7	96	7.2	5.6
21-8-09	29.4	24.4	96	54.2	6.8
22-8-09	30.1	24.6	96	2.4	7.1
23-8-09	28.9	24.5	84	2.8	0.0
24-8-09	29.1	23.1	96	19.8	0.0
25-8-09	28.6	23.4	96	0.8	0.7
26-8-09	24.8	23.6	96	48.8	0.0
27-8-09	30.5	23.6	96	24.2	2.1
28-8-09	31.6	24.8	96	10.6	8.1
29-8-09	26.9	24.1	96	1.2	0.0
30-8-09	28.9	23.5	96	25.4	3.8
31-8-09	31.7	23.7	90	14.6	0.0

iii) September '09

Date	Maximum temperature (^oC)	Minimum temperature (^oC)	Relative humidity (%)	Rainfall (mm)	Sunshine hours
1-9-09	27.6	24.8	80	15.3	0.0
2-9-09	26.8	23.9	89	9.5	0.0
3-9-09	28.8	23.4	96	14.4	0.0
4-9-09	29.9	24.4	92	18.8	0.0
5-9-09	24.1	23.2	96	64.8	0.0
6-9-09	25.9	24.5	90	7.6	0.0
7-9-09	29.3	24.9	96	6.8	0.0
8-9-09	31.5	24.5	92	0.0	0.0
9-9-09	31.9	24.5	92	0.0	1.2
10-9-09	31.9	24.2	96	0.0	0.0
11-9-09	32.8	23.0	96	0.0	2.1
12-9-09	32.1	24.6	96	0.0	0.0
13-9-09	30.7	24.0	96	18.2	1.0
14-9-09	30.1	25.3	96	7.5	1.0
15-9-09	31.1	24.8	96	4.2	1.0
16-9-09	31.1	24.2	96	0.0	2.0
17-9-09	26.1	24.4	96	7.4	2.1
18-9-09	26.1	23.9	96	5.0	0.0
19-9-09	31.8	23.9	96	33.8	.0.0
20-9-09	30.7	24.0	96	34.6	0.0
21-9-09	29.9	23.7	96	74.8	00
22-9-09	31.0	23.8	96	18.8	0.0
23-9-09	30.5	23.6	96	0.0	0.0
24-9-09	30.7	23.9	96	16.8	0.0
25-9-09	30.9	24.2	96	1.8	0.0
26-9-09	29.2	26.2	96	1.8	0.0
27-9-09	29.5	23.6	96	5.0	4.5
28-9-09	30.9	24.4	96	13.2	0.0
29-9-09	30.9	25.3	92	0.0	0.0
30-9-09	33.5	25.2	92	0.0	0.0

iv) October '09

Date	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Rainfall (mm)	Sunshine hours
1-10-09	26.4	24.2	89	6.8	0.5
2-10-09	27.6	23.8	88	7.3	0.0
3-10-09	30.6	23.7	96	60.8	2.8
4-10-09	31.2	23.9	96	23.0	7.8
5-10-09	31.2	24.9	91	3.6	7.0
6-10-09	30.6	22.8	96	1.2	8.0
7-10-09	31.1	23.6	92	0.8	5.1
8-10-09	32.2	23.7	96	0.6	9.5
9-10-09	32.1	23.1	96	0.0	9.6
10-10-09	32.8	23.3	96	0.0	9.9
11-10-09	32.6	23.8	96	0.0	0.0
12-10-09	32.8	23.8	96	0.0	6.0
13-10-09	32.1	24.6	92	0.0	3.6
14-10-09	32.3	23.7	96	0.0	4.0
15-10-09	29.6	23.5	96	6.8	8.5
16-10-09	31.5	23.9	96	0.8	0.0
17-10-09	33.2	23.5	91	0.0	0.0
18-10-09	32.3	24.2	96	0.0	0.0
19-10-09	32.5	24.0	96	2.2	0.0
20-10-09	34.6	24.9	96	0.0	0.0
21-10-09	32.5	24.0	95	0.0	8.0
22-10-09	32.4	24.6	91	7.2	0.0
23-10-09	31.6	24.1	95	0.0	8.2
24-10-09	31.6	24.7	94	0.0	7.2
25-10-09	33.8	24.1	95	0.0	0.0
26-10-09	30.8	24.6	92	0.0	5.7
27-10-09	33.9	24.7	96	0.0	0.9
28-10-09	31.5	24.5	96	0.0	7.0
29-10-09	33.5	23.5	90	18.8	3.8
30-10-09	31.1	24.2	87	0.0	0.0
31-10-09	32.6	24.5	91	0.0	0.0

v) November '09

Date	Maximum temperature (^oC)	Minimum temperature (^oC)	Relative humidity (%)	Rainfall (mm)	Sunshine hours
1-11-09	39.1	26.8	85	0.0	7.7
2-11-09	33.1	24.9	86	0.0	8.6
3-11-09	32.6	25.1	86	0.0	5.5
4-11-09	33.1	25.3	87	0.0	5.3
5-11-09	32.7	25.2	83	0.0	4.5
6-11-09	30.4	24.9	87	0.0	0.1
7-11-09	27.6	23.7	88	0.0	0.3
8-11-09	29.3	23.9	87	60.4	0.5
9-11-09	28.6	23.6	87	6.4	2.1
10-11-09	25.1	23.4	86	7.2	1.0
11-11-09	25.0	24.1	87	44.4	0.0
12-11-09	32.2	24.9	91	42.8	6.1
13-11-09	28.8	24.6	87	0.0	4.0
14-11-09	28.5	25.3	88	1.2	2.5
15-11-09	29.5	25.4	88	0.0	0.0
16-11-09	30.4	26.4	85	37.6	2.9
17-11-09	30.5	26.3	85	0.0	0.0
18-11-09	29.7	25.6	83	0.0	4.1
19-11-09	30.2	25.1	87	0.0	5.2
20-11-09	31.8	23.4	86	0.0	6.1
21-11-09	27.3	24.7	89	54.4	0.0
22-11-09	31.9	24.2	90	8.4	0.0
23-11-09	32.0	23.5	85	26.4	8.5
24-11-09	32.5	25.8	90	0.6	0.0
25-11-09	33.8	26.2	94	5.4	0.0
26-11-09	31.4	26.1	92	0.0	9.3
27-11-09	31.1	21.6	91	0.0	0.0
28-11-09	31.8	22.6	91	0.0	0.0
29-11-09	32.4	23.1	91	0.0	9.0
30-11-09	31.8	23.7	87	0.0	0.0

vi) December '09

Date	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Rainfall (mm)	Sunshine hours
1-12-09	32.1	23.6	91	0.0	2.1
2-12-09	32.1	24.1	91	0.0	8.7
3-12-09	34.5	24.5	87	0.0	6.4
4-12-09	32.4	24.9	95	1.2	6.1
5-12-09	32.8	23.7	91	0.0	8.9
6-12-09	33.0	23.8	90	0.0	6.4
7-12-09	32.5	22.0	86	0.0	7.3
8-12-09	34.6	24.4	87	0.0	9.4
9-12-09	33.6	23.4	90	0.0	9.8
10-12-09	34.0	22.5	93	0.0	9.5
11-12-09	32.8	19.3	93	0.0	9.0
12-12-09	31.5	20.2	91	0.0	8.5
13-12-09	33.0	19.9	90	0.0	7.4
14-12-09	34.0	22.3	86	0.0	9.8
15-12-09	33.8	25.3	82	0.0	7.4
16-12-09	33.9	24.3	78	0.0	4.1
17-12-09	34.6	23.9	83	0.0	9.2
18-12-09	34.5	23.6	87	0.0	8.4
19-12-09	34.1	23.2	85	0.0	8.0
20-12-09	34.1	23.9	85	0.0	9.2
21-12-09	33.5	24.0	90	0.0	8.1
22-12-09	30.4	23.2	86	0.0	2.9
23-12-09	32.1	23.0	84	0.0	5.0
24-12-09	33.8	24.3	82	0.0	7.0
25-12-09	33.6	23.8	82	0.0	1.2
26-12-09	31.8	23.6	82	0.0	7.0
27-12-09	32.4	23.2	87	8.0	4.6
28-12-09	31.9	23.4	90	11.4	2.8
29-12-09	32.6	22.3	94	6.2	3.8
30-12-09	31.0	22.8	91	0.0	2.9
31-12-09	31.8	21.2	90	0.0	8.1

vii) January '10

Date	Maximum temperature (^{o}C)	Minimum temperature (^{o}C)	Relative humidity (%)	Rainfall (mm)	Sunshine hours
1-1-10	32.5	22.9	90	0.0	9.3
2-1-10	33.6	21.5	88	0.0	9.0
3-1-10	33.5	21.5	81	0.0	9.2
4-1-10	33.5	21.6	85	0.0	9.4
5-1-10	33.5	20.7	85	0.0	9.5
6-1-10	34.2	20.8	84	0.0	9.0
7-1-10	33.8	20.6	85	0.0	9.1
8-1-10	33.9	22.4	85	0.0	9.3
9-1-10	34.4	22.9	89	0.0	8.7
10-1-10	28.3	22.5	92	0.0	8.3
11-1-10	33.2	22.1	88	2.2	10.0
12-1-10	33.4	23.1	94	0.0	9.7
13-1-10	33.1	23.5	86	1.2	9.7
14-1-10	32.1	23.6	89	2.3	9.2
15-1-10	29.7	23.0	82	0.0	9.0
16-1-10	32.3	20.4	89	0.0	9.8
17-1-10	33.2	22.2	84	0.0	9.8
18-1-10	32.9	20.2	83	0.0	9.8
19-1-10	33.3	21.1	83	0.0	8.0
20-1-10	34.0	22.1	89	0.0	9.2
21-1-10	33.5	21.9	83	0.0	9.5
22-1-10	33.5	22.0	79	0.0	8.9
23-1-10	33.4	20.2	79	0.0	8.8
24-1-10	33.6	21.0	78	0.0	9.5
25-1-10	32.9	21.2	82	0.0	6.0
26-1-10	34	20.5	86	0.0	4.8
27-1-10	32.9	22.0	85	0.0	8.0
28-1-10	33.2	21.7	84	0.0	9.1
29-1-10	35	21.8	83	0.0	8.9
30-1-10	35.2	21.0	87	0.0	9.8
31-1-10	34.7	20.8	85	0.0	9.4

viii) February '10

Date	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Rainfall (mm)	Sunshine hours
1-2-10	33.9	22.2	82	0	9.6
1-2-10	34.6	22	87	0	8.4
3-2-10	34.4	22.5	88	0	9.3
4-2-10	35.2	19.7	82	0	9.0
5-2-10	33.9	21.0	85	0	9.4
6-2-10	34.8	20.2	84	0	9.9
7-2-10	35.7	20.5	86	0	8.9
8-2-10	33.0	21.5	86	0	10.0
9-2-10	35.2	26.2	84	0	10.0
10-2-10	35.4	23.7	83	0	10.1
11-2-10	35.4	24.2	81	0	9.0
12-2-10	34.8	24.8	82	0	9.4
13-2-10	34.4	23.6	81	0	10.0
14-2-10	33.6	23.8	81	0	8.7
15-2-10	25.7	24.8	82	0.	8.9
16-2-10	34.7	23.9	81	0	9.6
17-2-10	35.0	23.4	88	0	9.1
18-2-10	33	25.7	82	0	9.3
19-2-10	35.5	25.8	82	0	9.8
20-2-10	35.2	23.9	86	0	8.9
21-2-10	37.6	23.8	81	0	8.2
22-2-10	37.2	24.3	85	0	9.3
23-2-10	37.1	23.8	82	0	9.0
24-2-10	38.0	24.0	79	0	9.2
25-2-10	37.0	24.0	79	0	9.3
26-2-10	37.2	23.9	86	0	9.0
27-2-10	36.2	25.0	86	0	8.9
28-2-10	37.0	25.1	89	0	9.5

INSECT POLLINATORS OF OIL PALM IN KERALA

By

S. SAMBATH KUMAR
(2008 - 11 - 118)

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the
requirement for the degree of

Master of Science in Agriculture

(AGRICULTURAL ENTOMOLOGY)

Faculty of Agriculture
Kerala Agricultural University, Thrissur

Department of Agricultural Entomology

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR - 680 656
KERALA, INDIA

2010

ABSTRACT

Oil palm, *Elaeis guineensis* (Jacq.) (Arecaceae) is one of the most commonly available and extensively cultivated perennial trees in many parts of the world. Previously pollination was considered as a serious constraint, so manual pollination was often carried out, to sustain the yield. Wind and honey bees play an important role in pollination of many crops. But they alone can not give adequate level of pollination in all circumstances. In nature, pollination by specific insect species is vital for many crops. In this context, the present investigation on the "Insect pollinators of oil palm in Kerala" was carried out in the Plantation Corporation of Kerala, Athirappilly and Laboratory trails were conducted in the Department of Agricultural Entomology, College of Horticulture, Vellanikkara during 2009 to 2010.

Fifteen different insect species were observed to visit on the inflorescence. Insect species such as, African oil palm weevil, *Elaeidobius kamerunicus* (Coleoptera: Curculionidae); an earwig, *Forficula* sp.? (Dermaptera); a moth, *Pyroderces* sp.? (Lepidoptera: Cosmopterigidae) and Indian honey bees, *Apis cerana indica* (Hymenoptera: Apidae) were main species from the collection on male and female inflorescences.

Population of different insect visitors on anthesising female inflorescence was highly varied and *E. kamerunicus* was found to be more, among all insect species. Weevils were found to be visiting the female flowers between 10.00 a.m. to 2.00 p.m. and the peak weevil population was observed on the 1^{st} and 2^{nd} day of anthesis, around 12.00 noon. But, on male inflorescence weevil population was less during 10.00 to 2.00 p.m. Thereafter, it was gradually increased and attained the maximum at 4.00 p.m. Highly significant positive ($r = 0.712^{**}$) correlation was observed between population of *E. kamerunicus* on 1^{st} day of anthesis of female flowers and per cent pollination whereas, it was not significant ($r = 0.199$) on the 2^{nd} day of anthesis which indicates that maximum amount of pollination occurred in the 1^{st} day of anthesis.

Weevils of *E. kamerunicus* were congregating on the male inflorescence during the entire period of anthesis and their statistical median weevil population was 48, 76, 80 and 35, 56 and 72 on top, middle and bottom portions of male inflorescence during rainy and summer seasons respectively.

Adult weevils of *E. kamerunicus* feed on anthers of male inflorescence and multiply. Everyday, during occasional visits to female inflorescence, they would shed the pollen grains and get back to its original place of host which would cause adequate level of pollination of female flowers. The anise seed like odour (estragole 5, 4 allylanisole) attract the weevils towards both male and female inflorescences.

The biology of *E. kamerunicus* was carried out in both rainy and summer seasons under wire cage. The female weevil laid eggs singly on the spent male inflorescence of oil palm. The fecundity ranged from 32 to 33 eggs (median = 32) in rainy and 34 to 35 eggs (median = 35) in summer seasons with an ovipositional period of 1 to 2 days during both seasons.

The eggs hatched into grubs within 1 to 2 days. The grub period lasted for 8 to 10 days in rainy and 7 to 9 days in summer seasons respectively with three larval instars. The grubs pupated for 3 to 4 days in rainy and summer seasons and the adult weevils emerged out. The total life cycle from egg to adult was completed within 14 to 16 and 11 to 14 days in rainy and summer seasons respectively. The longevity of adult weevils varied with the sex and males lived longer than females. The life span of male weevils was 5 to 7 and 4 to 6 days during both rainy and summer seasons respectively. Female weevils lived for 4 to 6 days in rainy and 4 to 5 days in summer seasons.

Among the duration of different life stages *viz.*, egg, larva, pupa and adult of *E. kamerunicus,* the grub period was found to be longest (7 to 9 days) followed by adult longevity (male = 5 to 6 days; female = 5 days), pupa (3 to 4 days) and egg (1 to 2 days). The number of female weevils in the field was more, when compared to the male with the sex ratio (♂ : ♀) of 1 : 1.87 in rainy and 1 : 1.96 in summer seasons respectively.

Morphometric study of different life stages of *E. kamerunicus* showed that the diameter of egg measured 0.258 mm. The freshly laid eggs were creamy white in colour. The first instar grub was pinkish yellow in colour with brown head capsule and other instars are yellow coloured. The average length of I, II and III instar grubs were 1.59, 2.73 and 3.84 mm. Similarly mean body width of corresponding instars was 0.52, 0.86 and 1.62 mm. The pupa also showed yellow colour with the length of 3.53 mm and width of 1.63 mm. The newly emerged adult weevil was light brown in colour and later on changed to dark brown. The male and female weevils could be differentiated based on their size and additional structures on their body. Males (length = 4.13 mm; width = 1.54 mm)) were bigger than female (length = 3.81 mm; width = 1.28 mm). Males also had setae on the peripheral side of elytra with some dorsal spines. Female has smaller body and absence of above mentioned structures over its body.

Both male and female inflorescences were produced separately in successive whorls. Production of male inflorescence ranged from 0 to 2 from 10 different marked palm trees and at least one male inflorescence (mode = 1) could be seen in each tree from July '09 to Jan '10 except during Sep '09 (mode = 2). Female inflorescence production ranged from 0 to 1 during July '09 to Feb '10 except during Aug '09 (1 to 6) and Oct '09 (0 to 3). The mode value of female inflorescence production was 1 during July '09 and Aug '09 and it was zero from Sep '09 to Feb '10. Anthesis period of male inflorescence accounted for 10 to 14 days with more weevil population between 4^{th} to 7^{th} days which coincided with the maximum odour emission. Stigma receptivity lasted for 2 to 3 days but, insect visit was observed for only 2 days. So, assisted pollination can be done only up to 2 days of anthesis of female flowers. The bunch set was not found to be uniform in each month. The mode value of bunch set was varied in different months like 0, 1, 5, 5, 4, 6 and 2 from July '09 to Feb '10.

Production pattern of male and female inflorescence with regard to different climatic factors was recorded from July '09 to Feb '10. An increasing trend of male inflorescence production was observed from July '09 to Sep '09 (mode = 2) with the maximum and minimum temperature of 29.91 and 24.28 °C, relative humidity of 94.37%, rain fall of 12.67 mm and sun shine hours of 0.52 hrs. Later on uniform production was recorded until Jan '10 and no inflorescence was seen during Feb '10. Similarly female inflorescence production was found to be uniform during July '09 and Aug '09 (mode = 1) which coincided with monthly maximum (28.4 and 29.94 °C), minimum temperature (23.45 and 24.08 °C), relative humidity (98.38 and 93.52%), rain fall (19.72 and 12.31 mm) and sun shine hours of 2.48 and 3.05 hrs. There after, it was very much reduced (mode = 0). Bunch set was low in July '09 which, gradually increased and reached the maximum during Jan '10 (mode = 6) with the weather parameters such as, maximum (32.24 °C), minimum temperature (21.7 °C), relative humidity (85.23 %), rain fall (0.18 mm) and sun shine hours (8.96 hrs).

Correlation study of inflorescence production and various weather parameters showed that there was a significant positive correlation with relative humidity and rain fall and significant negative correlation with maximum temperature and sunshine hours. On the contrary, monthly bunch set showed a significant negative correlation with relative humidity. Wind could be offer only less contribution towards pollination and fruit set and, it was also not influenced by birds.

Totally 336 to 800 flowers were counted from female inflorescences (mean = 596.4) and the range of fruit count was from 186 to 583 (mean = 393) with 27 to 132 partially developed fruits (mean = 73.8) per bunch. Per cent pollination was from 60.36 to 88.37 (mean = 77.13 %). It took around 145 to 161 days for the complete development of fruits (mean = 153.3) and the bunch weight was 5 to 29 kg (mean = 17.13) with a mean fruit weight of 32.52 g per bunch.

Observations on period of stigma receptivity of female inflorescence and time of weevil visit to female flowers may be helpful to the farmers when they would need assisted pollination either manually or through artificial means by using *E. kamerunicus*. The present study showed that, they can restrict the pollination just for 2 days after anthesis which will ultimately save labour, money and time spent on this.

Artificial culturing of weevils can be done with kairomones to maintain their population during summer season since, very poor inflorescence production was noticed during summer. It is also necessary to retain the male inflorescence at least for one month after anthesis. This will help for multiplication of weevils. During rainy months, the spent inflorescence must be removed within 40 to 45 days to avoid disease occurrence.