COMPETITION BETWEEN CORCYRA CEPHALONICA (STAINT) AND EPHESTIA CAUTELLA (WLK.) AND STUDY OF RADIOSENSITIVITY OF THE IMMATURE STAGES OF CORCYRA CEPHALONICA

By

JOSEPH ALLOTEY

A THESIS SUBMITTED FOR THE DEGREE OF MASTER OF SCIENCE
AT THE UNIVERSITY OF GHANA, LEGON.

AUGUST 1982

DEPARTMENT OF ZOOLOGY
UNIVERSITY OF GHANA
LEGON
GHANA

This is to certify that this thesis has not been submitted for a degree to any other University. It is entirely my own work and all help has been duly acknowledged.

JOSEPH ALLOTEY

Dedicated To

GOD

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

This work incorporates results of 12 months of studies. Grateful acknowledgement is given to Prof. R. Kumar who originally suggested the investigation on Corcyra cephalonica which has assumed major pest status in Ghana. He also helped to provide important literature and assistance during progress and completion of work. I am indebted to Prof. W.Z. Coker, Head of Zoology Department and member of my supervisory committee, who kindly provided many facilities which permit basic and fascinating research in the Department and for his keen interest in the progress of the study. He also gave helpful comments on the manuscript.

Dr. B.D. Amoako-Atta of the Ghana Atomic Energy Commission (GAEC), Kwabenya introduced me to methods of study of radiosensitivity as well as composition of standard medium used in the present work. He readily made available to me, many of the sophisticated apparatus used in this investigation. My sincere thanks go to him. The other members of the staff of the Department of Biology, Food and Agriculture (GAEC) also deserve special mention for their interest in my work.

I wish to thank Mr. G.M. Hagan and Mr. E. Abitey of the Pest Infestation Unit of the Ghana Cocoa Marketing Board (GCMB), Tema, for making it possible for me to become acquainted with problems facing pest-infestation authorities and for permission to enter the cocoa warehouses during the duration of this project.

My special thanks go to Mr. J.C. Reynolds for his expert photography, keen interest and various suggestions and comments on many aspects of the present study. I am also thankful to the following persons at the Department of Zoology for the various forms of assistance rendered me at various stages of the work, Mr. N. Owusu, Mr. R.I. Aryee, Mr. K. Foli, Mr. F. Ansah, Dr. S.A. Whyte, Mr. A. Titiati, Mr. Barry Hughes, Mr. F. Azanu, Mr. Obeng, Mr. C. Kyorku, Mr. F. Adjoh, Mr. G. Dapaah, Mr. J.E. Kwaku-Kpikpi, Mr. S. Akasey for his expert driving and Miss Faustina Kwame for typing the manuscript.

Thanks are due Mr. Ken Brew of the Cocoa Research Institute, Tafo, Mr. S. Baah and Mr. E. Achianor both of the Computer Science Department for help with the statistical analysis.

I am also grateful to Mr. J. Rawnsley of the Food and Agriculture Organisation of the United Nations (FAO) Regional Office for Africa, Accra, for useful discussions on the pest status of <u>C. cephalonica</u> and <u>Ephestia cautella</u>.

The assistance received from the technical staff of the Department of Zoology, especially Mr. Ofosu-Barko for his deligent work and the Department of Biology, Food and Agriculture (GAEC) especially Mr. Nana Kwablah-Nketiah and Mr. Isaac

Tibu is fully acknowledged.

My profound gratitude goes to Mrs. Tina Allotey for her continued support and encouragement and to Mr. Mike Kofi Tetteh of the Institute of African Studies for his meticulous typing of this work.

Finally I am indebted to the Ghana Government who supported this work.

ABSTRACT

Competition between *Corcyra cephalonica* and *Ephestia cautella* and radiosensitivity of the immature stages of *C. cephalonica* was studied. Developmental periods of the two species under similar ambient conditions but different locations were determined. Competition under limited and abundance of standard medium and broken cocoa beans was studied when the two species exist alone, one before the other and when introduced together. It was concluded that in competition *E. cautella* becomes extinct, with *C. cephalonica* remaining as the successful species. A detailed study of oviposition preferences of the two species when given the choice of three food commodities; standard medium, broken cocoa beans and groundnut was studied. Other studies include egg-hatchability, age and effect of population on fecundity and for the first time the daily activity patterns of the larvae of *C. cephalonica* and *E. cautella* have been studied in a unique way. Radiosensitivity of the developmental stages: eggs, larvae and pupae of *C. cephalonica* has also been investigated.

Chapter 1

General Introduction

GENERAL INTRODUCTION

Corcyra cephalonica (Stantion) is a serious pest of stored products (groundnuts, cocoa, copra, sesame, sorghum, millet and rice), mainly in areas of tropical climate. The larvae infest the commodity, crawl and construct silken tunnels in which they live causing aggregation of produce. In flour mills, severe infestation cause clogging of pipes and machinery parts.

Prior to 1957, Rawnsley (personal communication) noted that the rice moth, *C. cephalonica* was virtually absent from Ghana. However the rise in importance of *C. cephalonica* over the last ten years is believed to be associated with the importation of low grade rice from the Far East.

Karsholt (1978) observed that *C. cephalonica* was among the three species of Lepidoptera in the free ports of Copenhagen, introduced with ships from warmer countries, though none have been established there. Freeman (1976) noted that of the moths associated with imported stored products to Britain, *C. cephalonica* is second only to *Ephestia cautella* (Walker) both in frequency of importation and in terms of numbers. A summary of the interceptions of the species at the ports of entry by advisers of the Ministry of Agriculture, Fisheries and Food (MAFF) and the Department of Agriculture and Fisheries for Scotland (DAFS) during the period 1967-1976 is shown in

Table 1. C. cephalonica is believed to be of eastern origin (Durant and Beveridge, 1913) but has become a cosmopolitan species (Ayyar, 1934; Pruthi and Singh, 1945; Rao, 1954; and Grist and Lever, 1969), having spread throughout the world with the importation of food stuffs. Highland (1978) observed that of the twenty-three species of stored product insects, collected and identified from 20 locations in nine countries and infesting foreign warehouses containing packaged foods, C. cephalonica and E. cautella were two of the three most common and among the most destructive pests.

As far back as 1946, Stroyan (1946) noted that C. cephalonica shows very catholic tastes ranging from whole wheat to rice, split pulses and mixed grains and replaces E. kuehniella (Zell.) in mills and E. elutella (Hubn.).

The other stored product moth utilised in this project, E. cautella (the tropical warehouse moth) is an important pest of stored food in the tropics, attacking a wide range of commodities which include groundnuts, palm kernels, cereals, oil seeds, spices, bones and cocoa beans. It is also known as the cocoa moth and causes great damage to this commodity in storage. It has also the nuisance factor of webbing. As an example of the damage caused by such a pest, it has been calculated by workers in Britain that in two years the closely related species E. elutella (Hubn) ate 300 lb of embryo of grain from 500 tons wheat. The ability of E. cautella to continue to breed in temperate climate and thus infest cocoa mills, chocolate factories and the like, makes it the most important pest of stored cocoa beans.

Sharma et al, (1978) while working on comparative host preference of the rice moth C. cephalonica and E. cautella showed that sorghum was the preferred host for both insects but survival to pupal and adult stage was greater for C. cephalonica than for E. cautella.

In Ghana, in 1957 a serious problem arose because of the increase in E. cautella infestation in stored cocoa beans associated with extended storage periods following the production of larger crops (Rawnsley, 1968). Rawnsley (1968) carried out a biological study on E. cautella over several months in selected warehouses and this included observations on the life cycle, mating habits, emergence pattern and flight periodicity, oviposition and egg viability.

Presently increasing attention is being directed to the problems concerning stored cocoa beans in warehouses at our ports as a result of imminent threat posed by the destructive moth C. cephalonica. Thus Aryeetey (personal communication) recently observed that C. cephalonica is rapidly rising as the most serious pest of stored cocoa beans in Ghana today. Cocoa bean, for a long time has been the mainstay of our economy and several other West-African countries. It is a commodity which fetches a high price on the commercial market. Hence the importance of any destructive agent on this commodity cannot be over emphasised.

Considering the above points, the growing anxiety among pest infestation authorities in our ports and the paucity of published information on the two moths in a competitive situation, it was decided that an investigation into this subject is not only welcome but may go a long way to:

1. add to our scientific knowledge on the two moths especially where they exist in a competitive situation;

2. offer an explanation of the recent observation on the sudden rise of C. cephalonica as the most important pest of stored cocoa beans in Ghana today.

Some information already exists on competition experiments on the closely related temperate species E. (Anagasta) kuehniella and C. cephalonica. Hosny et al. (1968) reported that whenever one of the two main flour mill moths, E. kuehniella and C. cephalonica were present in a certain flour mill, the other hardly exists in it. Cox et al. (1981) found that development of C. cephalonica was completed at temperatures from 17.5° to 35.5°C, with the highest and most rapid development occuring at 30 - 35°C. At 15°C larvae died young, but at 37.5°C some managed to pupate. Mean development was most rapid at 30°C taking only 23 days, while at 17.5°C it took 170 days. E. kuehniella on the other hand can complete development at temperatures down to 12.5°C but not at 31°C, the optimum being around 25°C (Jacob and Cox, 1977). Thus it can be seen why C. cephalonica takes over from E. kuehniella in hot damp climate as the major moth pest of flour mills, whereas the latter is better suited to more temperate conditions (Freeman, 1962). For example, Stoyan (1946) noted that C. cephalonica but not E. kuehniella was present in both dry damp areas of India. Freeman (1962) found an apparent gradation from C. cephalonica to E. kuehniella down the eastern coast of South America from the hot climate of Rio de Janeiro to the cooler Buenos Aires. Low moisture content of food may also be a factor here, since E. kuehniella can complete development at a humidity near 0% R.H. (Jacob and Cox, 1977) while the limit for C. cephalonica is nearer 10% R.H.

Questions that arise in any consideration of the nature of competition are: What precisely is the form of the competition process and what are the component elements? What constitutes a common resource of ecological requirement that can legitimately be considered the object of the competitive process? Is competition limited to interactions between individuals and species at the same trophic level, or is any interaction which has a deleterious effect on the existence or increased potential of another individual or species a form of competition? How can the action of competition be detected and evaluated in natural situations and what constitutes adequate proof of competition (Miller, 1967)?

Crombie (1946) found from his experiments with stored product insects that only those species with slightly different ecologies survived together, while with those with exactly the same requirements, one always eliminated the other.

The fact that in most laboratory competition experiments there is an extinction of one of the two species is certainly in accord with the competitive exclusion principle which states that two species of the same ecological niche cannot co-exist together or that because of the variability of nature, two species by the very fact of being different cannot have exactly the same niche.

The present project is in two parts. First part deals with study on competition between the two moths, C. cephalonica (Staint.) of the family Galleridae and E. cautella (Wlk.) of the family Phycitidae. This type of competition involves exploitation of such transient food supplies as stored products and in which individuals complete their life cycle as rapidly as possible before the food supply disappears or become unsuitable. There is therefore little opportunity for other forms of competition based, for example, on combat or acquisition of territories which would need a constant defence.

Interspecies differences such as: (i) feeding time; (ii) activity; (iii) oviposition preferences; (iv) aggressiveness, are some of the factors that appear to be of selective importance in such competitive situation. Competition between E. cautella and C. cephalonica in the present project was investigated in laboratory cultures of maize/wheat/glycerol (8:8:1) and on broken cocoa beans, maintained at conditions normally prevailing in storage sheds in Ghana (75-98 percent R.H,, 25.5°C, Rawnsley, 1968).

Both intra and inter specific competition was investigated when:

1. C. cephalonica was introduced before E. cautella and vice-versa;
2. When the two moths are introduced together, and
3. When the two species exist separately.

in a limited supply of food and when food is in abundance. Other aspects of the competitive studies include oviposition preferences on three food commodities: broken cocoa beans, groundnuts and standard medium (maize/wheat/glycerol) (8:8:1), competition for pupation sites, egg-hatchability, age and fecundity, and diurnal activity of the two moths using recording kymograph and some aspects of their biology.

Granting that the role of competition in the natural distribution of these moths is known, one could hardly overlook their destructive nature. In an attempt to suppress and control their population in infested stored products, several methods are being used as e.g. chemical control, temperature treatment and fumigation. However, on account of the increase of insecticide resistance, pollution and toxicity associated with insecticides, the use of radiation and genetic methods as an alternative way of control has attracted attention for some time.

Rawnsley (1958) described the limitation of insecticides for controlling E. cautella in Ghana. Amuh (1971) suggested the use of gamma radiation. Radiosensitivity in insects depends on the developmental stage, tissue, cell and chromosome type, its effects as measured by biological end points is expressed in egg hatchability, fecundity etc. Radiation has been exploited for direct control like genetic systems for long term control of insect pests in stored food commodities. As at present, radiosensitivity has been determined in some of the many economically important stored product pests. The radiosensitivity of an insect changes during morphological development (Ouye et al, 1964; Laudani et al, 1965; and Tilton et al.,1966) and second part of the present study deals with this aspect.

Cornwell (1966) proposed that 16 krad was adequate to control stored product coleoptera in bulk grain and Dayen and Ahmed (1969) concluded that 10-12 krad would control Latheticus oryzae Waterh. However stored product moths are much more radioresistant than beetles (Tilton and Brower, 1973). In the past control measures have been directed mostly against E. cautella (Mould and Rawnsley, 1962). However with the growing importance of C. cephalonica, the latter merits more attention.

Effects of gamma radiation on different morphological stages of E. cautella are known (Calderon and Genon, 1971; Ahmed et al., 1973; Cogburn et al., 1973; and Amoako-Atta and Partida 1976). However few radiation experiments have been carried out on C. cephalonica (Loaharanu et al, 1972; Abdu and El-sawar, 1974; Chand and Sehgal, 1978). Loaharanu et al., (1972), irradiated the eggs, pupae and adults of C. cephalonica. They employed the following doses: 0, 3, 6, 12.5 and 25 krads.

To use radiation successfully to control these destructive moths on cocoa beans, a knowledge of the effects of gamma radiation on different morphological stages of the insect is necessary.

The recent installation of an experimental grain irradiation unit with a capacity for treatment of approximately 85 bushel per hour at a dose of 15,000 - 25,000 rads by USDA, stored products Insect laboratory at savannah, Georgia, is evidence of the appreciable development and promise in this direction. Thus a study of radiosensitivity of some ages of eggs, larvae and pupae of C. cephalonica, though not aimed at finding an effective dose to control this species, will it is hoped, add to the existing information on the responses of this insect when irradiated with known doses of gamma radiation.

Table I:

Summary of the number of interceptions of C. cephalonica on imports to Britain in 1967 - 76 grouped by types of product and geographical origin of cargo (after Cox et al., 1981).

Cotton seed and products	-	1	-	-	409	98	-	508
Groundnuts and products	1	2	-	-	235	122	-	360
Other oil seeds	-	1	-	-	55	11	5	72
Rice and products	1	11	-	-	29	139	-	180
Maize and products	1	1	-	-	17	2	-	21
Other cereals	-	-	1	-	10	4	-	15
Cocoa and products	-	46	-	-	33	-	25	104
Nuts	-	4	-	-	18	26	-	42
Pulses and products	-	-	-	-	16	26	-	42
Others	1	8	-	6	54	57	11	137
Total number of interceptions	4	74	1	6	876	485	41	1487

Chapter 2

Materials and Methods

MATERIALS AND METHODS

2.1 Rearing

The moths C. cephalonica and E. cautella were reared on wheat bran, finely ground maize and glycerol medium in the ratio 8:8:1 (wt/wt) (Amoako-Atta and Partida, 1976) in glass culture cabinets (45 x 45 x 60cm) (Fig.1) at the stored products entomology laboratory of the Ghana Atomic Energy Commission and the research laboratory of the Department of Zoology, University of Ghana, Legon (Figs. 2 and 3). The insects were maintained at 25.5°C - 30±1°C and 75 - 89% R.H. with alternating 12-h-light and 12-h-dark cycle.

Procedures for maintaining cultures were similar to those described by Stong et al (1968). For example, (1) food was added to cultures if many young larvae crawled out of the medium, indicating a shortage of food; and (2) regular cleaning of emergence cabinets removed eggs along with old adults thus preventing hatching and possible contamination of other cultures with young larvae. New cultures were started weekly. It was necessary in this investigation to promote not only effective mass rearing which requires optimum dietary media but equally important to meet the insects behavioural requirements. The following precautionary measures were therefore taken:

1. Diseases were eliminated from stock cultures by "sterilization".

2. All equipment used in handling of insects was dry-heat sterilised at 100°C for at least 3 hours as a routine measure to prevent re-infestation.

2.2 Competition Study I

For competition studies in limited amount of food and space, 200 grams of standard medium (Maize/wheat bran/glycerol (8:8:1) was placed in glass (kilner) jars (22cm deep x 8cm diam). The lids had filter paper (8cm diam) fitted into them to allow for aeration. 50 uncollapsed eggs (determined by stereo microscope (Wild M5) were introduced into each of the jars. The jars were then placed in aluminium trays flooded with machine oil to prevent insects from crawling about (Fig.4). Eggs were introduced as follows:

1. 50 eggs of E. cautella and C. cephalonica were separately introduced into each glass jar (intra specific competition);

2. 25 eggs of E. cautella were introduced first and after two weeks 25 eggs of C. cephalonica were also introduced into the same glass jar (inter species competition) and vice versa;

3. 25 eggs of C cephalonica and E. cautella were

introduced together into the same glass jars.
(inter specific competition).

Five replicates of each set up were made.

In selecting particle size range for the standard medium, the Ro-tap testing sieve shaker (Model B) was used (Fig.5). The size ranges were 0.123 - 0.25 mm. For the measurements of such physical factors as temperature and humidity as obtained in the experimental jars, the electronic hygrometer/thermometer (model HT-ISN-I) (Fig.6) was used. The humidity/temperature sensor was inserted into the glass jars through a perforated polythene sheet in the lid. The polythene sheet was tightly fitted around the sensor. The ambient temperature and humidity were recorded with a thermo hygrograph (Fig.7) recording humidity range 0-100% and temperature range 0 to 50^{o}C respectively on a single chart in two colours.

2.3 Competition Study 2

Procedure for the competition experiment on broken cocoa beans, when food and space is limiting, was the same as competition study I. However, the culture medium used was broken cocoa beans (Fig.8). The corn sieve was used to select particle size range 2-5mm. The cocoa beans were obtained from the Ghana Cocoa Marketing Board (Infestation Division), Tema

Harbour.

2.4 Competition Study 3

Competition in abundance of food and space was studied in glass cabinets (45 x 45 x 60 cm), each containing 2kg of the standard medium. Uncollapsed eggs of the moths were introduced in each cabinet and observation on development and internal microclimate (R.H./temp.) were taken throughout the duration of the experiment. The eggs were introduced into the experimental glass cabinet as follows:

(1) 25 eggs of _E. cautella_ and _C. cephalonica_ were introduced separately into different cabinets;

(2) 25 eggs of _E. cautella_ were introduced first and after two weeks 25 eggs of _C. cephalonica_ were also introduced into same cabinet;

(3) 25 eggs each of _C. cephalonica_ and _E. cautella_ were introduced into same cabinet.

The above experiments were replicated twice. Similar experiments were set up with broken cocoa beans. The culture media were changed at the end of each generation (22 - 32 days). This was necessary to ensure minimum disturbance to the larvae.

2.5 Oviposition preferences

In order to determine the oviposition preferences for the two moths, E. cautella and C. cephalonica, three glass cabinets (45 x 45 x 60 cm) with replicates were used. Each glass cabinet contained 6 plastic petridishes (9cm diam) arranged in a circle, with side separation of 6.5 cm and radius of 10 cm. from the centre of the base of the cabinet (Fig.9). 40 grams of each commodity (broken cocoa beans, shelled groundnut and standard medium) were placed alternately in each petridish and 20 adults (10 males and 10 females) of each moth species which had just emerged from stock cultures were released into the cabinet from a central point on the top of the lid. The set up were as follows:

(1) E. cautella

(2) C. cephalonica

(3) C. cephalonica/E. cautella

In the case of last set up, 10 adults of each species (5 females and 5 males) were used. The moths were allowed to oviposit freely in the preferred food commodity. After ten days the petridishes were removed and the number of eggs/larvae counted under stereo microscope (Wild M5), and number of cocoons formed in each petridish was recorded after first emergence in the experimental cage.

2.6 Egg - hatchability

An egg laying apparatus consisting of glass (kilner) jars

(22 cm deep x 8 cm diam) provided with lid to which wire gauze (60-70 mesh) had been fitted, was used in this investigation. The glass jar with the lid in place was inverted over glass petridish (9cm diam) containing filter paper at the bottom. The filter paper provided a rough surface for oviposition. The moths laid within 12 hours sufficient number of eggs, of these 125 uncollapsed eggs were placed in five glass petri dishes (9 cm diam.) containing finely sifted (sieve size: 0.123 mm) maize, in batches of 25 each. There were five replications. Observations on hatching of eggs were made daily at 9.00 am.

2.7 Age and Fecundity

For the determination of the age and fecundity, all adults emerged on a particular day from stock cultures were transferred to a separate glass (kilner) jar (22cm deep x 8 cm diam) for egg laying. The number of eggs laid was noted daily in all the age groups till all the females were dead.

2.8 Activity Pattern

Fig. 10 shows the apparatus used for recording movements of 50 mature larvae of each moth species. The larvae were inserted in a small cylindrical container of aluminium foil (15.5 cm x 3.5 cm) which had perforated transparent side windows, the latter allowing observations to be made on the larvae. The cage was suspended on a thin copper wire stretching between two stands. A thin lever was fastened across the top of the cage and a counterpoise of plasticine was used to maintain balance of the writing lever. The movements of the larvae within the cage caused changes in the centre of gravity of the cage and these movements were recorded on a smoked drum which revolved once every 24 hours. Ambient temperature and humidity were recorded on a thermo hygrograph. The same age group larvae were selected from stock cultures and weighed on a Metler balance before subjecting them to a run. Each run was replicated. No food was provided for the experimental insects in the cage. Thus the experiment was run when the insects occurred separately. The activity pattern was investigated under normal day and night hours.

2.9 Competition for Pupation Sites

Preliminary investigation with pupation rolls (rolls of corrugated cardboard 2.5cm wide by ca. 7.5cm) on the surface of standard medium in glass stock culture jars (22cm deep x 8cm diam) showed that mature larvae about to pupate, normally crawl away from the food, wander around the inner walls of the glass jars and then enter pupation rolls.

Thus in order to determine competition for pupation sites, a corrugated cardboard (1.8cm wide x 2.5cm in length) containing six pupation sites was placed in the centre of a glass petri dish (9cm diam.) and five mature larvae of each species selected from stock cultures were weighed, marked with coloured but inert dyes (red, yellow, green, blue) and released into the petri dish. The set up was replicated five times and repeated with 16 larvae of each species and 11 pupation sites. Observation on their interaction and behaviour was noted till all the pupation sites were filled (Fig. 11).

2.10 Radiosensitivity

The developmental stages of the following ages of C. cephalonica were used:

(1) eggs: 1, 2, and 3 days old;

(2) larvae: early instar larvae (5 days after the hatching) and late instar larvae (5 days before pupation);

(3) pupae: 4-day-old.

The 7 doses used for the eggs, larvae and pupae were 0, 5, 10, 20, 30, 40, 50 and 100 krad. A cobalt - 60 irradiator with a source of ca. 1,600 ci at dose rates of 2687 to 2736 rada/min belonging to the Ghana Atomic Energy Commission (Fig. 12) was used. All doses were verified by Fricke dosimetry system. The Fricke dosimetry is the most reliable and popular chemical method of measurement of absorbed dose in aqueous systems. It is based on the oxidation of ferrous to ferric ions on exposure of an acidified solution to ionizing radiations. A sample of the prepared solution is irradiated in a glass or plastic container with internal dimensions greater than 8mm and a thickness of at least 1mm. The exact time of irradiation is accurately determined. The amount of ferric ions produced is normally determined using a spectrometric method which is rapid and convenient.

2.10.1 Eggs

Eggs were counted as day old if they were 12 hours in age after being laid. 25 uncollapsed eggs (determined by microscopic examinations) were placed in glass vials (2.5cm diam. x 5.5cm deep). After treatment, the eggs were carefully placed in glass petri dishes (9cm diam.)containing finely sifted (sieve size: 0.063mm) maize. Eggs were counted as hatched if the larvae were successful in emerging from the chorions. Each test was replicated five times.

2.10.2 Larvae

Larvae were obtained by sifting from weekly stock cultures. For post irradiation culture, they were transferred immediately after gamma exposure to glass jars (22cm deep x 8cm diam.) containing adequate quantities of standard medium for development.

2.10.3 Pupae

Preliminary investigation showed that moths emerge 32 ± 1 days after cultures were established (Table 3) with peak pupal formation on the 26th day. Thus 26th day old cultures were used to obtain last instar larvae, mature larvae about to pupate normally crawl from food (see 2.7). To obtain pupae of known age, pupation rolls initially placed on the culture medium from cultures 25 days old were removed and fresh pupation rolls were put in the cultures for 8 - 12 hours then removed, unrolled and the last instar larvae that had entered to pupate collected.

25 larvae were placed on about 5cm diam. pupation rolls. They generally pupated between 12 - 24 hours after the last instar had been reintroduced into the pupation rolls.

Pupae were considered to be 1 day old after the larvae were held in the culture room until the pupae reached the selected age for irradiation (4 days old).

Five replications of 25 pupae each were used for each age group. Glass jars (8cm diam x 9cm deep) with open tops were used to hold pupation rolls during radiation. Treated pupation rolls were transferred from the glass jars into separate glass jars and returned in the jars to the culture room where adults emerged. The number of normal and deformed adults emerging from the pupation rolls was recorded.

Fig.1: Glass culture cabinets used for rearing
C. cephalonica and E. cautella.

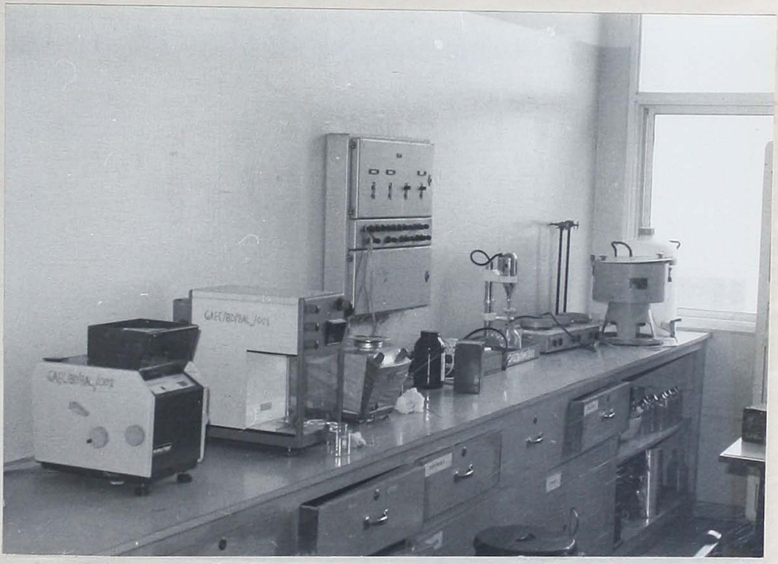


Fig. 2: Research Laboratory, Ghana Atomic Energy Commission (GAEC), showing some of the apparatus used in the present work.

Fig. 3: Research Laboratory of the Zoology Department, Legon, showing some of the apparatus used in the present study.

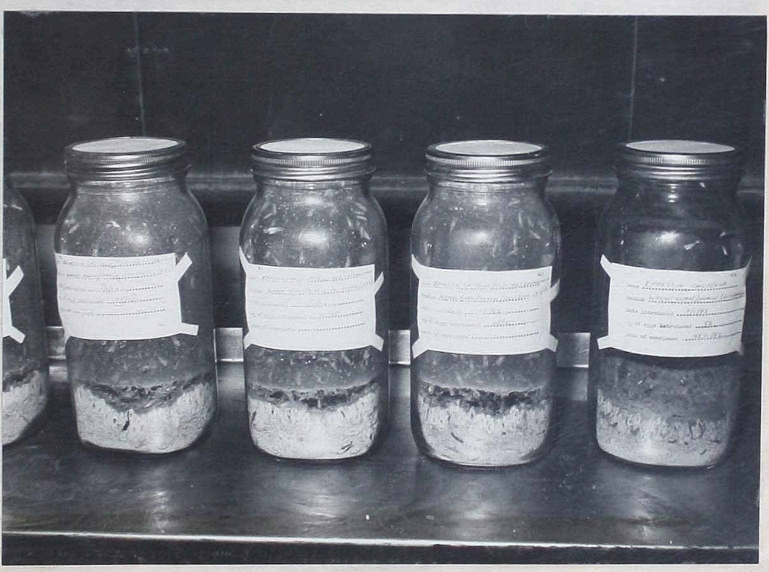


Fig. 4: Experimental glass (kilner) jars, containing standard medium.

Fig. 5: Ro-tap testing sieve shaker (Model B), used for determining particle size ranges for food medium.

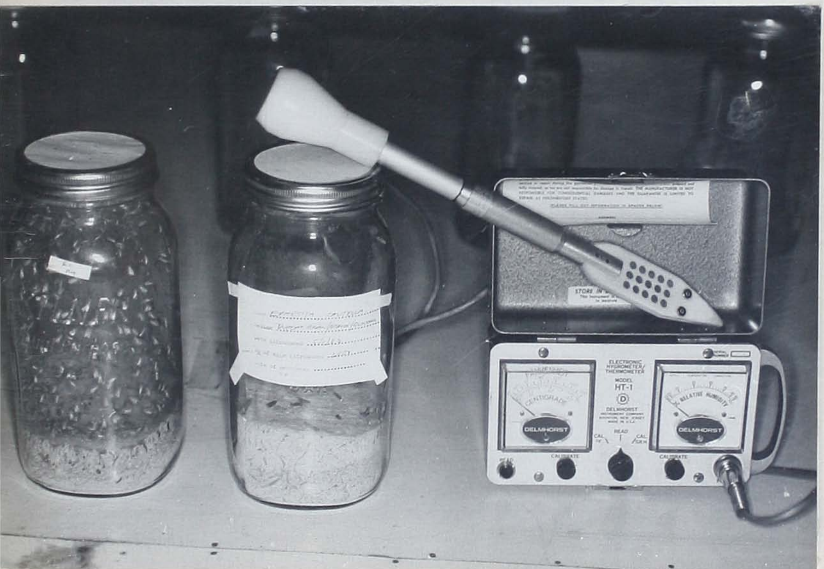


Fig. 6: Electronic hygrometer/thermometer (model RT-ISN-I) used for determining internal microclimate of experimental glass jars and cabinets.

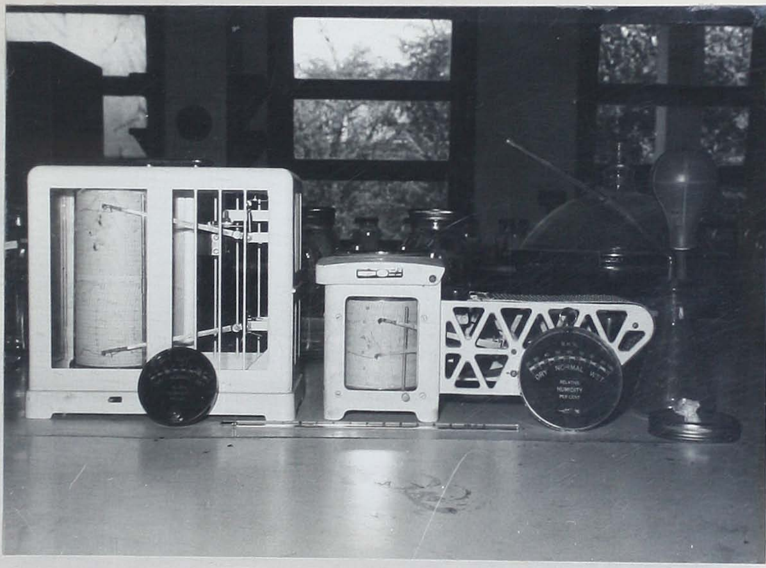


Fig. 7: Thermohygrograph, for recording humidity range 0 - 100 percent and temperature range 0 - 50^{o}C, used for ambient temperature and humidity determination.

Fig. 8: Experimental glass jars with broken cocoa beans, standing on aluminium tray, flooded with machine oil.

Fig. 9: Apparatus set-up for determination of Oviposition preferences.

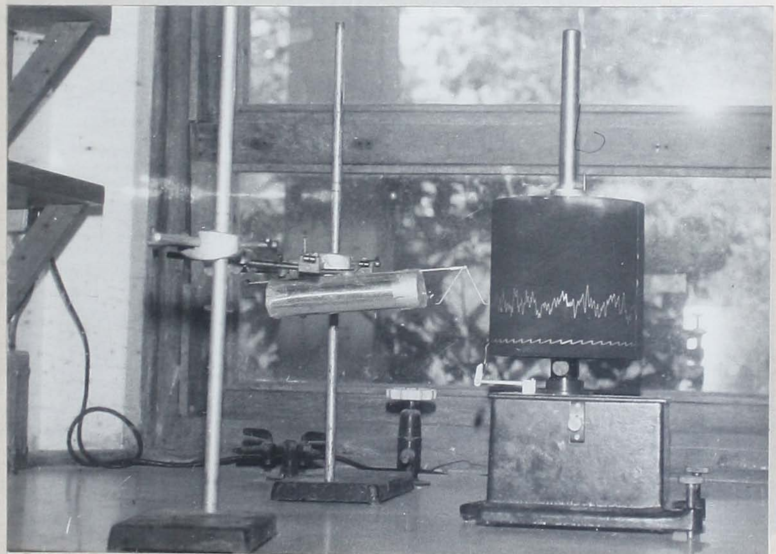


Fig. 10: Kymograph set-up used in recording daily activity patterns of C. cephalonica and E. cautella respectively.

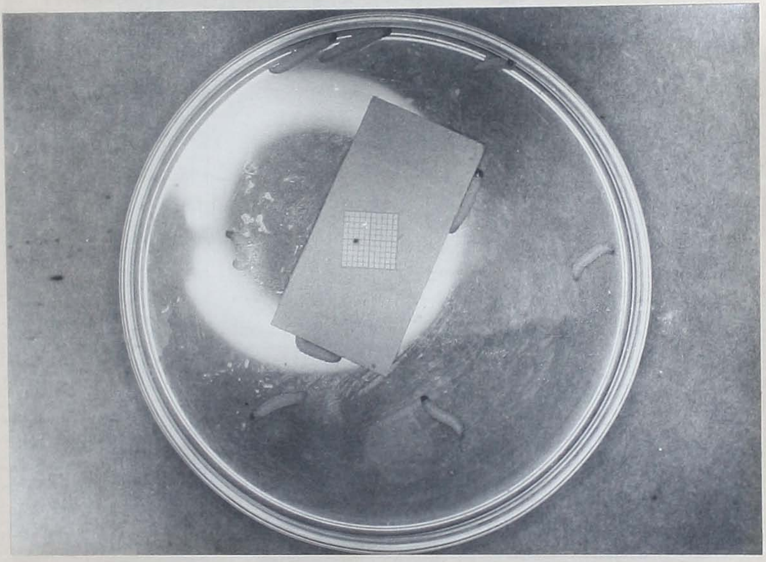


Fig. 11: Apparatus set-up for studying competition for pupation sites.

Fig. 12: Gamma cell 220 (Cobalt-60 irradiator source) at the Ghana Atomic Energy Commission, Kwabenya, used for the radiosensitivity experiments with C. cephalonica.

Chapter 3

Description of Pest Species

DESCRIPTION OF THE PEST SPECIES

3.1 Introduction

The moths C. cephalonica and E. cautella as stated earlier belong to the families Galleriidae and Phycitidae respectively. The caterpillars of both families have been known to spin prolific threads of silk during the wandering stage. Their life histories are fundamentally quite similar, they are also not divergent as to size, although C. cephalonica is somewhat larger. So far as is known there seems to be little difference between the behaviour of C. cephalonica and E. cautella (Riley, 1966). They are cosmopolitan in distribution.

3.2 Developmental Characteristics

3.2.1 Eggs

The eggs of the two moth species are white and oval in shape with the surface more deeply sculptured in E. cautella than in C. cephalonica. The size ranges are: 0.55 x 0.35mm for C. cephalonica and 0.48 x 0.35mm for E. cautella. There is a short nipple-like process at one end of the egg, and this appears to be more prominent in C. cephalonica than in E. cautella (Fig. 13). The eggs have been described by Grist and Lever (1969).

3.2.2 Larvae

The larvae of the two moths have well developed prolegs on abdominal segments 3-6 and 10. Newly hatched larvae of C. cephalonica are cream white with pale whitish abdominal cuticle, while those of E. cautella are yellowish or pinkish (depending on nutrition). The mature larvae are cream coloured (15 x 3mm) in C. cephalonica (Fig. 14) and pinkish (11 x 2mm) in E. cautella (Fig. 15). The larvae of the two species can further be distinguished by the conspicuous seta above each spiracle of the first abdominal segments. This arises from a clear zone of the cuticle surrounded by a dark ring in C. cephalonica while in E. cautella, it arises directly from a small pigmented spot. In addition, the posterior rims of the larval spiracles of C. cephalonica are thickened (Hinton and Corbet, 1972). The male larvae of E. cautella are distinguished by their dark testes, which are easily seen through the body integuments (Boles and Marzkey, 1966). The larvae of C. cephalonica and E. cautella have been described (Ayyar, 1934; Hinton, 1963; Hinton and Corbet, 1972). Thus Ayyar (1934) described eight instars in both sexes of C. cephalonica but pointed out that there was frequent deviation from this number. Richards and Thomson (1932) noted that variation in the larval instars in E. cautella is linked with sex.

3.2.3 Cocoon and Pupa

The last instar larvae of C. cephalonica and E. cautella spin characteristic closely-woven, elongate and tough cocoons that become covered in debris and food material. In the present work, the cocoon of C. cephalonica was found to be much more strongly woven and much tougher than that of E. cautella. The cocoon has been found to be double layered (Carmona, 1958). Each cocoon contains a dark brown pupa. A row of tubercles (Fig.16) lies along the dorsal mid-line of the pupa of C. cephalonica (Grist and Lever, 1969). This is absent in E. cautella (Fig. 17). Table 2 shows the measurements for pupae of C. cephalonica and E. cautella.

Table 2:

Measurements for pupae of C. cephalonica and E. cautella.

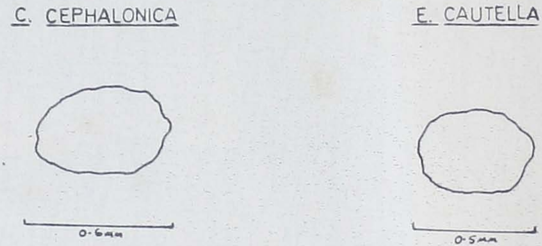
	C. cephalonica		E. cautella	
	Length (mm)	Width (mm)	Length (mm)	Width (mm)
Ayyar (1934)	7.5 - 8.5	1.45 - 2.6		
Present Project (1982)	8.5 -10.1	1.6 - 2.8	6.5 - 7.7	1.9 - 2.2

The emergence of the adult is facilitated by the structure of cocoon (Hodges, 1979), which has a line of weakness anteriorly where each of the two layers are loosely bound. The layers are then easily split when the adult emerges head first. Such an arrangement is presumably necessary to provide full protection to the anterior end of the pupa whilst allowing emergence of the adult, from the cocoon (Hodges, 1979). The adult has sucking (non-biting) mouth parts.

3.2.4 Adults

The moth E. cautella has a wing expanse of 14-17mm, while that of C. cephalonica is 17-22mm. E. cautella has a long and narrow appearance, more narrow bodied than C. cephalonica. When at rest the wings of E. cautella are held closely to the body, while in C. cephalonica, when viewed from above, their forewings are broad with distinct shoulders and are held only adpressed to the body; the hindwings of C. cephalonica have a fringe of short posteriorly directed hairs. The wings of E. cautella are dull greyish brown with an outer pale band and a broad inner edge (Fig. 18). C. cephalonica without the wing scales are mid-grey brown with thin lines of darker shade along the wing veins. The wings without the scales are uniform light brown. C. cephalonica may be recognised by the form of its labial palps which point straight forward; in the male they are blunt and inconspicuous while in the female they are long and pointed (Fig.19). Both sexes of C. cephalonica (the males of which are smaller than females) may be distinguished from E. cautella in which the labial palps curve upwards in the front of the head (Hinton and Corbet, 1972).

FIG.13. EGGS OF C. CEPHALONICA AND E. CAUTELLA SHOWING SHORT NIPPLE-LIKE PROCESS AT ONE END OF EACH EGG.



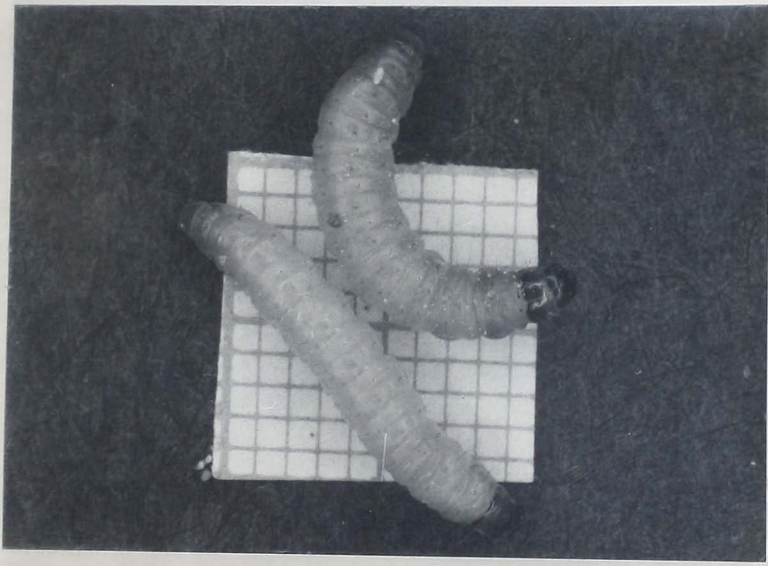


Fig. 14: Mature larvae of C. *cephalonica*.

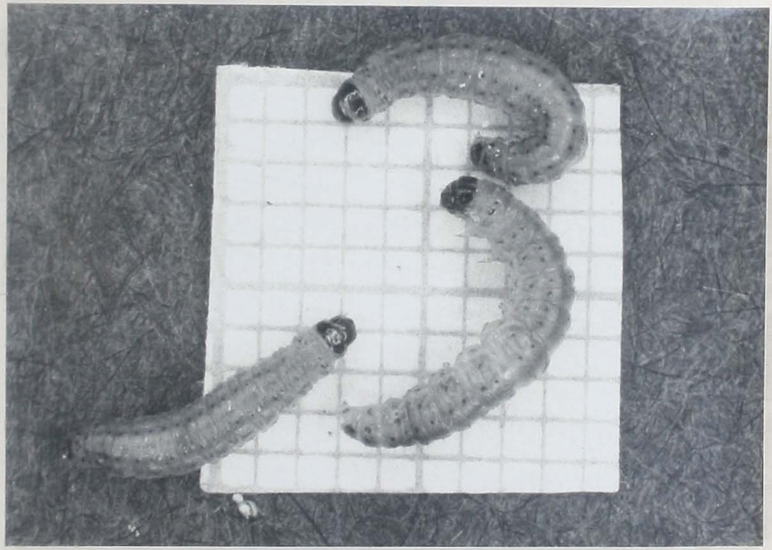


Fig. 15: Mature larvae of E. cautella.

C. CEPHALONICA

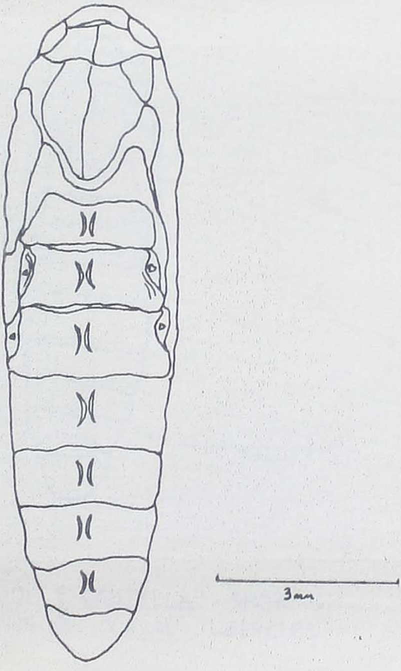


FIG.16: PUPA OF C. CEPHALONICA SHOWING DORSAL TUBERCLES

E. CAUTELLA

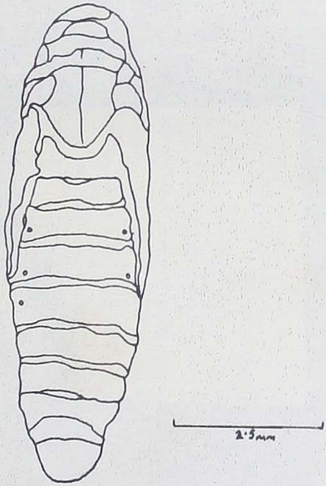


FIG. 17: PUPA OF E. CAUTELLA SHOWING ABSENCE OF DORSAL TUBERCLES

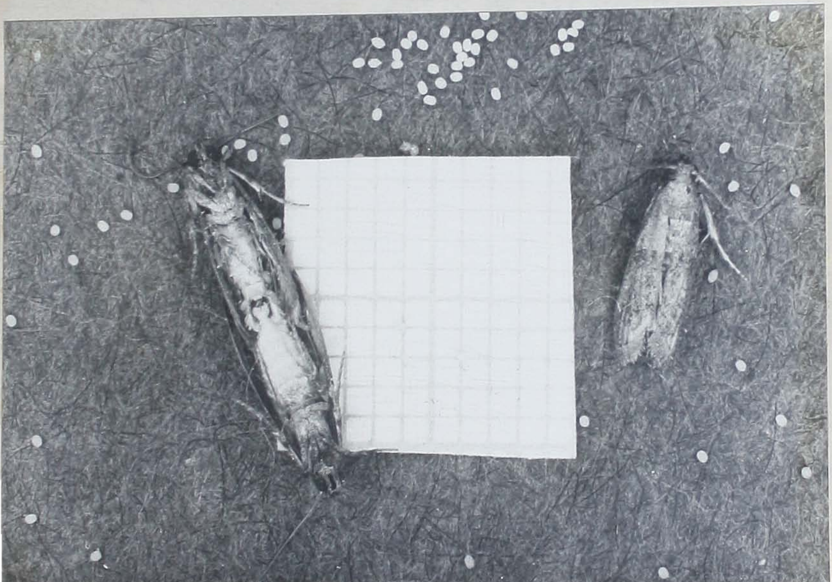


Fig. 18: Adults and eggs of E. cautella.

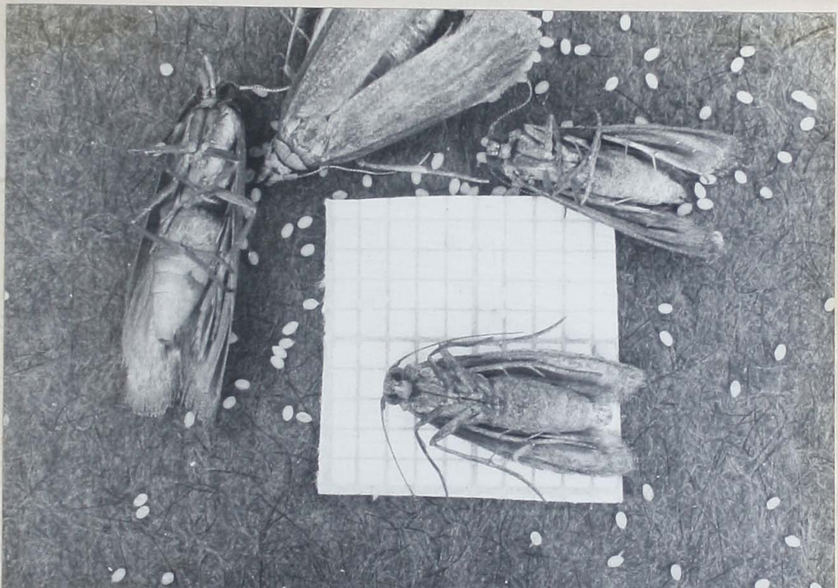


Fig. 19: Adults and eggs of C. cephalonica.

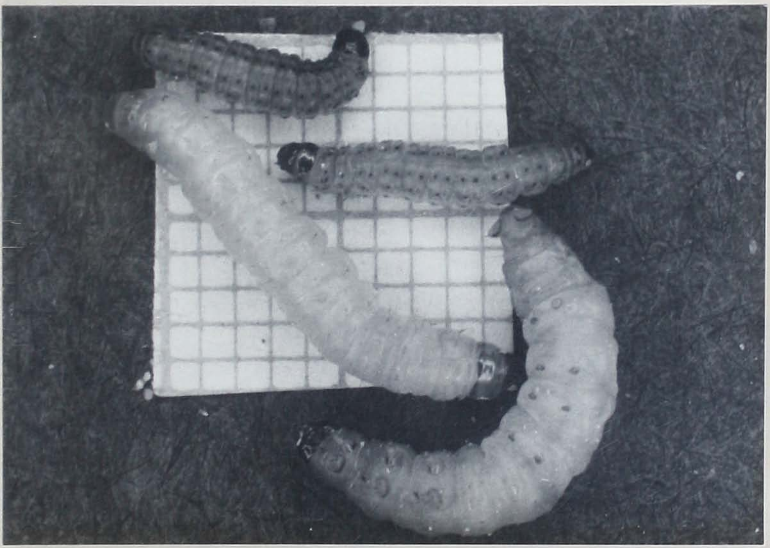


Fig. 20: Comparative sizes of larvae of *C. cephalonica* and *E. cautella* in competitive situation in Experimental glass jars.

Chapter 4

Results of Competition Studies Between *C. cephalonica* and *E. cautella.*

RESULTS OF COMPETITION STUDIES
BETWEEN *C. CEPHALONICA* AND
E. CAUTELLA

4.1 Rearing

Table 3:

Summary of mean developmental periods (temp. 25.5 - 30±1°C, R.H. : 75-89 percent) for *C. cephalonica* and *E. cautella* at Legon and Kwabenya.

	C. cephalonica		*E. cautella*	
	Legon	Kwabenya	Legon	Kwabenya
Range	29-31	29-34	21-24	21-24
Mean	30.2	30.3	22.5	21.6
Standard Deviation	0.93 (n=13)	1.67 (n=8)	1.05 (n=13)	1.19 (n=8)

Table 3 shows the ranges and means for the mean developmental periods for *C. cephalonica* and *E. cautella* at Legon and Kwabenya. The raw data are given in tables 1 and 2 of the appendix tables. A students' *t* distribution testing the Null Hypothesis, was used to investigate the difference between the mean developmental periods of the two pest species at the two locations mentioned earlier. The Null Hypothesis: $H_o : \bar{x}_1 - \bar{x}_2 = D$, and $D = 0$; supposes that the sample means of two independent populations are equal, when no difference exists between the populations. In such conditions the *t* calculated should be less than the t tabulated. If H_o is rejected, the conclusion is that the samples represent two populations with different means. The detailed calculations of the t values are shown in the appendices (Appendix tables 57, 58).

The results of the t - test showed that there was no significant difference ($t_{(cal.)}$ 0.178 < $t_{(tab.)}$ 2.093 $\nu = 19$, $a = 0.05$) between the mean developmental periods at Legon and Kwabenya, and likewise for E. cautella ($t_{(cal.)}$ < 0.417 $t_{(tab.)}$ 2.093, $\nu = 19$, $a = 0.05$). Kwabenya is within 5 kilometers radius of Legon.

Observations show that insects emergence start as early as 5.30 p.m. with peak emergence around 7.00 p.m.; that larvae failed to penetrate deeply into medium and crowding often occured, as small larvae crawled up the sides of culture cabinets even when plentiful supply of food was present. Also mature larvae about to pupate move to the top layer of the food medium where almost all pupation takes place, however some pupated in pieces of corrugated cardboards (3.0cm wide x 25cm in length) placed on the surface of the food medium.

4.2 Competition Study 1

The percentage adult increase or reduction of generation two (G2) over generation one (G1) in limited amount of standard medium is presented on table4. The detailed calculations of the percentages are given in appendix table 59.

Observations show that the sizes of emerged adults of C. cephalonica and E. cautella in generation two (G2) were much smaller than those in generation one (G1). This reduction in size apparently could be due to the effects of crowding in the larval stages of these moths in the food medium. In such biological environment, the effects of one larva upon the other occur either directly or indirectly through the reaction of the larva on the physical environment. For example, conditioning of the medium by waste products etc. Careful observations of experimental jars (Fig.4) revealed the presence of some dead larvae on the surface of the food medium. The number of dead larvae was found to increase during generation two (G2). Ambient temperature and humidity (see appendices) were found to equilibrate rapidly with the microclimate (see HT/electronic hygrometer recordings in the appendices) of the experimental jars. For this reason ambient temperature and humidity are likely to play an important role in larval development. The raw data on adult moth emergence (C. cephalonica, E. cautella) under the various conditions are given in appendix tables 3 - 12.

Table 4:

Percentage adult increase or reduction of generation two (G2) over generation (G1) in limited amount of standard medium.

	EC_{50}	CC_{50}	$E + \frac{C}{2}$		$C + \frac{E}{2}$		CC/EC	
			EC	CC	CC	EC	EC	CC
Set 1	2032.7	1693.0	2786.1	1843.8	3188.6	10.9	4.0	2465.9
Set 2	1951.4	1491.6	2687.8	1675.6	2667.1	5.6	3	2379.3
Mean Percent. Increase	1992.1	1592.3	2737.0	1759.7	2927.9	8.3	3.5	2422.6

The analysis of variance using the F-test (see appendix tables 63, 66, 69, 72, 75, 81, 84, 88 -90) shows that significant differences exist between the various treatments $(C+\frac{E}{2}, E + \frac{C}{2}$, etc.) and between the two generations (G2, G1)). Tests of significance of individual treatments are normally applied only when preliminary analysis of variance has indicated that there are significant differences between the treatment means. Thus in order to test for the significance of individual differences between treatment means $(C + \frac{E}{2}, E + \frac{C}{2}$ etc.), the method of least significant differences (LSD) was used.

In using the method of randomised block design (see appendix tables 64, 66), the analysis of variance (given earlier) will have a component "between block" i.e. between replicates and another "within blocks" that is within treatments $(E + \frac{C}{2}, C + \frac{E}{2}$ etc.). The only new calculation was the block sums of squares (SS) obtained by summing the squares of the 5 blocks totals, dividing by 8 treatment values (including G1, G2) because each is a total of 8 treatments and subtracting the correction factor (CF). The sum of squares within blocks is then obtained by difference from the total sum of squares. The results are then tabulated as follows (using standard contractions for the column headings):

ANALYSIS OF VARIANCE

Source of Variation	DF.	S.S.	M.S.	F
Blocks				
Treatments				
Total				

This arrangement makes it possible to compare treatments within blocks. The variance-ratio tables are read at 5 percent and 1 percent levels of significance. For example a figure which is significant at the 1 percent level, means that it lies above the figure which would be reached by chance only once in hundred times on the average. A clear picture of comparisons between treatment means ($C + \frac{E}{2}$, CC/EC, etc.) in generation one (G1) and generation two (G2) and their interactions are given on tables 5 - 8, which show summaries of the analysis of variance on competition in standard medium (limited amount of food and space) for emerged adults of *C. cephalonica* and *E. cautella* respectively.

Table 5:

Summary of analysis of variance on competition in standard medium (limited amount of food and space) for emerged adults of C. cephalonica, using IBM computer.

RANDOMISED BLOCK DESIGN

PAGE 1. SET 1

LEAST SIGNIFICANT DIEFERENCE TEST

LSD AT 5 PERCENT = 51.3191 LSD AT 1 PERCENT = 76.4687

TRT. MEANS		COMPARED.	TRT. MEANS DIFFERENCE	COMMENTS
G1, E + C/2	-	G1, C+E/2	0.2000	NS
G1, CC/EC	-	G1, C+E/2	2.3999	NS
G1, CC	-	G1, C+E/2	15.8000	NS
G2, E + C/2	-	G1, C+E/2	279.2000	**
G2, CC/EC	-	G1, C+E/2	433.0000	**
G2, C+E/2	-	G1, C+E/2	488.0000	**
G2, CC	-	G1, C+E/2	519.2000	**
G1, CC/EC	-	G1, E+C/2	2.1999	NS
G1, CC	-	G1, E+C/2	15.6000	NS
G2, E+C/2	-	G1, E+C/2	279.0000	**
G2, CC/EC	-	G1, E+C/2	432.80000	**
G2, C+E/2	-	G1, E+C/2	487.8000	**
G2, CC	-	G1, E+C/2	519.0001	**
G1, CC	-	G1, CC/EC	13.4000	NS
G2, E+C/2	-	G1, CC/EC	276.8000	**
G2, CC/EC	-	G1, CC/EC	430.6000	**
G2, C+E/2	-	G1, CC/EC	485.6000	**
G2, CC	-	G1, CC/EC	516.8000	**
G2, E+C/2	-	G1, CC	263.4000	**
G2, CC/EC	-	G1, CC	417.2000	**
G2, C+E/2	-	G1, CC	472.2000	**
G2, CC	-	G1, CC	503.4000	**
G2, CC/EC	-	G2, E+C/2	153.8000	**
G2, C+E/2	-	G2, E+C/2	208.8000	**
G2, CC	-	G2, E+C/2	240.0000	**
G2, C+E/2	-	G2, CC/EC	55.0000	*
G2, CC	-	G2, CC/EC	86.2000	**
G2, CC	-	G2, C+E/2	31.2000	NS

* ...Denotes Significant at 5 Percent Level

** ...Denotes Significant at 1 Percent Level

NS ...Denotes not Significant at either 1 or 5 Percent Level

Table 6:

Summary of analysis of variance on competition in standard medium (limited amount of food and space) prefor emerged adults of C. cephalonica

RANDOMISED BLOCK DESIGN

PAGE 1, SET 2

LEAST SIGNIFICANT DIFFERENCE TEST

LSD AT 5 PERCENT = 53.5101 LSD AT 1 PERCENT = 79.7333

TRT. MEANS		COMPARED TRT. MEANS	DIFFERENCE	COMMENTS
G1, E+C/2	-	G1, C+E/2	0.1999	NS
G1, CC/EC	-	G1, C+E/2	1.3999	NS
G1, CC	-	G1, C+E/2	16.2000	NS
G2, E+C/2	-	G1, C+E/2	271.2000	**
G2, CC/EC	-	G1, C+E/2	420.8000	**
G2, C+E/2	-	G1, C+E/2	436.6000	**
G2, CC	-	G1, C+E/2	476.2000	**
G1, CC/EC	-	G1, E+C/2	1.2000	NS
G1, CC	-	G1, E+C/2	16.0000	NS
G2, E+C/2	-	G1, E+C/2	271.0000	**
G2, CC/EC	-	G1, E+C/2	420.6000	**
G2, C+E/2	-	G1, E+C/2	436.4000	**
G2, CC	-	G1, E+C/2	478.0000	**
G1, CC	-	G1, CC/EC	14.8000	NS
G2, E+C/2	-	G1, CC/EC	269.7999	**
G2, CC/EC	-	G1, CC/EC	419.4000	**
G2, C+E/2	-	G1, CC/EC	435.2000	**
G2, CC	-	G1, CC/EC	476.7999	**
G2, E+C/2	-	G1, CC	254.9999	**
G2, CC/EC	-	G1, CC	404.6000	**
G2, C+E/2	-	G1, CC	420.4000	**
G2, CC	-	G1, CC	462.0000	**
G2, CC/EC	-	G2, E+C/2	149.6000	**
G2, C+E/2	-	G2, E+C/2	165.4000	**
G2, CC	-	G2, E+C/2	207.0000	**
G2, C+E/2	-	G2, CC/EC	15.7999	NS
G2, CC	-	G2, CC/EC	57.3999	*
G2, CC	-	G2, C+E/2	41.5999	NS

*...Denotes Significant at 5 percent Level

**...Denotes Significant at 1 Percent Level

NS...Denotes not Significant at either 1 or 5 Percent Level

Table 7:

Summary of analysis of variance on competition in standard medium (limited amount of food and space) for emerged adults of E. cautella.

RANDOMISED BLOCK DESIGN

PAGE 2, SET I

LEAST SIGNIFICANT DIFFERENCE TEST

LSD AT 5 PERCENT = 75.5876 LSD AT 1 PERCENT = 112.6302

TRT. MEANS		COMPARED. TRT. MEANS	DIFFERENCE	COMMENTS
G2, C+E/2	-	G2, CC/EC	1.4000	NS
G1, CC/EC	-	G2, CC/EC	19.2000	NS
G1, C+E/2	-	G2, CC/EC	19.3999	NS
G1, E+C/2	-	G2, CC/EC	20.7999	NS
G1, EC	-	G2, CC/EC	40.2000	NS
G2, E+C/2	-	G2, CC/EC	601.000	**
G2, EC	-	G2, CC/EC	832.5999	**
G1, CC/EC	-	G2, C+E/2	17.8000	NS
G1,C+E/2	-	G2, C+E/2	18.0000	NS
G1, E+C/2	-	G2, C+E/2	19.4000	NS
G1, EC	-	G2, C+E/2	36.8000	NS
G2, E+C/2	-	G2 C+E/2	599.5999	**
G2, EC	-	G2, C+E/2	831.1999	**
G1, C+E/2	-	G1, CC/EC	0.1999	NS
G1, E+C/2	-	G1, CC/EC	1.5999	NS
G1, EC	-	G1, CC/EC	21.0000	NS
G2, E+C/2	-	G1, CC/EC	581.8000	**
G2, EC	-	G1, CC/EC	813.4000	**
G1, E+C/2	-	G1, C+E/2	1.4000	NS
G1, EC	-	G1, C+E/2	20.8000	NS
G2, E+C/2	-	G1, C+E/2	581.5999	**
G2, EC	-	G1, C+E/2	813.1999	**
G1, EC	-	G1, E+C/2	19.4000	NS
G2, E+C/2	-	G1, E+C/2	580.1999	**
G2, EC	-	G1, E+C/2	811.7999	**
G2, E+C/2	-	G1, EC	560.8000	**
G2, EC	-	G1, EC	792.4000	**
G2, EC	-	G2, E+C/2	231.6000	**

*...Denotes Significant at 5 Percent Level

**...Denotes Significant at 1 Percent Level

NS...Denotes not Significant at either 1 or 5 Percent Level.

Table 8:

Summary of analysis of variance on competition in standard medium (limited amount of food and space) for emerged adults of E. cautella.

RANDOMISED BLOCK DESIGN

PAGE 2. SET 2

LEAST SIGNIFICANT DIFFERENCE TEST

LSD AT 5 PERCENT = 81.5936 LSD AT 1 PERCENT = 121.5796

TRT.	MEANS	COMPARED. TRT.	MEANS	DIFFERENCE	COMMENTS
G2, C+E/2	-	G2, CC/EC		0.6000	NS
G1, CC/EC	-	G2, CC/EC		19.4000	NS
G1, C+E/2	-	G2, CC/EC		20.4000	NS
G1, E+C/2	-	G2, CC/EC		22.4000	NS
G1, EC	-	G2, CC/EC		41.7999	NS
G2, E+C/2	-	G2, CC/EC		617.5999	**
G2, EC	-	G2, CC/EC		826.7999	**
G1, CC/EC	-	G2, C+E/2		18.8000	NS
G1, C+E/2	-	G2, C+E/2		19.8000	NS
G1, E+C/2	-	G2, C+E/2		21.8000	NS
G1, EC	-	G2, C+E/2		41.1999	NS
G2, E+C/2	-	G2, C+E/2		617.0000	**
G2, EC	-	G2, C+E/2		826.1999	**
G1, C+E/2	-	G1, CC/EC		1.0000	NS
G1, E+C/2	-	G1, CC/EC		3.0000	NS
G1, EC	-	G1, CC/EC		22.3999	NS
G2, E+C/2	-	G1, CC/EC		598.2000	**
G2, EC	-	G1, CC/EC		807.4000	**
G1, E+C/2	-	G1, C+E/2		2.000	NS
G1, EC	-	G1, C+E/2		21.3999	NS
G2, E+C/2	-	G1, C+E/2		597.2000	**
G2, EC	-	G1, C+E/2		806.4000	**
G1, EC	-	G1, E+C/2		19.3999	NS
G2, E+C/2	-	G1, E+C/2		595.2000	**
G2, EC	-	G1, E+C/2		804.4000	**
G2, E+C/2	-	G1, EC		575.8000	**
G2, EC	-	G1, EC		785.0000	**
G2, EC	-	G2 E+C/2		209.1999	*

*...Denotes Significant at 5 Percent Level

**...Denotes Significant at 1 Percent Level

NS...Denotes not Significant at either 1 or 5 Percent Level.

4.3 Competition Study 2

Table 9:

Percentage adult increase or reduction of generation two (G2) over generation one (G1) in limited amount of broken cocoa beans.

	EC_{50}	CC_{50}	$E \cdot \frac{C}{2}$		$C \cdot \frac{E}{2}$		CC/EC	
			EC	CC	CC	EC	CC	EC
Set 1	709.2	1643.6	30.9	1340	2503.6	11.1	2644.2	0
Set 2	719.6	1584.6	58.3	2126.7	2416.4	19.0	3011.4	0
Mean Percent. Increase	714.4	1614.1	44.6	1733.4	2460.0	15.1	2827.8	0

Table 9 shows the percentage adult increase or reduction of generation two (G2) over generation one (G1) in limited amount of broken cocoa beans. The detailed calculations of the percentages are given in appendix table 60.

Observations show that both C. cephalonica and E. cautella have same developmental period of 41 days on broken cocoa beans. The raw data for the emerged adult moth (C. cephalonica, E. cautella) in competition in broken cocoa beans under the various conditions (CC/EC, $C \cdot \frac{E}{2}$ etc.) are given in appendix tables 15-24.

The analysis of variance was in the same manner as before (see appendix tables 75-86). Tables 10-13 give detailed comparison between treatment means ($C \cdot \frac{E}{2}$, $E \cdot \frac{C}{2}$ etc), in generations one (G1) and generation two (G2).

Table 10:

Summary of analysis of variance on competition in broken cocoa beans (limited amount of food and space) for emerged adults of C. cephalonica.

RANDOMISED BLOCK DESIGN

PAGE 3, SET 1

LEAST SIGNIFICANT DIFFERENCE TEST

LSD AT 5 PERCENT = 50.0494 LSD AT 1 PERCENT = 74.5768

TRT.	MEANS	COMPARED TRT.	MEANS	DIFFERENCE	COMMENTS
G1, E+C/2	-	G1, CC/EC		1.4000	NS
G1, C+E/2	-	G1, CC/EC		2.6000	NS
G1, CC	-	G1, CC/EC		13.4000	NS
G2, E+C/2	-	G1, CC/EC		125.4000	**
G2, CC/EC	-	G1, CC/EC		218.8000	**
G2, C+E/2	-	G1, CC/EC		271.7999	**
G2, CC	-	G1, CC/EC		353.0000	**
G1, C+E/2	-	G1, E+C/2		1.1999	NS
G1, CC	-	G1, E+C/2		12.0000	NS
G2, E+C/2	-	G1, E+C/2		124.0000	**
G2, CC/EC	-	G1, E+C/2		217.4000	**
G2, C+E/2	-	G1, E+C/2		270.4000	**
G2, CC	-	G1, E+C/2		351.6000	**
G1, CC	-	G1, C+E/2		10.8000	NS
G2, E+C/2	-	G1, C+E/2		122.8000	**
G2, CC/EC	-	G1, C+E/2		216.2000	**
G2, C+E/2	-	G1 C+E/2		269.2000	**
G2, CC	-	G1, C+E/2		350.4000	**
G2, E+C/2	-	G1, CC		112.0000	**
G2, CC/EC	-	G1, CC		205.4000	**
G2, C+E/2	-	G1, CC		258.4000	**
G2, CC	-	G1, CC		339.6000	**
G2, CC/EC	-	G2, E+C/2		93.4000	**
G2, C+E/2	-	G2, E+C/2		146.3999	**
G2, CC	-	G2, E+C/2		227.6000	**
G2, C+E/2	-	G2, CC/EC		52.9999	*
G2, CC	-	G2, CC/EC		134.2000	**
G2, CC	-	G2, C+E/2		81.2000	**

*...Denotes Significant at 5 Percent Level

**...Denotes Significant at 1 Percent Level

NS...Denotes not Significant at either 1 or 5 Percent Level.

Table 11:

Summary of analysis of variance on competition in broken cocoa beans (limited amount of food and space) for emerged adults of C. cephalonica.

RANDOMISED BLOCK DESIGN

PAGE 3, SET 2

LEAST SIGNIFICANT DIFFERENCE TEST

LSD AT 5 PERCENT = 34.3904 LSD AT 1 PERCENT = 51.2438

TRT.	MEANS	COMPARED	TRT.	MEANS	DIFFERENCE	COMMENTS
G1, C+E/2	-	G1, CC/EC			0.2000	NS
G1, C+E/2	-	G1, CC/EC			4.6000	NS
G1, CC	-	G1, CC/EC			14.6000	NS
G2, E+C/2	-	G1, CC/EC			182.6000	**
G2, CC/EC	-	G1, CC/EC			255.7999	**
G2, C+E/2	-	G1, CC/EC			315.0000	**
G2, CC	-	G1, CC/EC			362.0000	**
G1, C+E/2	-	G1, E+C/2			4.4000	NS
G1, CC	-	G1, E+C/2			14.3999	NS
G2, E+C/2	-	G1, E+C/2			182.4000	**
G2, CC/EC	-	G1, E+C/2			255.6000	**
G2, C+E/2	-	G1, E+C/2			314.8000	**
G2, CC	-	G1, E+C/2			361.8000	**
G1, CC	-	G1, C+E/2			10.0000	NS
G2, E+C/2	-	G1, C+E/2			178.0000	**
G2, CC/EC	-	G1, C+E/2			251.1999	**
G2, C+E/2	-	G1, C+E/2			310.4000	**
G2, CC	-	G1, C+E/2			357.4000	**
G2, E+C/2	-	G1, CC			168.0000	**
G2, CC/EC	-	G1, CC			241.1999	**
G2, C+E/2	-	G1, CC			300.4000	**
G2, CC	-	G1, CC			347.4000	**
G2, CC/EC	-	G2, E+C/2			73.1999	**
G2, C+E/2	-	G2, E+C/2			132.4000	**
G2, CC	-	G2, E+C/2			179.4000	**
G2, C+E/2	-	G2, CC/EC			59.2000	**
G2, CC	-	G2, CC/EC			106.2000	**
G2, CC	-	G2, C+E/2			47.0000	*

*.. Denotes significant at 5 percent Level

**.. Denotes significant at 1 percent Level

NS Denotes significant at either 1 or 5 percent Level

Table 12:

Summary of analysis of variance on competition in broken cocoa beans (limited amount of food and space) for emerged adults of E. cautella.

RANDOMISED BLOCK DESIGN

PAGE 4 SET 1

LEAST SIGNIFICANT DIFFERENCE TEST

LSD AT 5 PERCENT = 20.3997 LSD AT 1 PERCENT = 30.3969

TRT.	MEANS	COMPARED TRT.	MEANS DIFFERENCE	COMMENTS
G2, C+E/2	-	G2, CC/EC	0.4000	NS
G1, CC/EC	-	G2, CC/EC	2.0000	NS
G2, E+C/2	-	G2, CC/EC	3.4000	NS
G1, C+E/2	-	G2, CC/EC	3.6000	NS
G1, E+C/2	-	G2, CC/EC	11.0000	NS
G1, EC	-	G2, CC/EC	26.2000	*
G2, EC	-	G2, CC/EC	185.8000	**
G1, CC/EC	-	G2, C+E/2	1.6000	NS
G2, E+C/2	-	G2, C+E/2	3.0000	NS
G1, C+E/2	-	G2, C+E/2	3.2000	NS
G1, E+C/2	-	G2, C+E/2	10.6000	NS
G1, EC	-	G2, C+E/2	25.7999	*
G2, EC	-	G2, C+E/2	185.3999	**
G2, E+C/2	-	G1, CC/EC	1.3999	NS
G1, C+E/2	-	G1, CC/EC	1.6000	NS
G1, E+C/2	-	G1, CC/EC	9.0000	NS
G1, EC	-	G1, CC/EC	24.2000	*
G2, EC	-	G1, CC/EC	183.8000	**
G1, C+E/2	-	G2, E+C/2	0.2000	NS
G1, E+C/2	-	G2, E+C/2	7.6000	NS
G1, EC	-	G2, E+C/2	22.7999	*
G2, EC	-	G2, E+C/2	182.3999	**
G1, E+C/2	-	G1, C+E/2	7.4000	NS
G1, EC	-	G1, C+E/2	22.5999	*
G2, EC	-	G1, C+E/2	182.2000	**
G1, EC	-	G1, E+C/2	15.1999	NS
G2, EC	-	G1, E+C/2	174.8000	**
G2, EC	-	G1, EC	159.6000	**

* ..Denotes significant at 5 percent level

** ..Denotes significant at 1 percent level

NS ..Denotes not signifi- at either 1 or 5 percent level.

Table 13:

Summary of analysis of variance on competition in broken cocoa beans (limited amount of food and space) for emerged adults of E. cautella.

RANDOMISED BLOCK DESIGN

PAGE 4 SET 2

LEAST SIGNIFICANT DIFFERENCE TEST

LSD AT 5 PERCENT = 20.0288 LSD AT L PERCENT = 29.8442

TRT.	MEANS	COMPARED TRT. MEANS	DIFFERENCE	COMMENTS
G2, C+E/2	-	G2, CC/EC	0.8000	NS
G1, CC/EC	-	G2, CC/EC	2.8000	NS
G1, C+E/2	-	G2, CC/EC	4.2000	NS
G2, E+C/2	-	G2, CC/EC	7.0000	NS
G1, E+C/2	-	G2, CC/EC	12.0000	NS
G1, EC	-	G2, CC/EC	27.6000	*
G2, EC	-	G2, CC/EC	199.6000	**
G1, CC/EC	-	G2, C+E/2	2.0000	NS
G1, C+E/2	-	G2, C+E/2	3.4000	NS
G2, E+C/2	-	G2, C+E/2	6.2000	NS
G1, E+C/2	-	G2, C+E/2	11.2000	NS
G1, EC	-	G2, C+E/2	26.7999	*
G2, EC	-	G2, C+E/2	198.7999	**
G1, E +C/2	-	G1, CC/EC	1.4000	NS
G2, E+C/2	-	G1, CC/EC	4.2000	NS
G1, E+C/2	-	G1, CC/EC	9.2000	NS
G1, EC	-	G1, CC/EC	24.7999	*
G2, EC	-	G1, CC/EC	196.7999	**
G2, E+C/2	-	G1, C+E/2	2.8000	NS
G1, E+C/2	-	G1, C+E/2	7.8000	NS
G1, CC	-	G1, C+E/2	23.4000	*
G2, EC	-	G1, C+E/2	195.3999	**
G1, E+C/2	-	G2, E+C/2	5.0000	NS
G1, EC	-	G2, E+C/2	20.6000	*
G2, EC	-	G2, E+C/2	192.6000	**
G1, EC	-	G1, E+C/2	15.6000	NS
G2, EC	-	G1, E+C/2	187.6000	**
G2, EC	-	G1, EC	172.0000	**

* .. Denotes significant at 5 percent level

** .. Denotes significant at 1 percent level

NS .. Denotes not significant at either 1 or 5 percenta level.

4.4 Competition Study 3

The results of competition in abundance of standard medium and abundance of broken cocoa beans are presented on tables 14 and 15 respectively. The detailed calculations of the percentages are given in appendix tables 61 and 62. The results of the analysis of variance (see appendix tables 87-90) show that there are significant differences at the 5 percent level of significance between emerged adults of *C. cephalonica* and *E. cautella* in the various treatments and generations.

Observations show that the sizes of emerged adults are bigger than those in the experiments in limited amount of food and space. Observations also showed that there were few dead larvae on the surface of the food medium (standard medium, broken cocoa beans) in generation two and generation three (standard medium) respectively. Thus in situations where resources (food, space) are not in short supply, competition occurs when for example, larvae seeking that resource harm one another in the process (interference). Observations also show that adult male moths emerged a day or two earlier than female moths.

Table 14:

Percentage adult increase or reduction of generation two (G2) over generation one (G1) and generation three (G3) over generation two (G2) in abundance of standard medium.

					E + C/2				C + E/2				CC/EC			
	EC_{50}		CC_{50}		EC		CC		CC		EC		CC		EC	
	G2/G1	G3/G2	G2/G1	G3/G2	G2/G1	G3/G2	G2/G1	G3/G2	G2/G1	G3/G2	G2/G1	G3/G2	G2/G1	G3/G2	G2/G1	G3/G2
Set 1	2054.3	476.2	1609.3	229.2	2952.2	31.4	1872.7	225.0	2861.9	271.2	779.2	153.5	2700.0	271.5	2345.8	313.2
Set 2	2155.6	507.3	1587.8	268.9	3800.0	40.8	2318.2	102.0	2517.4	313.8	1100.0	56.13	2834.8	98.6	260.4	94.7
Mean % Increase	2105.0	491.8	1598.6	249.1	3376.1	36.1	2095.5	163.5	2689.7	292.5	939.6	104.8	2767.4	185.1	1303.1	204.0

Table 15:

Percentage adult increase or reduction of generation two (G2) over generation one (G1) in abundance of broken cocoa beans.

	EC_{50}	CC_{50}	$E + \frac{C}{2}$		$C + \frac{E}{2}$		CC/EC	
			EC	CC	CC	EC	CC	EC
Set 1	954.8	1472.4	221.1	1733.3	2325	200	2277.8	157.1
Set 2	977.8	1569.2	205.9	1743.8	2111.1	136.4	2281.3	150
Mean Percent. Increase	966.3	1520.8	213.5	1738.6	2218.1	168.2	2279.6	153.6

4.5 Oviposition Preferences

The raw data from the experiments on oviposition preferences are given in appendix tables 25-30. The chi-squared (X^2) test was used to analyse the results (see appendix tables 91-96 for detailed calculation of X^2 values). Tables 16 - 21 show the results of the analysis.

Careful examination of table 16 shows that the X^2 value of 157.5 with two degrees of freedom corresponds to a probability of less than 0.001. This shows highly significant departure from random expectation based on the hypothesis that it is a matter of equal chance (Null hypothesis) as to which food medium is preferred for oviposition by the two moths, E. cautella and C. cephalonica.

On examining differences between expected and observed values in the individual cells of the table; three main tendencies become apparent:

(1) E. cautella tends to prefer standard medium when in competition with C. cephalonica for oviposition sites;

(2) C. cephalonica tends to prefer broken cocoa beans more than the other given food commodities;

(3) C. cephalonica tends to prefer groundnut next to broken beans.

Tables 17 and 18 show that when E. cautella and C. cephalonica occur separately and when given the choice of ovipositing in the three food commodities mentioned earlier, standard medium is the most preferred food commodity. This trend is repeated in tables 19-21. However table 18 shows that C. cephalonica is not found only on standard medium but occurs to a lesser extent on broken cocoa beans. Thus the above results for oviposition preferences can be summarised in order of preference as follows:

(1) Condition CC/EC

E. cautella: (standmedium > groundnut > broken cocoa beans)

C. cephalonica: (broken cocoa beans > groundnut > standmedium)

(2) Condition CC, EC

E. cautella: (standard medium > broken cocoa beans > groundnut).

C. cephalonica: (standard medium > broken cocoa beans > groundnut).

The above results suggest that *C. cephalonica* poses a real danger to cocoa beans when in competition with *E. cautella*. Where *C. cephalonica* exists alone under similar conditions, cocoa beans are still affected. The destructive nature of *C. cephalonica* can be seen by comparison of Figs. 21-27, which clearly shows that much more damage is done by *C. cephalonica* than *E. cautella* in all the three given food commodities (pictures taken from petridishes used in the set-up for oviposition preferences, see Fig.9).

Observations on the petridishes (using Wild M5 stereo microscope) two weeks after setting up the experiments for oviposition preferences, revealed that apart from the young larvae present in the petridishes, there were a large number of eggs (collapsed) in some of the petridishes containing shelled groundnut. Almost invariably there were dead female moths in these petridishes. Dying females of the moths have been observed in some cases to discharge eggs by the involuntary abdominal peristalsis preceeding death. Thus the presence of the large number of collapsed eggs could be linked with the dead female moths.

Table 16:

Analysis for oviposition preferences tests for *E. cautella* and *C. cephalonica* when introduced together (CC/EC).

Species of Insect (larvae)		Standard Medium	Broken Cocoa Beans	Shelled Ground-nut	(Total)
	Observed	124.5	1	12	(137.5)
E. cautella	Expected	81.4	36.9	18.9	
	Difference	+43.1	-35.9	-6.9	
	Observed	7.5	58.5	18.5	(84.5)
C. cephalonica	Expected	50.1	22.6	11.6	
	Difference	-42.6	+35.9	+6.9	
(Total)		(131.5)	(59.5)	(30.5)	(222)

$X^2_{(2)} = 157.5$, $P < 0.001$ ∴ Highly significant

Table 17:

Analysis for oviposition preferences tests for *E. cautella* (EC).

	E. cautella, (larvae)		
Food Medium	Observed	Expected	Deviation
Standard medium	69.5	29.5	+40
Broken cocoa beans	12	29.5	-17.5
Shelled groundnut	7	29.5	-22.5
(Total)	(88.5)	(88.5)	(0.0)

$X_{(2)} = 84.25$ $P < 0.001$ ∴ Highly significant

Table 18:

Analysis for oviposition preferences tests for *C. cephalonica* (CC)

	C. cephalonica, (larvae)		
Food medium	Observed	Expected	Deviation
Standard medium	58.5	33.67	+24.83
Broken cocoa beans	41	33.67	+7.33
Shelled groundnut	1.5	33.67	-32.17
(Total)	(101.0)	(101.0)	(0.0)

$\chi^2_{(2)} = 50.65$ $P < 0.001$ ∴ Highly significant

Table 19:

Analysis for oviposition preferences tests for *C. cephalonica* (CC).

	C. cephalonica (cocoon)		
Food medium	Observed	Expected	Deviation
Standard medium	79.5	62.83	+16.67
Broken cocoa beans	62.5	62.83	- 0.33
Shelled groundnut	46.5	62.83	-16.33
(Total)	(188.5)	(188.5)	(0.0)

$\chi^2_{(2)} = 10.39$, $P < 0.01$ $\therefore$ significant

Table 20:

Analysis for oviposition preferences tests for *E. cautella* (EC)

	E. cautella, (cocoon)		
Food medium	Observed	Expected	Deviation
Standard medium	66.5	41	+25.5
Broken cocoa beans	31.5	41	-9.5
Shelled groundnut	25	41	-16
(Total)	(123)	(123)	(0.0)

$\chi^2_{(2)} = 24.3$, $P < 0.001$ ∴ Highly significant

Table 21:

Analysis for oviposition preferences tests for *E. cautella* and *C. cephalonica* when introduced together (CC/EC)

	C. cephalonica/E. cautella (cocoon)		
Food medium	Observed	Expected	Deviation
Standard medium	105	62.17	+42.83
Broken coco beans	59	62.17	-3.17
Shelled groundnut	22.5	62.17	-39.67
(Total)	(186.5)	(186.5)	(0.0)

$\chi^2_{(2)} = 54.93$, $P < 0.001$ ∴ Highly significant

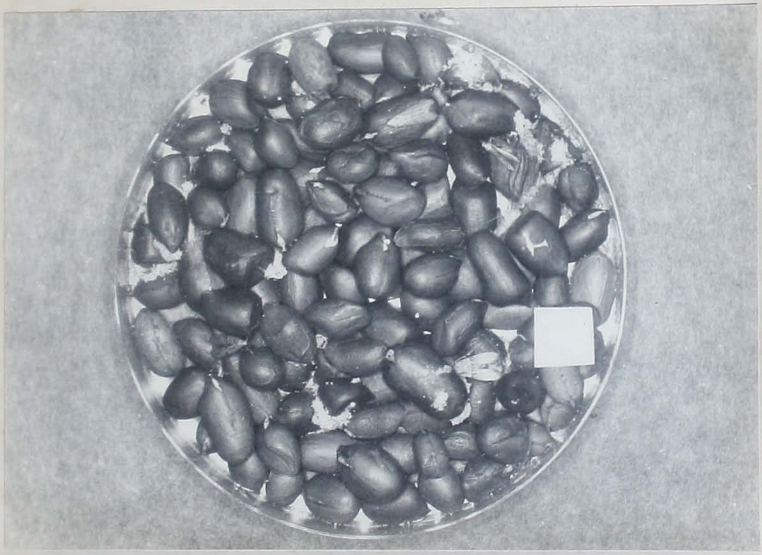


Fig. 21: E. cautella on shelled groundnut (Oviposition preferences determination) Note webbing and extent of damage after 9 weeks.

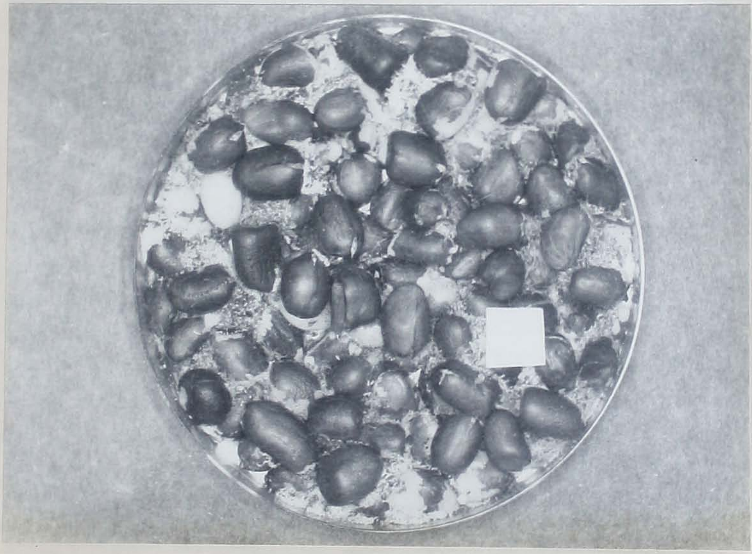


Fig. 22: C. cephalonica on shelled groundnuts (Oviposition preferences determination) Note webbing and extent of damage after 9 weeks.

Fig. 23: C. cephalonica on shelled groundnuts (Oviposition preferences determination) Note webbing and extent of damage after 15 weeks.

Fig. 24: E. cautella on broken cocoa beans (Oviposition preferences determination). Note webbing and extent of damage after 9 weeks.

Fig. 25: C. cephalonica on broken cocoa beans (Oviposition preferences determination). Note webbing and extent of damage after 9 weeks.

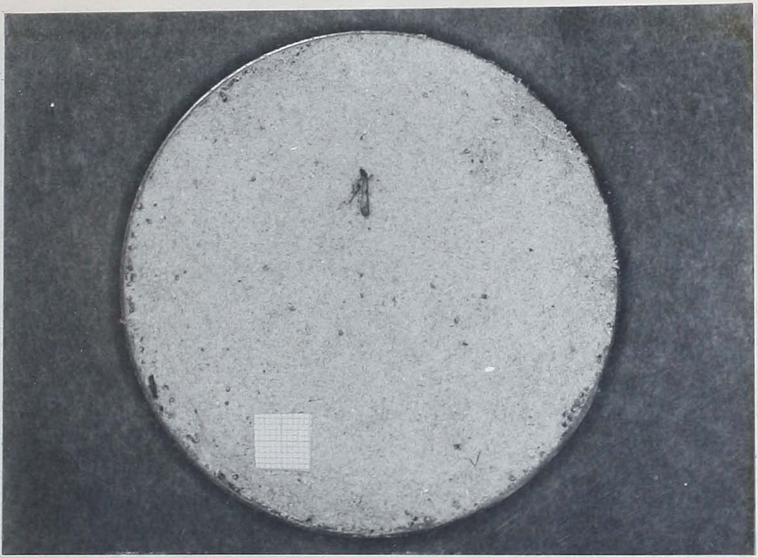


Fig. 26: *E. cautella* on standard medium (Oviposition preferences determination). Note matty appearance and extent of damage after 9 weeks.

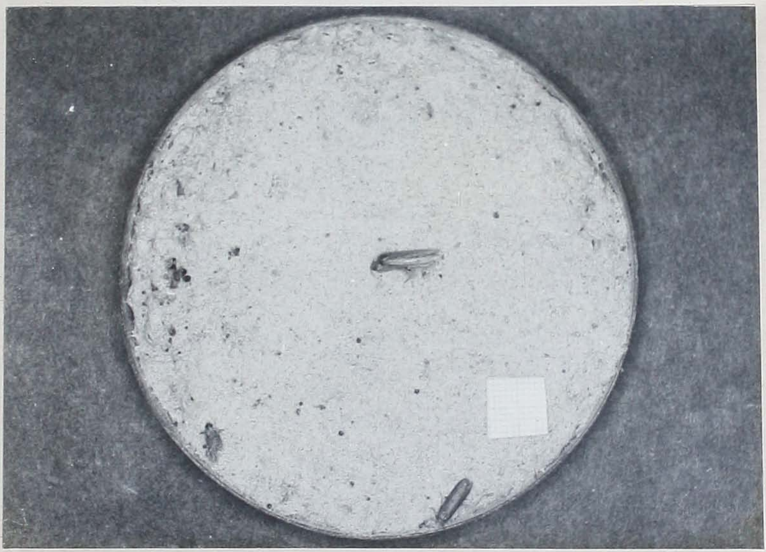


Fig. 27: C. cephalonica on standard medium (Oviposition preferences determination). Note matty appearance and extent of damage after 9 weeks.

4.6 Egg-hatchability

Table 22:

Percentage egg-hatchability of E. cautella and C. cephalonica.

	Percent. Egg-hatchability
E. cautella	94.4
C. cephalonica	85.6

Table 22 above shows the percentage egg-hatchability of E. cautella and C. cephalonica from observations on batches of 650 eggs of each species. The raw data for E. cautella and C. cephalonica are given in appendix tables 31 and 32 respectively. From table 2, it can be seen that E. cautella has greater percentage egg-hatchability than C. cephalonica. Observations (see appendix tables 31, 32) show that egg-hatchability reached a maximum on the fifth day from the time of oviposition and then declined to a low level. It was observed that young larvae emerging from egg cases move randomly apparently in search of food supply.

4.7 Age and Fecundity

Table 23:

Mean fecundity per female of E. cautella and C. cephalonica when paired 1 male to 1 female (from 20 adults reared on 200 grams of standard medium).

	E. cautella	C. cephalonica
Set 1	168.4	132.5
Set 2	160.5	145.3
Mean for set 1 and 2	164.5	138.9

Table 23 shows that E. cautella has a mean fecundity of 164.5 eggs per female. This is higher than the mean fecundity of 138.9 eggs per female for C. cephalonica. That the number of eggs laid per female of each species varies, is shown in appendix tables 33-36. Under increased population conditions, fecundity per female becomes lowered (table 24).

Observations show that oviposition begins some hours after copulation, occuring thereafter mostly at night. The raw data on age and fecundity are given in appendix tables 33-38.

Table 24:

Mean Fecundity per female of E. cautella and C. cephalonica (from 200/100 adults reared on 200 grams of standard medium).

	E. cautella	C. cephalonica
Pairing (♂ : ♀)	50:50	10:10
No. of adults reared	200	100
Mean fecundity	108.3	88.1

4.6 Activity Pattern

Many animals are active by day or by night, showing a diurnal rhythm of activity. Figs. 28 and 29 show the daily activity pattern of the larvae of C. cephalonica and E. cautella under 12 hours normal day light and 12 hours normal darkness. Fig. 30 shows a comparison of part of the activity pattern (night) of E. cautella and C. cephalonica respectively. A study of the kymograph records (Figs.28,29) shows that both C. cephalonica and E. cautella become active from around 3 p.m. and remain very active during the night but become less active during the day. This rhythm of activity was repeated in all the kymograph records studied.

Observations (from the transparent window of the container, (Fig. 10) show that as the larvae move about, trails of silken threads are left behind which do not particularly define a clear path, and where a number of these silken threads are found a webbing is formed. The larvae were not provided with food for the duration of the experiment (24 hours), thus the activity pattern observed on the kymograph records could be that of search for food by the larvae.

From Figs. 28 and 29, it can be seen that the amplitudes in the kymograph records are longer for C. cephalonica than for E. cautella. This may reflect on their relative sizes and weights (same age and number introduced) as well as their activities during the period.

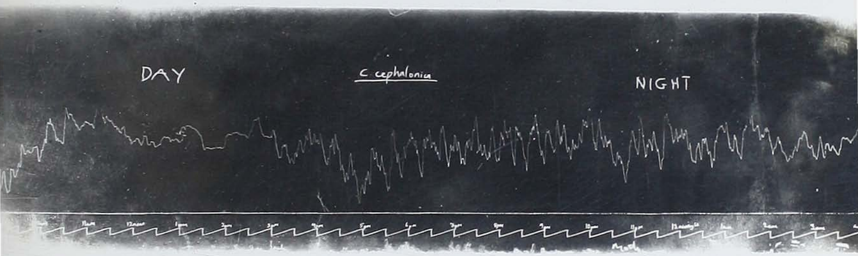


Fig. 28: Daily activity pattern of larvae of *C. cephalonica*, under 12 hours normal daylight and 12 hours normal darkness.

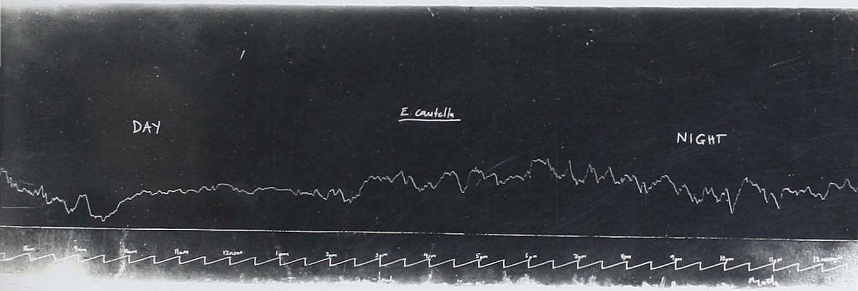


Fig. 29: Daily activity pattern of larvae of <u>E. cautella</u>, under 12 hours normal daylight and 12 hours normal darkness.

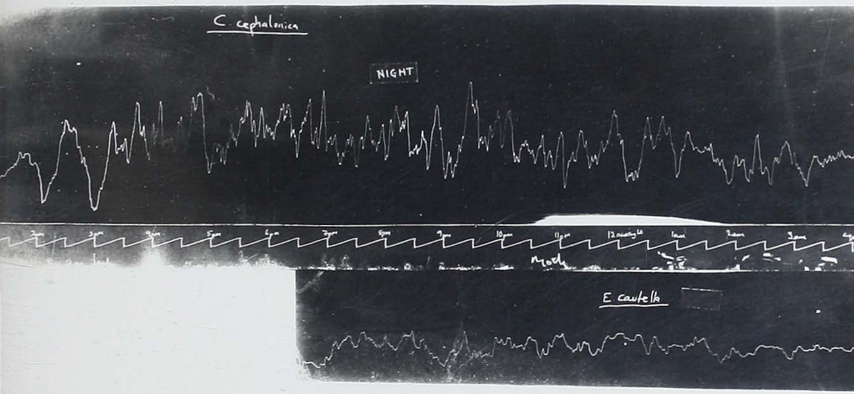


Fig. 30: Comparison of activity patterns (night) of C. cephalonica and E. cautella, under normal 12 hours daylight and 12 hours normal darkness.

4.9 Competition for Pupation Sites

In competing for pupation sites made of corrugated cardboard, tables 25 and 26 show that C. cephalonica always turnsout as the better competitor, occupying 80-90.9 percent of the pupation sites as compared to 9.1 - 20 percent for E. cautella. 6 and 11 pupation sites were competed for by 5 and 16 mature larvae of each species. The raw data are given in appendix tables 39-42.

Observations on the movement of the larvae of the two species prior to occupying pupation sites showed that the larvae tend to move around the bottom edge of the petridish and when they come into contact, larvae of the same species literally walked over each other. However, this is not often the case when it involves larvae of two different species. In the latter situation, E. cautella either retreats by fast backward movements or avoids C. cephalonica by moving towards the centre of the petridish (avoidance reaction). There were situations where there were actual biting of E. cautella by C. cephalonica and sometimes there were counter attacks by E. cautella. In a separate experiment in which different sizes (age groups) of E. cautella were introduced into the same petridish with mature larvae of C. cephalonica. It was found that the ability of E. cautella larvae to counter-attack and thus bite C. cephalonica depended, to some extent, on the size (age), that is young larvae of E. cautella almost always displayed avoidance reaction towards mature larvae of C. cephalonica. Similar observation was made on the reverse situation, that is young larvae of C. cephalonica avoided mature larvae of E. cautella.

As mentioned earlier, most of the pupation sites were occupied by C. cephalonica. It was observed that even when E. cautella was the first to occupy a pupation site, C. cephalonica always invariably replaced it; especially when the latter entered the already occupied site from the rear (each site had two openings). In cases where C. cephalonica attempted to enter a pupation site already occupied by E. cautella from the front, E. cautella defended the site by opening the jaws and sometimes biting the intruder. Thus it was not always easy for C. cephalonica to displace E. cautella from a pupation site (inter specific interaction). Similar observations were made when it involved larvae of the same species, i.e. either E. cautella or C. cephalonica (intra specific interaction).

Table 25:

Summary of results of competition between C. cephalonica and E. cautella for pupation sites (using corrugated cardboard with 6 pupation sites).

	PERCENT. SUCCESS (SITES)	
	E. cautella	C. cephalonica
Set 1	20.0	80.0
Set 2	20.0	80.0

Table 26:

Summary of results of competition between C. cephalonica and E. cautella for pupation sites (using corrugated cardboards with 11 pupation sites).

	PERCENT. SUCCESS (SITES)	
	E. cautella	C. cephalonica
Set 1	9.1	90.9
Set 2	9.1	90.9

4.10 Discussion

Although the primary concern of this study lies in the quantitative description of what happens when C. cephalonica and E. cautella are cultured as competing populations on standard medium and broken cocoa beans, it is impossible to discuss this phenomenon with cogency until there is a clear understanding as to how each species behaves when grown by itself in the absence of such competition. Thus the results compared the two competing species when alone (i.e. control condition CC, EC); one after the other (condition $C + \frac{E}{2}$, $E + \frac{C}{2}$) and when introduced together (condition CC/EC).

Many generalisations have been made on competition experiments with other stored product insects such that:

(1) One species or the other will always become extinct, given enough time;

(2) Under other sets of conditions the outcome of competition depends on the initial number of each species introduced in the culture;

(3) Under some sets of conditions one of the two species will become extinct;

(4) In some cases the outcome of competition is completely uncertain; one species or the other becomes extinct, with probabilities dependent on the environmental conditions and the initial number of the two species.

Most of the experiments fall into category 4. In the present case both C. cephalonica and E. cautella compete with each other continuously all through the life cycle from egg laying to the emergence of adult moths. Aspects of interference including competition for pupation sites (Fig. 11), mutual interruption of rhythmic behaviour patterns of larvae (Figs. 28, 29), oviposition preferences, egg mortality caused by mechanical interference of larvae (condition $C + \frac{E}{2}$, $E + \frac{C}{2}$), and competition for food materials in the larval stage. Consequently it is to be supposed that the process of extinction is very rapid and the end result is clear cut.

Tables 4, 5 show the percentage adult increase or decrease of generation two over generation one in limited amount of standard medium and broken cocoa beans. It can be seen that single species populations of C. cephalonica and E. cautella are better maintained on standard medium than on broken cocoa beans, the mean percentage increase for C. cephalonica being 1592.3 percent on standard medium and 1614.1 percent on broken cocoa beans. The mean percentage increase for E. cautella is 714.4 percent on broken cocoa beans and 1991.7 percent on standard medium. Thus it can be seen that a population of C. cephalonica does better in a medium of broken cocoa beans than E. cautella, the latter thriving well on standard medium. In abundance of standard medium and broken cocoa beans, the mean percentage adult increases were 1520.8 percent (standard medium) and 1598.55 percent (broken cocoa beans) for C. cephalonica. For E. cautella the figures were 966.3 percent (broken cocoa beans) and 2104.95 percent (standard medium) respectively. Except for the differences in numbers, the pattern displayed in abundance of food and space was similar to that in limited amount of food and space.

That E. cautella did better in standard medium than C. cephalonica, could be seen by further examination of table 6. The mean percentage increase of generation three (G3) over generation two (G2) is 491.8 percent for E. cautella and 249.1 percent for C. cephalonica. These latter results ($\frac{G3}{G2}$) as compared with the previous results ($\frac{G2}{G1}$) show that an equilibrium is gradually being approached by the two separate populations. The findings agree with those of other authors (Park, 1948; Istock, 1978; Escalante and Rabinovich, 1979) who found that control cultures (CC or EC) free of inter-species complications eventually assume characteristic "equilibria" that are sustained for relatively long periods of time in terms of generations. From the analysis of variance (see appendix tables 63-90), the F-test establishes that there is significant difference between the two generations (G2, G1) at 5 percent and 1 percent levels of probability.

Howe (1965) estimates that under optimum conditions of temperature (28-32°C) a population of C. cephalonica can multiply itself ten times per calendar month. This increase is very low by comparison with the estimated increase for E. cautella which is about fifty times per calendar month. Teotia and Singh (1975) noted that under conditions of abundance of space, the daily rate of increase of C. cephalonica was 1.131 which enabled this insect to multiply 2.35 times every week. However when this insect was reared in a limited space on the same food (coarsely crushed jowar (variety 8^B) and under the same conditions of temperature and relative humidity (26.5±1°C and 73±1 percent R.H.), the rate of growth in its population was considerably reduced.

In the foregoing pages attention has centred on populations of C. cephalonica and E. cautella reared apart (EC, CC) as intra-species systems, however the story is complicated, although not rendered insoluble by the presence of a competitor ($C + \frac{E}{2}$, $E + \frac{C}{2}$, EC/CC). The latter could modify the intraspecies relations in a way that would diverge markedly from those of control cultures (EC, CC) for example there may be actual behaviour co-actions between the two forms that inhibit one, inhibit both, or favour one and which undoubtedly would vary with the density and ecological age of the ecosystem. For example, such coactions could involve alteration of temperature, moisture content and oxygen concentration within the medium (microclimate)(Figs. 4, 8) from that obtaining in the control. According to Crombie (1945) differential conditioning of the medium might concern the reduction of available food, the elaboration of environmental poisons, such as excrement, carbon dioxide etc.

The outcome of mixed species populations of C. cephalonica and E. cautella when reared in limited and abundance of food and space (standard medium, broken cocoa beans) under conditions; $C+\frac{E}{2}$, $E+\frac{C}{2}$, C/E is shown in tables 4-7, while the raw data are given in appendix tables 3-24. The analysis of variance using the F-test (Appendix tables 63-90) shows that there are not only significant differences between the populations of C. cephalonica and E. cautella under these treatments (alone, one after the other, introduced together) but also that significant differences exist in the interaction between the populations of the two species in the two generations (G2, G1) and between replicates, populations and generations. The detailed differences are shown in tables 5-8 and 10-13. However, no significant difference was found between the replicates.

Careful examination of tables 4 and 5 show that in limited amount of food and space the mean percentage increase of $\frac{G2}{G1}$ for condition $E+\frac{C}{2}$ in standard medium is EC = 2737.0 percent, CC = 1759.7 percent and in broken cocoa beans; EC = 44.6 percent; CC = 1733.4 percent. Thus it can be seen from the percentages that even when E. cautella is established before C. cephalonica, the effects of the interspecific interaction on the population growth becomes clear in the second generation, especially on broken cocoa beans, where there was great reduction in the population of E. cautella (EC = 44.6 percent CC = 1733.4 percent). The percentage reduction in population of E. cautella under condition $C+\frac{E}{2}$ becomes more explicit in both standard medium and broken cocoa beans. Under condition CC/EC, E. cautella was virtually extinct; CC = 2422.6 percent, EC = 3.5 percent for standard medium; and CC = 2827.8 percent, Ec = 0 percent on broken cocoa beans. Thus from the above findings it can be said that in a limited amount of food and space, C. cephalonica almost always comes out as the better competitor (conditions $C+\frac{E}{2}$, CC/EC), and seems to be doing well even under condition $E+\frac{C}{2}$ (EC = 2737.0 percent, CC = 1759.7 percent) in standard medium. However under condition $E+\frac{C}{2}$ in broken cocoa beans, C. cephalonica clearly outcompetes E. cautella (CC = 1733.4 percent, EC = 44.6 percent). The results of competition in abundance of food and space are shown in tables 6 and 7. Critical examination of table 6 shows that in standard medium even though E. cautella appears to be doing well under condition E $\frac{C}{2}$ for $\frac{G2}{G1}$ (EC = 3376.1 percent, CC = 2095.5 percent), C. cephalonica outcompetes it in the third generation $(\frac{G3}{G2})$ (CC = 163.5 percent, EC = 36.1 percent). In broken cocoa beans, C. cephalonica again is the superior competitor under all the three conditions ($C+\frac{E}{2}$, $E+\frac{C}{2}$, CC/EC) in the second generation.

Factors which operate in this mixed species population ecosystem of C. cephalonica and E. cautella can be specified, according to Park (1954), under three general categories: - physical environment, population processes and survival responses as follows:

1. Physical environment
   - A. Temperature
   - B. Humidity
   - C. Interaction of temperature with humidity
   - D. Habitat: food and space as renewed each 32days.

2. Population process
   - A. Cannibalism
   - B. Density-related "behaviours"
   - C. Conditioning of the medium

3. Survival responses
   - A. Egg fecundity
   - B. Egg fertility
   - C. Rate and mortality of larval-pupal development.
   - D. Adult mortality.

The factors listed under "physical environment" are self explanatory, however the "population process" are those activities that emerged from the population's own activity. They achieve causal significance when they influence group survival in one direction or another. Thus egg-cannibalism by large larvae is, under conditions of high population density an extremely powerful source of mortality. It is complex because the egg-numbers are in continual state of flux, simultaneously increased by oviposition and decreased by cannibalism and thus very little information can be obtained about the involved rates of egg survivorship from data of standing crop of eggs. Ciesielska (1975) described studies on the effect of inter-specific interactions on the course of egg laying under conditions of a free choice of the site of egg laying, and of the impact of these interactions on the population size at early stages of its growth.

Intensive investigation on competition (Park, 1954; Frank, 1957; Huffaker, 1958; Park, 1962) emphasises that laboratory model itself presents complexities not inherent in Volterras' theory (1926) which for example, implies logistic growth for single species populations. That extinction of one of two competing species invariably resulted, has been pointed out (Cole, 1960; Debach and Sundby, 1963; Nathanson, 1975 ; Blakley and Dingle, 1978; Laraichi, 1978; and Escalante and Rabinovich, 1979).

Thus the major ecological findings on the above discussion is that when C. cephalonica and E. cautella are brought into competition, E. cautella invariably becomes extinct, with C. cephalonica assuming a role of population regulator. According to these authors (Park, 1948; Pontin, 1961; Debach, 1966; Ayala, 1970 and Pianka, 1974), in the face of such stringent competition it becomes impossible for both species to co-exist even though individually they are well adapted to their habitat and its surrounding physical environment. Fig. 20 shows comparative sizes of larvae of C. cephalonica and E. cautella in competitive situation in experimental jars. Larval competition in C. cephalonica and E. cautella is probably for enough food to reach sufficient size to pupate and then emerge as an adult. Hagvar (1972) for example, found that survival of larvae in Syrphus corollae was significantly smaller when mixed with S. ribesii than under intraspecific conditions (25.0 percent and 73.1 percent respectively). The results are explained by the different sizes, natural food demands, feeding efficiencies and predatory tendencies of the two species. Gilpin (1974) noted that the mechanism of larval competition is not simple exploitation, but must also involve some component of interference. Pianka (1974) defined interference competition as competition by direct interaction, such as aggressive encounters between competitors; and exploitation competition as the more indirect inhibitory effects, such as those arising from reduced availability of common resource. Aggressive behaviour in the larvae of C. cephalonica and E. cautella was seen in competition for pupation sites using corrugated cardboards (Fig. 11). It was found that 80 - 90 percent of the pupation sites were occupied by _C. cephalonica_ while _E. cautella_ occupied 9.1 - 20 percent of the pupation site (Table 26, 26). Aggressive behaviour in the larvae of other stored product insects has been described, (for example, Umeya _et al_., 1975).

In a competitive situation where various degrees of crowding obtain (Rafes _et al_., 1979) not only will fecundity be affected but competition for pupation sites. In the present investigation almost all the mature larvae pupated near the surface of the food medium. One clear result of competitive interactions of the two species when food is limiting is a dramatic decrease in adult size. Adults of _C. cephalonica_ and _E. cautella_ may compete for egg-laying space in crowded cultures, or the larvae may reduce the quality of the medium for nutrition and as an oviposition site. Thus the discrete stages of the life cycle probably interact in interspecies competition for two somewhat different resources. If the interactions were sufficiently balanced in magnitude and timing, it would be possible to maintain a two species population through time but not an equilibrium population.

Table 23 shows that a species difference in fecundity exists in a highly favourable environment. For example, _E. cautella_ has a mean fecundity per female of 164.5, when 200 adults were reared on 200 grams of standard medium. Mean fecundity was lowered in both E. cautella and C. cephalonica when a large number of adults (population effect) were reared on small amount of standard medium. For example in C. cephalonica (Table 14), mean fecundity was lowered to 88.1 per female when 100 adults were reared in 200 grams of standard medium, while in E. cautella, it was lowered to 108.3 when 200 adults were reared on 200 grams of standard medium.

Table 22 shows that the percentage egg-hatchability of E. cautella (94.4 percent) was greater than that of C. cephalonica (85.6 percent). The results of egg-hatchability are in close agreement with those obtained by Rawnsley (1968) for E. cautella (98 percent) under similar conditions. Carmona (1958) and Kamel and Hassanein (1967) studied percentage hatch of C. cephalonica under various conditions of relative humidity and temperature (20 - 31, 24 - 32°C, 57 - 63 percent and 20 - 80 percent R.H.) and concluded that the larvae of the parental generation is an important factor as 78 percent of the egg laid by adults reared on either decorticated groundnuts or wheat hatched compared with only 42 percent when adults were reared on a mixture of wheat and flour. Thus in a competitive situation high percentage-hatchability may be advantageous because of egg-cannibalism.

Results (Figs. 28, 29) show that daily activity patterns of the larvae of C. cephalonica and E. cautella overlap. This means increase in interaction between the two species in competitive situation. Such interaction may lead to competitive exclusion, the principle of which states that two species of the same ecological niche cannot co-exist together or that because of the variability of nature, two species by the very fact of being different cannot have the same niche.

From the discussion so far, it seems clearly established that competition between C. cephalonica and E. cautella always ensues when they are brought together as components of the same ecosystem. This may be expected on the basis of their ecology. They have similar life histories, inhabit the same food medium, have same behavioural mechanism, have similar daily activity patterns (larvae), but slight differences in egg-hatchability (94.4 percent for E. cautella and 85.6 percent for C. cephalonica) and fecundity (164.5 for E. cautella and 138.9 percent for C. cephalonica). C. cephalonica larvae are slightly larger (Fig. 20) than those of E. cautella. Considering the above facts, it seems that the results of the competition between C. cephalonica and E. cautella can be explained to a large extent on the different sizes of the larvae (C. cephalonica larger than E. cautella) and the more aggressive behaviour of the larvae of C. cephalonica (see competition for pupation sites). On broken cocoa beans, both C. cephalonica and E. cautella have same developmental period of 41 days (see appendix tables 14-24) as compared to standard medium (23 days for E. cautella, 30 days for C. cephalonica; see appendix tables 3-13), hence the severity of the competition (CC/EC) on broken cocoa beans. For example, E. cautella becomes extinct (0 percent) in the second generation (table 5). Also in competitive situation between C. cephalonica and E. cautella for oviposition preferences, when given the choice of three food commodities (standard medium, broken cocoa beans, and shelled groundnut), C. cephalonica tends to prefer broken cocoa beans, while E. cautella tends to prefer standard medium (see table 16). On recent observation by Aryeetey (personal communication) that C. cephalonica has taken over E. cautella on as the more important pest of cocoa in storage sheds in Ghana, the results of the present investigation attempts to explain the reason behind this observation.

Field observation (Cocoa warehouses at Tema Habour) during the duration of this investigation revealed unsustained increase in the population of the larvae of the two moth species in the stacks of cocoa beans awaiting fumigation. This situation is apparently due to heavy infestation. The population of the insects has exploded as a result of inadequate control measures, which can be traced back to the regional depots. This certainly has caused the down-grading of the cocoa beans and consequent great economic loss to Ghana. Recently an attempt at long-term storage of cocoa beans in concrete silos was conducted at the Cocoa Products Factory (GCMB) Tema (Vander-puye and Awuah, 1974), to ascertain:

1. How long cocoa beans can be stored in silos in the humid tropics without any deterioration in quality, and
2. What problems may arise during storage and how these problems can be solved.

According to the authors these problems could be kept under control by observing the following rules among others:

1. Keeping insects (C. cephalonica, E. cautella etc.) out of storage area
2. Fumigation, as soon as any infestation by insect is detected, and
3. Care taken not to fumigate cocoa beans and storage areas too often as this will lead to an increase in chemical residue in the cocoa beans from the fumigant.

Thus it is important that our storage problems are considered vis à vis insect control measures. In the current reported experiments, laboratory observations show that insects' (C. cephalonica and E. cautella) emergence starts as early as 5.30 p.m. with peak emergence around 7.00 p.m. However, field observation on the control of these insects show that not only is warehouse hygiene not being strictly adhered to but also the times of fogging (spraying with pyrethrins) starts around 3.30 p.m. In the light of present findings, the time of fogging should be changed to around 4.30 - 5.30. That C. cephalonica is more destructive than

E. cautella can be seen by examination of Figures 21 - 27, taken from the experiments on oviposition preferences.

4.11 Conclusion

Considering the range of conditions (CC, EC, $C + \frac{C}{2}$, $E + \frac{E}{2}$, CC/EC) employed in the current experiments and the clear cut results obtained in these various situations, the major conclusion emerging are:

1. that both species of moth (C. cephalonica and E. cautella) cannot live together for any extended period, and
2. that in competition E. cautella becomes extinct, with C. cephalonica remaining as the successful species.

The last event happens much more frequently than would be expected on the hypothesis that it is a matter of equal chance as to which species survives. From the view point of the current work the practical importance of controlling these pests, especially C. cephalonica (now the most important of the pests of stored cocoa beans) lies on the recommendation that the present time of fogging in our cocoa warehouses be changed from 3.30 p.m. to around 4.30 - 5.30 p.m. In cocoa exporting countries such as Ghana, where increasing significance is being placed on stored-cocoa beans, insect control by fumigation and fogging, such an important information cannot be overlooked. Also the results of the present investigation offers an explanation to the recent observation by Aryeetey (personal communication) that C. cephalonica is rapidly becoming the most important pest of stored cocoa beans. Finally it could be stated that C. cephalonica poses a real danger to our food storage (cocoa, groundnut etc.) industries. Its destructive nature causes in cases of heavy infestation, tight matting together of food material with webbing, larval galleries, cocoons, frass and excreta.

Chapter 5

Results of Radiosensitivity Studies

RESULTS OF RADIOSENSITIVITY STUDIES

5.1 Irradiated Eggs

Tables 27, 28, 29, give the percentage hatch for eggs treated with gamma radiation at each of the 3 ages. From tables and Figs. 31 and 32, it can be seen clearly that the percentage hatch was inversely correlated with the dose received and positively correlated with the age of the eggs. However, a critical examination of tables 27 and 28, do not show much difference in radiation effect between 1-day-old and 2-day-old eggs, as compared to 3-day-old eggs (table 29) which were more radioresistant. The tables and figures mentioned earlier show that a dose as low as 5 krad could reduce hatchability to less than 7.5 percent in 1-day-old and 2-day-old eggs, and to less than 39.5 percent in 3-day-old eggs; while a larger dose, 25 krad virtually reduced hatchability to less than 1.6 percent in 2-day-old and 3-day-old eggs and effecting 100 percent reduction in hatchability in 1-day-old eggs. The raw data are given in appendix tables 43-49.

Observation shows that many 3-day-old eggs were embryonated (ie. showing embryonic development though unhatched) after treatment with 5 krad. [illegible] Radiosensitivity of insects depends on the developmental stage, tissue, cell and chromosome type.

Table 27:

Percentage hatch of 1-day-old eggs when exposed to gamma radiation.

		0 KRAD	5 KRAD	10 KRAD	20 KRAD	25 KRAD	30 KRAD	40 KRAD	50 KRAD	100 KRAD
Set 1	Percent Hatch	82.4	7.2	2.4	2.4	0	1.6	1.6	3.2	0
Set 2	Percent Hatch	80.0	6.4	1.6	1.6	0	0.008	0.008	0	0

Table 28:

Percentage hatch of 2-day-old eggs when exposed to gamma radiation

		0 KRAD	5 KRAD	10 KRAD	20 KRAD	25 KRAD	30 KRAD	40 KRAD	50 KRAD	100 KRAD
Set 1	Percent Hatch	78.4	5.6	8.0	4.0	0.008	0.008	0.008	0.008	0.008
Set 2	Percent Hatch	72.8	7.2	4.0	2.4	1.6	0	0.008	0	0

Table 29:

Percentage hatch of 3-day-old eggs when exposed to gamma radiation

		0 KRAD	5 KRAD	10 KRAD	20 KRAD	25 KRAD	30 KRAD	40 KRAD	50 KRAD	100 KRAD
Set 1	Percent Hatch	82.4	34.4	20.0	6.4	1.6	0.008	0	0.008	0
Set 2	Percent Hatch	80.8	39.2	24.8	13.6	0.008	0	0	0.008	0

FIG. 31 PERCENTAGE HATCH OF 1-DAY OLD, 2-DAY OLD AND 3-DAY OLD EGGS OF *C. CEPHALONICA* EXPOSED TO GAMMA RADIATION (SET 1)

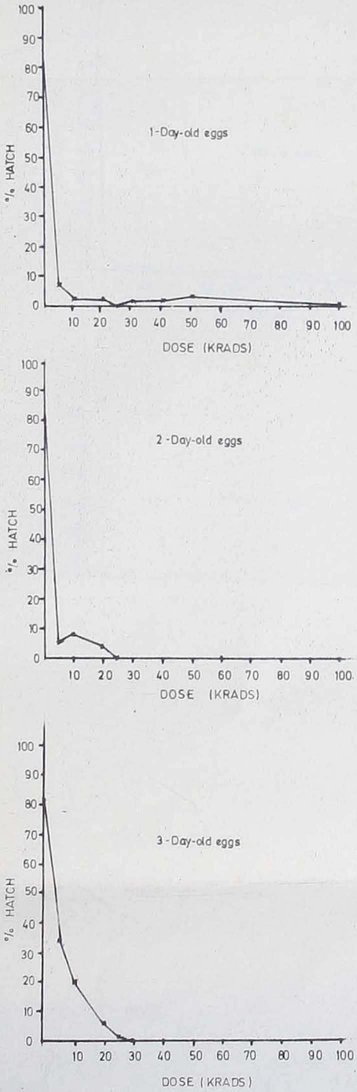
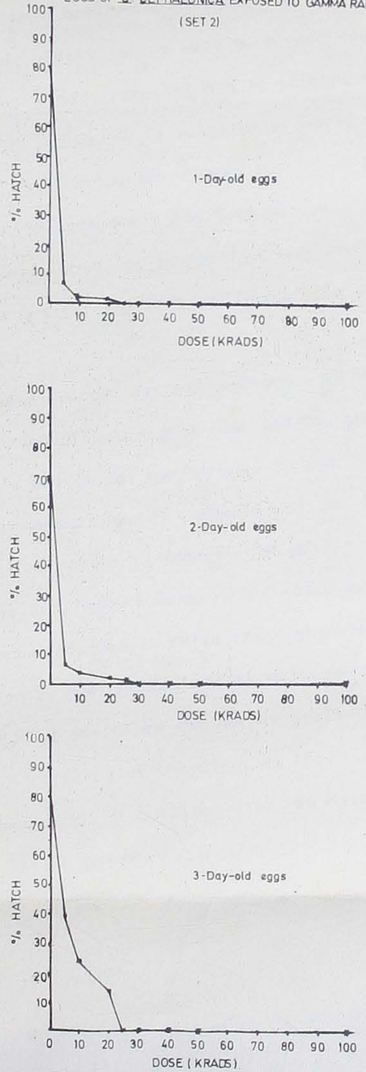


FIG 32: PERCENTAGE HATCH OF 1-DAY OLD, 2-DAY OLD AND 3-DAY OLD EGGS OF *C. CEPHALONICA* EXPOSED TO GAMMA RADIATION (SET 2)



5.2 Irradiated Larvae

The percentages of adult emergence and sex-ratio when early and late larvae were treated with gamma radiation are shown in tables 30 and 31. Early larvae were much more radiosensitive than late larvae. At 5 krad, about 50 and 70 percent of the larvae emerged as adults following irradiation of early and late larvae. After exposure to 25 krad, there were less than 10 and 20 percent adult emergence in both early and late larvae. The pattern of adult emergence in both age groups is shown in Figs. 33 and 34. In general the greater the dose the lesser the percentage of adult emergence.

Observations show that the sex-ratio of adults from the irradiated larvae of both age groups did not show a clear picture in favour of a particular sex (tables 30 and 31); adults inspected for radiation damages appear unchanged at the lower dose of 5 krad as compared to controls (5 krad). The mating behaviour of the emerged males and females were not affected by the irradiation, since females continued to raise their abdominal tips, suggesting communication by pheromones, whilst males were not only attracted and aroused, but performed the normal preliminary dances of rapid moving and fluttering of the wings as they move around the female prior to successful copulation. The raw data for the experiment are given in the appendices (tables 50-53).

Table 30:

Percentage adult emergence and sex ratio when early larvae (5 days after hatching) were exposed to gamma radiation.

		0 KRAD	5 KRAD	10 KRAD	20 KRAD	25 KRAD	30 KRAD	40 KRAD	50 KRAD	100 KRAD
Set 1	Percent Emer-gence	80.8	53.6	47.2	11.2	8.8	9.6	8.0	6.4	5.6
	Sex Ratio ♂:♀	1:1.1	1:1.5	1:3.2	1:1.8	1:8.1	1:7.1	1:7.1	1:1.6	1:1.3
Set 2	Percent Emer-gence	84.4	52.0	45.6	10.4	9.6	8.0	6.4	5.6	3.2
	Sex Ratio ♂:♀	1:1.2	1:1.7	1:1.5	1:1.6	2:1	2:3.1	1:1	1:3.1	3:1

Table 31:

Percentage adult emergence and sex ratio when late larvae (5 days before pupation) were exposed to gamma radiation.

		0 KRAD	5 KRAD	10 KRAD	20 KRAD	25 KRAD	30 KRAD	40 KRAD	50 KRAD	L00 KRAD
Set 1	Percent Emer-gence	83.2	71.2	28.0	18.4	18.4	12.8	11.2	6.4	8.0
	Sex Ratio ♂:♀	1:1.1	1:4.1	1:1.1	1:1.1	1:1.6	1:1.3	1:3.1	1:7	1:1.7
Set 2	Percent Emer-gence	85.6	72.8	24.8	20.0	17.6	12.0	10.4	8.0	5.6
	Sex Ratio ♂:♀	1:1.1	1:2.1	1:2.1	1:2.1	1:1.2	1:1.1	1:1	1:1.3	1:2.5

FIG. 33: PERCENTAGE OF ADULT EMERGENCE WITH DOSE WHEN EARLY LARVAE, LATE LARVAE AND 4-DAY OLD PUPAE OF C. CEPHALONICA WERE TREATED WITH GAMMA RADIATION (SET 1)

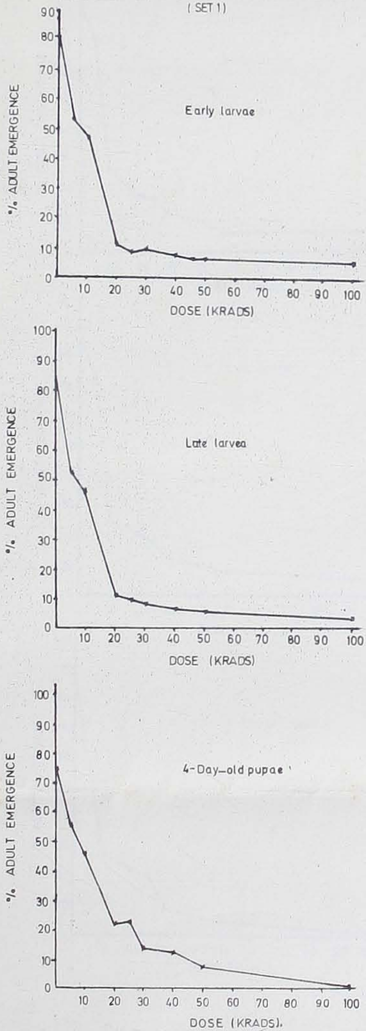
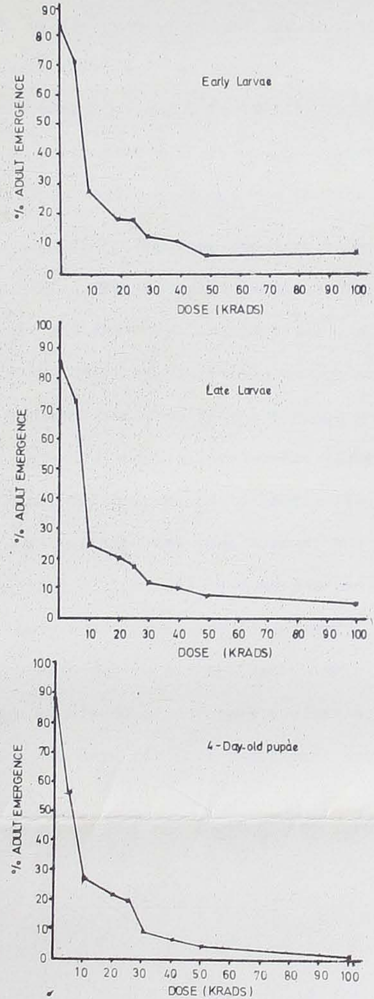


FIG. 34: PERCENTAGE OF ADULT EMERGENCE WITH DOSE WHEN EARLY LATE LARVAE AND 4 DAY OLD PUPAE OF C. CEPHALONICA WERE TREATED WITH GAMMA RADIATION (SET 2)



5.3 Irradiated Pupae

The percentage of eclosion of irradiated 4-day-old pupae decreased as the dose increased (table 32); this pattern of adult emergence after irradiation is shown in Figs. 33 and 34. Few adults emerged from pupae treated with 30, 40, 50 or 100 krads. No consistent difference was observed between the sexes (sex-ratio) in adult emergence due to irradiation.

Observations show that the life span of adult moths emerged from irradiated developmental stage decreased with increase in dose levels and that exposure of 4-day-old pupae to 50 and 100 krads did not only reduce the percentage moth emergence significantly, but also resulted in the emerged moths having deformed wings or extended abdominal segments. Other emerged adults which appear normal (wing-wise) could hardly fly out even when the lid of the rearing glass jars were opened; and when disturbed with a thin glass rod, they only showed delayed avoidance reaction by moving slowly away. Note not flying away. There were some adults with deformed wings in all the doses administered, with the percentage magnitude of deformed adults increasing with increased dose. The raw data for this experiment are shown in appendix tables 53-55.

Table 32

Percentage adult emergence and sex ratio when 4-day-old pupae were exposed to gamma radiation.

		0 KRAD	5 KRAD	10 KRAD	20 KRAD	25 KRAD	30 KRAD	40 KRAD	50 KRAD	100 KRAD
Set 1	Percent Emergence	73.6	54.4	34.8	20.8	21.6	12.0	11.2	6.4	0.008
	Sex Ratio ♂:♀	2:1.1	2:2.1	4:1	2:7.1	4:1	2:8.1	2:5.1	7:1	1:0
Set 2	Percent Emergence	87.2	56.8	27.2	21.6	20.0	9.6	7.2	4.8	1.6
	Sex Ratio ♂:♀	1:1.1	1:3.1	1:3.1	1:7.1	2:6.1	2:1	1:1.3	2:1	2:0

5.4 Discussion

The results from this study on the radiosentivity of C. cephalonica confirm previous findings by other authors, namely that radiosensitivity affects different developmental stages in such a way that mortality increases with increased dose. For example Srisan Loaharanu et al. (1972) treated the eggs, pupae and adults of C. cephalonica with gamma irradiation; they exposed - 1-3 days old eggs of the rice moth to 0, 3, 6, 12.5 and 25 krads, and estimated the LD_{50} and LD_{99} for eggs as 9 and 42 krads respectively. A dose of 25 krads caused 100 percent mortality in larvae irradiated at egg stage. Abdu and Elsawaf (1974), irradiated eggs, larvae, pupae and 24 hours old adults of C. cephalonica with gamma radiation (2-8 krads) and found that the life span of adult moths emerged from irradiated developmental stage decreased with dose levels and that the life span of adults emerged from irradiated eggs were shorter than with adults that emerged from other developmental stages.

The data (tables 27, 28) on C. cephalonica show that a dose of 5 krad led to a decrease in hatchability on the average of about 6.6 percent for 1 and 2 day-old eggs and 36.8 percent for 3 day-old eggs as compared to control (0 krad) 80 percent, while a larger dose of 25 krad did not only reduce hatchability to less than 1.6 percent in 2 and 3 day-old eggs but caused 100 percent reduction in 1 day-old eggs. The high radiosensitivity of newly laid eggs (1 day-old) might be ascribed to the inhibition of mitosis (Ahmed et al., 1973). Ahmed et al. (1973) found that gamma irradiation of 6 and 10 krad resulted in 100 percent death of 0-6 and 18-24 hour old E. cautella eggs. Gonen and Fishbain (1973) found that egg hatch in 0-24hours old and 48-72 hours old eggs of E. cautella were not significantly influenced over an irradiation range of 0-15 krad and that only higher doses than these caused a significant decrease in egg hatch. They also found that between doses of 15 and 30 krad only about 1 percent of the irradiated eggs developed to the adult stage, and with 35 krad, no adults were obtained. Ahmed et al., (1973), on differential radiosensitivity of Ephestia and Oryzaeplulus eggs, found that old eggs (48-60 hour old) appeared to be more resistant to somewhat high dose of gamma radiation (15 krad) while 0-12 hour old eggs were killed by a lower dose.

From the foregoing discussion, a somewhat similar outcome of C. cephalonica eggs has also been observed in E. cautella; when early and late larvae of C. cephalonica were irradiated (tables 30, 31) 50 and 70 percent emerged as adults; at 25 krads, emergence was as low as 10 and 20 percent for both age groups respectively. Thus the age of the larvae at the time of irradiation significantly affected adult emergence. Ahmed et al. (1971) found that late instar larvae of E. cautella were more resistant to radiation and that higher doses were required to inhibit pupation and adult emergence.

Susceptibility of gamma irradiation at all levels of treatment was noted with 4-day-old pupae of C. cephalonica, where emergence was on an average 55.6 percent, 20.8 percent, 5.6 percent and 0.8 percent at 5, 50 and 100 krads (table 31) showing correlation between dosage and emergence. Other authors such as Ouye et al., (1964) on the pink bollworm, Pectinophora gossipiella (Saunders), Cogburn et al. (1966) and Qureshi et al.)(1968) on the Angoumois grain moth, Sitotroga cerealella (Olivier) and the Indian meal moth Plodia interpunctella (Hubner), and Amoako-Atta and Partida (1976) on E. cautella found that age of pupae when treated and sensitivity correlate negatively.

Most of the emerged adults from both larvae and pupae in the present study were affected to various degrees by gamma irradiation. With the larvae, adults emerging from 5 krad irradiation remained unchanged at least morphologically, however with the increase in dosage for both larvae and pupae, defects and deformities can appear during morphogenesis. For example, abnormal wings, legs and extended abdominal appendages were noticed in the present investigation. Other somatic deffects which were observed consisted of depressed flying ability, locomotory activity and changed feeding behaviour.

The results (Figs. 30, 31, 32) points to 25 krad as the dosage to effect the necessary radiation disinfestation in C. cephalonica, since not only was emergence less than 21 percent in all the developmental stages (eggs, larvae and pupae) but also radiation damages were noted. These results are in line with the minimum legally allowable dose (20-25) krad for the control of all stored product insects according to the U.S. Food and Drug Administration (Anonymous 1968).

For practical purposes of irradiating storage pests it would be preferable if low doses of radiation were used. Radiation is known to induce long-lived free radicals in grain and the toxicity, carcinogenicity and mutagenecity of the free radical have not yet been adequately evaluated. Since lower doses give fewer free radicals, the lowest possible doses should be used to eliminate the storage pest. For this reason sterilising doses rather than insecticidal doses should be selected. Sterilising doses generally are by far lower than insecticidal doses. Minimum sterilising doses may be in the range of 20 krad or higher.

Field observations show that C. cephalonica generally pupates along the outer layer of cocoa bags, but probably a few larvae pupate inside the stacked bags as noted by Rawnsley (1958, 59) for E. cautella. It should be possible in the next few years to set up a large irradiation unit to de-infest our stacks of cocoa beans awaiting exportation; just like the experimental grain irradiation unit set up by the USDA at Savannah, Georgia. However, it must be stressed that this method will be economical only on a commercial scale, because of the high cost of radiation equipment. On the other hand, time gained (since irradiation will be for a few minutes), the residue free approach, subsequent escape from the danger of tainting the flavour of our cocoa beans with insecticides (remember danger from insecticide resistance) and finally but not the least the long term storage advantage from this method makes irradiation an attractive method of pest control.

Inspite of the merits of direct food irradiation, as discussed above, with the aim of direct killing or sterilisation of the resident pest population, attention should be given to the sterile male technique. This technique which is species-specific comprises the releases of large number of steilised insects of a species into a pest population. However one of the disadvantages is the case where released adults also feed on the stored product. Pupal irradiation of C. cephalonica (now the most important cocoa pest) might prove to be more advantageous from the stand point of sterile-insect male technique provided that successful competitive males could be provided. The sterile-male technique has been proposed as a residue free method of controlling lepidopterous pests of stored food commodities (Bull and Wond, 1963; Amuh, 1971; Ahmed et al., 1972; Ashrafi et al., 1972; Brower and Tilton, 1975; etc.).

5.5 Conclusion

In conclusion the relationship between developmental stage (eggs larvae, pupae) and radiosensitivity is very important in respect to the application of radiation for insect control. It has been demonstrated that radiosensitivity will rapidly decrease during insect development from embryo to adult. This is due to restricted period of mitotic activity in the different stages, cell division and differentiation mainly occur during embryonic development and during brief periods just before moulting, in later pupal stages and in gonads of the adult. 25 krads was found to be the most likely dose for radiation disinfestation of C. cephalonica. But refined studies of each particular stage at different ages should be carried out in order to find correct recommended dose for disinfestation purposes.

Chapter 6

Summary

SUMMARY

1. Competition between *Corcyra cephalonica* and *Ephestia cautella* and radiosensitivity of the immature stages of *C. cephalonica* was studied.

2. Preliminary rearing studies showed that there were significant differences in developmental periods of *C. cephalonica* and *E. cautella* under similar ambient conditions (25.5 - 30 1°C, 75.5 - 89 percent R.H.) in two locations (Legon and Kwabenya).

3. Competition was studied under the following conditions: alone (CC, EC, i.e. control), one before the other ($E + \frac{C}{2}$, $C + \frac{E}{2}$) and when introduced together (CC/EC).

4. Populations of *C. cephalonica* and *E. cautella* thrive well under control condition (CC, EC) both in limited and abundance of food. However *E. cautella* is well maintained in standard medium than on broken cocoa beans, while *C. cephalonica* appeared to be doing well in both cases.

5. *C. cephalonica* came out as the better competitor under conditions ($C + \frac{E}{2}$, CC/EC) in limited amount of standard medium over two generations and seemed to be doing equally well under condition ($E + \frac{C}{2}$).

6. Competition in limited amount of broken cocoa beans showed that *C. cephalonica* is the best competitor under all conditions ($E + \frac{C}{2}$, $E + \frac{C}{2}$, CC/EC), *E. cautella* was virtually extinct (0 percent) under condition CC/EC in the second generation.

7. Competition in abundance of food and space, point to *C. cephalonica* as the best competitor in both standard medium and broken cocoa beans. This was clearly seen in the third generation under all conditions ($C+\frac{E}{2}$, $E+\frac{C}{2}$, CC/EC).

8. Oviposition preferences by the two species when given the choice of ovipositing freely in standard medium, broken cocoa beans and groundnut is as follows (in order of preference):

Condition CC/EC

E. cautella: (standard medium > groundnut > broken cocoa beans).

C. cephalonica: (broken cocoa beans > groundnut > standard medium).

Condition CC, EC

E. cautella: (standard medium > broken cocoa beans > groundnut).

C. cephalonica: (standard medium > broken cocoa beans > groundnut).

9. Much more damage is caused by *C. cephalonica* than *E. cautella* on the food commodities : broken cocoa beans, standard medium and groundnut. This explains the rapid establishment of *C. cephalonica* on cocoa beans in Ghana.

10. Egg-hatchability studies of 650 eggs of each species gave the following percentages:

E. cautella 94.4 percent

C. cephalonica 85.6 percent

11. Fecundity was greater in *E. cautella* (164.5 percent) than *C. cephalonica* (138.9 percent).

12. Daily activity patterns of the larvae of *C. cephalonica* and *E. cautella* overlap, showing peak activities after 3.00 p.m.

13. The time of adult emergence (*C. cephalonica* and *E. cautella*) under laboratory conditions start as early as 5.30 p.m. with peak emergence around 7.00 p.m. This necessitates change in the present time (3.30 p.m.) of fogging (spraying with pyrethrins) in our warehouses to around 4.30 - 5.30 p.m., for the control of these pests.

14. In competing for pupation sites made of corrugated folds of cardboards, *C. cephalonica* turns out to be the best competitor occupying 80 - 90.9 percent of pupation sites as compared to 9.1 - 20 percent of *E. cautella*.

15. Radiosensitivity of eggs (1 day-old, 2 day-old and 3 day-old), larvae (early and late larvae), and 4 day-old pupae was found to increase with increased dose.

16. For irradiation disinfestation purposes, a maximum dose of 25 krad was found sufficient to control all developmental stages of *C. cephalonica*.

Chapter 7

Literature Cited

LITERATURE CITED

1. Abdu, R.M. and El-sawaf, B.M. (1974). Lifespan of adult rice moth Corcyra cephalonica (staint.) emerged from different irradiated stages IAEA Information circular on radiation techniques and their application to insect pests No.17.

2. Ahmed, M.S.H. Ouda, N.A., Lamooza, S.B., Al-Hakkak, Z.S. and Al-Saqur, A.M. (1971). Disinfestation of dry dates by gamma radiation IAEA Information circular on radiation techniques and their application to insect pests No.13.

3. Ahmed, M.S.H., Z.S. Al-Hakkak, and A.M. Al-Saqur (1972). Inherited sterility in the figmoth, Cadra (Ephestia) cautella Walker. Pages 383-9 in Peaceful uses of Atomic Emergy (4th Int. Conf. Geneva, 1971). IAEA, Vienna.

4. Ahmed, M.S.H., N.A. Ouda, S.B. Lamooza, and Z.A. Al Hasany (1973). Differential radiosensitivity of some developmental stages of stored-date insects IAEA Information circular on radiation techniques and their application to insect pests No.15.

5. Ahmed, M.S.H., Zuhair, S. Al-Hakkak and Alhan M. Al-Saqur (1973). Effect of different doses of gamma radiation on Ephestia cautella eggs. IAEA Information circular

on radiation techniques and their application to insect pests. No.16.

6. Amoako-Atta, B. and Partida, G.J. (1976). Sensitivity of almond moth pupae to gamma radiation (Lepidoptera: pyralidae). Journal of the kansas Entomological Society 49: 133-140.

7. Amuh, I.K.A. (1971). Potentialities for application of the sterile-male technique to the control of the acocoa moth, Candra cautella Walker, pages 7-11 in Application of Induced sterility for control of Lepidopterous populations (Proc. Panel Vienna, 1970 IAEA, Vienna.

8. Anonymous, (1968). Low-dose gamma radiation for the treatment of food. Fed. Regist., Title 21, Subpart G., p.2 section 121: 3003, 1967.

9. Ashrafi, S.H., E.W. Tilton, and J.H. Brower, (1972). Inheritance of radiation-induced partial sterility in the Indian meal moth. J. Econ. Entomol. 65: 1265-8.

10. Ayala, F.J. (1970). Competition, co-existence and evolution In M.K. Hecht and W.C. Steere (eds). Essays in evolution and genetics. Appleton-century-crofts, New York, pp.121-158.

11. Ayyar, P.N.K. (1934). A very destructive pest of stored products in South India, Corcyra cephalonica Stainton Bull. Ent. Res., 25: 155-169.

12. Blakley, RN.R., Dingle, H. (1978). Competition: butterflies eliminate milkweed bugs from a carribean Island. Oecologia, 37 (1): 133-136.

13. Boles, H.P., and Marzke, F.O. (1966). Lepidoptera infesting stored products, p. 259-70. In C.H. Smith (ed.). Insect colonization and Mass Production, Academic Press, N.Y., 618 pp.

14. Brower, J.H., and E.W. Tilton (1975). Potential for control of Cadra cautella (Walker) by release of fully or partially sterile males. Int. J. Appl. Radiat. Iset. 26: 720-5.

15. Bull, J.O., and T. Wond (1963). Control of the Mediterranean flour moth, Anagasta kuehniella Zell, by gamma radiation. U.K. At. Energy Auth. Rep. AERE-R 3967:42.

16. Carmona, M.M. (1958). A entomofauna dos produtos armazenados Corcyra cephalonica (Stainton). Estudos, Ensaios e Documentos. Jta. Invest. Ultramar nos. 55, 127pp.

17. Calderon, M. and Gonen, M. (1971). Effects of gamma radiation on Ephestia cautella (Wlk.). (Lepidoptera: Phycitidae) 1. Effects on adults. J. stored Prod. Res. 7: 85-90.

18. Chand, A.T., Sehgal, S.S. (1978). Sensitivity of Corcyra cephalonica eggs related to their age. Entomon. 3(1): 7-9.

19. Ciesielska, Z. (1975). Studies of interspecific competition at early growth stages of a population of granary beetles Oryzaephilus usurinamensis L. (Silvanidae) Sitophilus granarius L. (Curculionidae) and Rhizopertha dominica F. (Bostrychidae) (Col.). Ekol. Pol. 23 (1): 163-183.

20. Cogburn, R.R., E.W. Tilton, and W.E. Burkholder, (1966). Gross effects of radiation on the Indian-meal moth and the Angoumois grain moth. J. Econ. Entomol. 59: 682-85.

21. Cogburn, R.R., E.W. Tilton, and J.H. Brower (1973). Almond moth: gamma radiation effects on the life stages. J. Econ. Entomol. 66: 745-51.

22. Cole, L.C. (1960). Competitive exclusion. Science 132:348-349.

23. Cox, P.D., L.A. Carwford, G. Gjestrud, C.H. Bell and C.R. Bowley (1981). The influence of temperature and humidity on the life cycle of Corcyra cephalonica (Stainton) (Lepidoptera : Pyralidae). Bull. ent. Res. 71: 171-181.

24. Cornwell, P.B. (1966). The entomology of radiation disinfestation on grain. Pergamon Press, New York. 236pp.

25. Crombie, A.C. (1945). On competition between different species of gramivorous insects. Proc. Roy. Soc. (B) 132: 362-395.

26. Dayen, A., and M. Ahmed (1969). The susceptibility of the long headed flour beetle, Laetheticus oryzae Waterh. to gamma radiation. Nucl. Sci. Appl., 5 (A): 26-30.

27. Debach, P., and R.A. Sundby. (1963). Competitive displacement between ecological homologues. Hilgardia 34: 106-166.

28. Debach, P. (1966). The competitive displacement and co-existence principles. Annu. Rev. Entomol. 11: 183-212.

*29. Durant, J.H., and Beveridge, W.W. (1913). Report on the temperature reached in army biscuits during baking, especially with reference to the destruction of the imported flour moth Ephestia kuehniella. Journal of the Royal Army Medical Corps, 20: 615-634.

30. Escalante, G., Rabinovich, J.E. (1979). Population dynamics of Telenomus fariai (Hymenoptera: Scelionidae), a parasite of chagas' disease vectors ix. Larval competition and population size regulation under laboratory conditions. Res. Popul. Ecol., 20 (2): 235-246.

31. Frank, P.W., (1957). Coactions in laboratory populations of two species of Daphnia. Ecology; 38: 510-519.

31. Freeman, J.A. (1962). The influence of climate on insect populations of flour mills. Proc. 11th Int. Congr.

Ent., Vienna 1960 11: 301-8

33. Freeman, J.A. (1976). Problems of stored products entomology in Britain arising out of the import of tropical products. Ann. appl. Biol. 84: 120-124.

34. Gilpin, M.E. (1974). Intraspecific competition between Drosophila larvae in serial transfer systems (Dipt. Drosophilidae). Ecology, 55 (5): 1154-1159.

35. Gonen, M. and Fishbain, I. (1973). Sensitivity of different age eggs of the tropical warehouse moth, Ephestia cautella (Wlk.) (Lepidoptera, phycitidae) to gamma radiation. IAEA Information circular on radiation techniques and their application to insect pest. No. 16.

36. Grist, D.H., and Lever, R.H. (1969). Pests of rice. Tropical Science Series, Longmans.

37. Hagvar, E.B. (1972). The effects of intra - and interspecific larval competition for food (Myzus persicae) (Hem., Hom., Aphididae) on the development at 20°C of Syrphus ribesii and Syrphus corollae (Dipt., Syrphidae). Entomophaga, 17: 71-77.

38. Highland, H.A. (1978). Insects infesting foreign warehouses containing packaged foods. J. Ga. Entomol. Soc., 13 (3): 251-256.

39. Hinton, H.E. (1963). The larvae of the Lepidoptera associated with stored products. Bulletin of Entomological Research, 34 (3): 163-212.

40. Hinton. H.E. and Corbet, A.S. (1972). Common insect pests of stored food products. British Museum (Natural History), Economic series No.15. 62pp.

41. Hodges, R.J. (1979). A review of the biology and control of the rice moth Corcyra cephalonica stainton (Lepidoptera: Galleriinae). Tropical Products Institute, G125 vi 20pp.

42. Hosay, M.M., Hassanein, M.H. and Kamel, A.H. (1968). Interspecific competition between Ephestia kuehniella and Corcyra cephalonica. Bulletin Societe Entomologique d' Egypte, 52: 445-456.

43. Howe, R.W. (1965). A summary of estimates of optimal and minimal conditions for population increase of some stored product insects. Journal of Stored Products Research, 1 (2): 177-184.

44. Huffaker, C.B. (1958). Experimental studies on predation : Dispersion factors and predatory-prey oscillations. Hilgardia 27: 343-383.

45. Istock, C.A. (1978). Logistic interaction of natural population of two species of waterboatmen. Amer. Nat., 111 (1978): 279-287.

46. Jacob, T.A. and Fox, P.D. (1977). The influence of temperature and humidity on the life cycle of Ephestia kuehniella Zeller (Lepidoptera: Pyralidae). J. stored Prod. Res. 13: 107-118.

47. Kamel, A.H. and Hassanein (1967). Biological studies on Corcyra cephalonica Stain. (Lepidoptera, Galleriidae). Bull. Soc. ent. Egypte 51: 175-196.

48. Karsholt, O. (1978). Some introduced Lepidoptera in the collection of the Zoological Museum, Copenhagan (Tineidae, Pyralidae). Nogle indslaebte sommerfugle i Zoologisk Museums sampling (Lepidoptera: Tineidae Pyralidae). Entomol. Medd., 46 (2): 65-67.

49. Laudani, H., E.W. Tilton, and J.H. Brower (1965) USDA research program and facilities for the use of gamma radiation in the control of stored product insects. Food Irradiat. 6: 1-246.

50. Loaharanu, S.M. Sutantawong, and A. Ungsunantwiwat (1972). The effect of gamma radiation on the rice moth, Corcyra cephalonica (staint.) Part II. Irradiation of the eggs, pupae and adults, IAEA Information circular on radiation techniques and their application to insect pests No.14.

51. Laraichi, M. (1978). Study of the intra - and interspecific competition between the Oophagus parasites of wheat bugs. Etude de la competition intra - et interspecific chez les parasites 00 phages des punaises des bles. Entomophaga, 23(2): 115-120.

52. Miller, R.S. (1967). Pattern and Process in competition. Adv. Ecol. Res. 4: 1-74.

53. Mould, H.A., and Rawnsley, J. (1962). The control of the cocoa moth Ephestia cautella in Ghana, W. Africa. Pyrethrum Post. 6(4): 7-10.

54. Nathanson, M. (1975). The effect of resource limitation on competing populations of flour beetles, Tribolium spp. (coleoptera, Tenebrionidae). Bull. Entomol. Res., 65(1): 1-12.

55. Ouye, M.T., R.S. Garcia, and D.F. Martin (1964). Determination of the optimum steilizing dosage for pink bollworms treated as pupae with gamma radiation. J. Econ. Entomol. 57: 387-90.

56. Park, T. (1948). Experimental studies of interspecies competition I. competition between populations of the flour beetles Tribolium confusum Daval and Tribolium castaneum Herbst, Ecol. Monogr., 18: 265-308.

57. Park, T. (1954). Experimental studies of interspecies competition II. Temperature, humidity and competition in two

58. Park, (1962). Beetles, competition and populations. Science 138: 1369-1375.

59. Pianka, E.R. (1974). Evolutionary Ecology Harper and Row, Publishers, Inc. New York, N.Y. 10022.

60. Pontin, A.J. (1961). Population stabilisation and competition between the ants Lasius flavus (F) and L. niger (L.) J. Anim, Ecol. 30: 47-54.

61. Pruthi, H.S. and Singh, M.(1945). Stored grain pests and their control. The Imperial council of Agricultural Research, Miscellaneous Bulletin No.57.

62. Qureshi, Z.A., D.A. Wilbur, and R.B. Mills (1968). Sublethal gamma radiation effects on prepupae, pupae and adults of Angoumois gain moth. J. Econ. Entomol., 61: 1699-1705.

63. Rafes, P.M., Raspovov, P.M.; Gninenko, J.I. (1979). Food competition of summer-autumn group birch pests in Transural (lands east of Ural). Ser. Biol., 1: 63-71.

64. Rao, D.S. (1954). Notes on rice moth, Corcyra cephalonica (staint.) (Family Galleriidae, Lepidoptera). India J. Ent., 16 (2): 95-114.

65. Rawnsley, J. (1958). Ephestia cautella; egg laying after knockdown by synorgized pyrethrin space spray. Ghana Cocoa Marketing Board Public No.6, Accra.

66. Rawnsley, J. (1959). Preliminary studies of the mating and egg laying habits of the cocoa moth Ephestia cautella. Ibid. No.5.

67. Rawnsley, J. (1968). Biological studies in Ghana in the control of Cadra cautella (Wlk.). the tropical warehouse moth. Ghana Jnl. Agric. Sci. 1: 155-159.

68. Richards, O.W. and Thomson, M.A. (1932). A contribution to the study of the genera Ephestia Gn. (including Stymax Dyar) and Plodia Gn. (Lepidoptera, Phycitidae), awith notes on parasites and larvae. Trans. R. Ent. Soc., London., 80: 169-250.

69. Riley, J. (1966). A record of suction trap catches during 24 hours in a groundnut warehouse at Apapa with areference to the flight activity of the moths Ephestia (Cadra) cautella (Wlk.) and Corcyra cephalonica (St.). Nigerian Stored Products Research Institute (N.S.P.R.I.) Ann. Rep. Fed. Min. of Information, Lagos Tech. Report No.3 pp. 33-34.

70. Sharma, G.K., Jain, K.L., Pareek (1978). Host preference and host-biology relations of Corcyra cephalonica, and Ephestia cautalla. Entomon., 3(1): 37-40.

71. Strong, R.G., G.J. Partida, and D.N. Warner (1968). Rearing stored product insects for laboratory studies: six species of moths. J. Econ. Entomol. 61: 1237-49.

72. Stroyan, H.L.G. (1946). Biological notes on Indian stored product insects. Entomologist 79: 135-139.

73. Teotia, T.P., and Yougeshwar Singh (1975). Studies on the growth of population of Corcyra cephalonica Stainton. Indian J. Ent. 37 (3): 272-285.

74. Tilton, E.W., and J.H. Brower (1973). Status of U.S. Department of Agriculture research and irradiation disinfestation of grain and grain products. Pages 295-309 in Radiation preservation of food IAEA Symp. 166/49, IAEA Vienna.

75. Tilton, E.W., E.W.E. Burkholder, and R.R. Cogburn, (1966). Effects of gamma radiation on Rhizopertha dominica, Sitophilus oryazae, Tribolium confusum, and Lasioderma serricorne. J. Econ. Entomol. 59: 1363-68.

76. Umeya, K., Kato, T., Kocha, T. (1975). Studies on the comparative ecology of bean weevils. VI Intraspecific competition in Callosobrunchus analis (F.) (Col. Curculionidae). Jap. J. Appl. Entomol. Zool., 19(1): 47-53.

77. Vanderpuije, I. , Awuah, P.K. (1974). Long-term storage of cocoa beans in Silos. Proceedings of the 4th Conference of West African Cocoa Entomologists pp. 106-110.

*78. Volterra, V. (1926). Variazioni e fluttuazioni del numero d'individui in specie animali conviventi. Mem. Accad. Lincei, 2: 31-113.

* Originals not seen.

Chapter 8

APPENDICES

Table 1:

Rearing in standard medium (25.5 - 30± 1°C, R.H. 75 - 89 per-cent) at Legon (Zoology Department).

Corcyra cephalonica				Ephestia cautella			
No. of Eggs	Date Introduced	Date of Emergence	Developmental period (days	No. of Eggs	Date Introduced	Date of Emergence	Developmental period (days)
200	2-10-81	30-10-81	29	400	2-10-81	23-10-81	22
200	2-10-81	30-10-81	29	400	3-10-81	24-10-81	22
200	4-10-81	3-11-81	31	400	5-10-81	26-10-81	22
200	4-10-81	3-11-81	31	1,000	6-10-81	26-10-81	21
200	4-10-81	3-11-81	31	1,000	10-10-81	29-10-81	20
200	4-10-81	3-11-81	31	1,000	26-10-81	17-11-81	23
200	4-10-81	3-11-81	31	1,000	26-10-81	18-11-81	24

Table 1: (Contd.)

	Corcyra cephalonica				Ephestia cautella			
	No. of Eggs	Date Intro-duced	Date of Emergence	Develop-mental period (days)	No. of Eggs	Date Intro-duced	Date of Emergence	Develop-mental period (days)
	200	4-10-81	3-11-81	31	1,000	27-10-81	18-11-81	23
	800	1-11-81	30-11-81	30	1,000	27-10-81	18-11-81	23
	1,000	2-11-81	30-11-81	29	800	27-10-81	18-11-81	23
	1,000	5-11-81	2-1-82	29	1,000	27-10-81	18-11-81	23
	800	4-12-81	3-1-82	31	250	8-11-81	30-11-81	23
TOTAL	6,600			393	10,250			292
MEAN				30.2				22.5

C. cephalonica

Range : 29-31
Mean : 30.2
Standard deviation: 0-93 (n = 13)

E. cautella

Range: 21-24
Mean : 22.5
Standard deviation: 1.05 (n = 13)

Rearing in standard medium (25.5 - 30 1°C, R.H. 75. - 89 per-cent) at Kwabenya (Ghana Atomic Energy Commission).

	Corcyra cephalonica				*Ephestia cautella*			
	No. of Eggs	Date Introduced	Date of Emergence	Developmental period (days)	No. of Eggs	Date Introduced	Date of Emergence	Developmental (period) (days)
	200	2-10-81	30-10-81	29	400	2-10-81	23-10-81	22
	200	4-10-81	3-11-81	31	400	3-10-81	26-10-81	24
	200	6-10-81	3-11-81	29	400	6-10-81	27-10-81	22
	200	7-10-81	9-11-81	34	1,000	8-10-81	27-10-81	20
	400	8-10-81	5-11-81	29	1,000	8-10-81	27-10-81	22
	400	13-10-81	11-11-81	30	1,000	10-10-81	31-10-81	21
	400	14-10-81	12-11-81	30	1,000	14-10-81	3-11-81	21
	400	14-10-81	12-11-81	30	2,000	29-10-81	18-11-81	21
TOTAL	2,400			242	7,200			173
MEAN				30.3				21.6

C. cephalonica

Range: 29-34
Mean: 30.3
Standard deviation: 1.67 (n = 8)

E. cautella

Range: 21-24
Mean: 21.6
Standard Deviation: 1.19 (n = 8)

Table 3:

Competition in standard medium (limited amount of food and space).

(SET 1)

	1ST GENERATION											2ND GENERATION		
EC_{50}	DATES (Emergence)													
REPLICATES	30/11	1/12	2/12	3/12	4/12	5/12	6/12	7/12	8/12	9/12	TOTAL	31/12-1/1/82		TOTAL
R1	1	10	17	4	3	2	-	-	-	-	37		R1	695
R2	6	9	10	8	2	-	-	-	2	2	40		R2	874
R3	5	8	14	9	6	3	1	-	2	1	48		R3	976
R4	3	6	7	16	3	2	-	-	-	-	37		R4	763
R5	2	5	6	18	6	5	-	-	-	-	42		R5	859
TOTAL											205	Total		4167
MEAN											41	Mean		833.4
Percent SURVIVAL											82 Percent			

<u>*Ephestia cautella*</u>

Date introduced: 8-11-81
Date of emergence: 30-11-81
Developmental period: 23 days
Time of observation: 7.30 p.m.

KEY

EC_{50} = *Ephestia cautella* (50 eggs introduced)

Table 4:

Competition in Standard Medium (limited amount of food and space).

(SET 2)

	1ST GENERATION											2ND GENERATION	
EC_{50}	DATES (Emergence)												
REPLICATES	27/12	28/12	29/12	30/12	31/12	1/1	2/1	3/1	4/1	5/1	TOTAL	27/1-30/1/82	TOTAL
R1	3	9	15	10	4	2	-	2	-	-	45	R1	801
R2	2	7	8	14	6	1	-	-	-	-	38	R2	635
R3	5	9	11	7	4	2	-	-	-	-	38	R3	960
R4	3	8	14	12	3	1	2	2	-	-	45	R4	863
R5	6	8	12	11	5	2	1	1	-	-	46	R5	878
TOTAL											212	TOTAL	4137
MEAN											42.5	MEAN	827.4
Percent SURVIVAL											84.8 Percent		

Ephestia cautella

Date introduced: 5-12-81
Date of emergence: 27-12-81
Developmental period: 23 days
Time of observation: 7.30 pm.

KEY

CC_{50} = Corcyra cephalonica (50 eggs introduced)

Table 5:

Competition in Standard Medium (limited amount of food and space).

(SET 1)

CC_{50} REPLICATES	1ST GENERATION DATES (Emergence) 7/12	8/12	9/12	10/12	11/12	13/12	14/12	15/12	16/12	17/12	18/12	TOTAL	2ND GENERATION 22/1-301/82	TOTAL
R1	1	4	6	2	6	2	2	3	2	-	-	28	R1	410
R2	3	10	9	2	6	1	2	-	2	-	-	35	R2	631
R3	2	5	7	2	3	2	1	-	1	2	-	25	R3	574
R4	4	4	3	3	4	4	2	2	3	2	1	32	R4	565
R5	2	2	7	4	5	3	1	2	1	1	-	38	R5	495
TOTAL												158	TOTAL	2675
MEAN												31.6	MEAN	535.0
Percent SURVIVAL												63 Percent		

Corcyra cephalonica

Date introduced: 8-11-81
Date of emergence: 7-12-81
Developmental period: 30 days

KEY

CC_{50} = Corcyra cephalonica (50 eggs introduced)

Table 6:

Competition in Standard Medium (limited amount of food and space).

(SET 2)

CC_{50} REPLICATES	1ST GENERATION DATES (Emergence) 3/1	4/1	5/1	6/1	7/1	8/1	9/1	10/1	11/1	12/1	13/1	TOTAL	16/2-21/2/82		TOTAL
R1	2	6	7	4	4	3	2	1	3	-	-	32		R1	506
R2	3	9	10	3	5	3	3	1	-	-	-	37		R2	374
R3	4	6	5	3	3	2	1	2	1	-	-	27		R3	510
R4	2	4	7	4	5	2	1	2	3	2	-	32		R4	565
R5	3	10	9	2	4	4	3	-	2	1	-	38		R5	521
TOTAL												166	TOTAL		2476
MEAN												33.2	MEAN		495.2
Percent SURVIVAL												66 per-cent			

Corcyra cephalonica

Date introduced: 5-12-81
Date of emergence: 3-1-82
Developmental period: 30 days

KEY

CC_{50} = Corcyra cephalonica (50 eggs introduced)

Table 7:

Competition in Standard Medium (limited amount of food and space).

(SET 1)

E + $\frac{C}{2}$	1ST GENERATION (E. cautella)											1ST GENERATION (C. cephalonica)										2ND GENERATION		
	DATES (Emergence)																						TOTAL	
REPLICATE	30/11	1/12	2/12	3/12	4/12	5/12	6/12	7/12	8/12	9/12	TOTAL	22/12	23/12	24/12	25/12	26/12	27/12	28/12	29/12	30/12	TOTAL	3/2-8/2	EC	CC
R1	1	4	9	2	-	-	-	-	-	-	16	3	4	3	2	2	1	2	-	1	17	R1	607	265
R2	1	4	6	5	4	3	-	-	-	-	23	2	5	3	4	-	1	-	-	-	15	R2	659	274
R3	1	3	4	5	5	1	-	-	-	1	20	3	2	5	3	2	-	1	1	-	17	R3	530	318
R4	2	4	7	7	2	1	1	-	-	-	24	1	3	4	2	3	-	2	-	1	16	R4	811	321
R5	1	3	8	6	6	1	-	-	-	-	25	2	4	3	2	-	2	1	1	-	15	R5	402	297
TOTAL											108										80		3009	1475
MEAN											21.6										16		601.8	295
Percent SURVIVAL											86.4										64			

Ephestia cautella

Date introduced: 8-11-81

Date of emergence: 30-11-81

Developmental period: 23 days

Time of observation: 7.30 pm.

KEY

E + $\frac{C}{2}$ = E. cautalla introduced first (25 eggs) and after 2 weeks, C. cephalonica introduced (25 eggs)

Table 8:

Competition in Standard Medium (limited amount of food and space).

(SET 2)

$E + \frac{C}{2}$	1st GENERATION (C. cautella)									1ST GENERATION (C. cephalonica)										2ND GENERATION	TOTAL	
	DATES (Emergence)																					
REPLICATES	27/12	28/12	29/12	30/12	31/12	1/1	2/1	3/1	TOTAL	18/1	19/1	20/1	21/1	22/1	23/1	24/1	25/1	26/1	TOTAL	2/2-5/3/82	EC	CC
R1	2	3	8	7	3	1	-	-	24	2	3	3	1		2	-	-	-	16	R1	500	319
R2	1	5	6	7	3	1	-	-	23	1	4	3	2	3	2	-	-	-	19	R2	680	266
R3	1	4	9	4	4	1	1	1	25	3	3	2	2	1	-	1	1	1	17	R3	830	263
R4	1	4	6	5	4	-	-	-	20	1	5	1	3	-	1	-	-	1	15	R4	683	232
R5	1	5	9	3	2	-	2	-	23	3	5	2	3	2	-	2	2	-	19	R5	398	361
TOTAL									115										86		3091	1441
MEAN									23										17.2		618.2	288.2
Percent SURVIVAL									92 Percent										68.8 Percent			

Ephestia cautella

Date introduced: 5-12-81
Date of emergence: 27-12-81
Developmental period: 23 days
Time of observation: 7.30 pm.

Table 9:

Competition in Standard Medium (limited amount of food and space).

(SET 1)

$C+\frac{E}{2}$	1ST GENERATION (C. cephalonica)										1ST GENERATION (E. cautella)					2ND GENERATION		
	DATES (Emergence)															TOTAL		
REPLICATES	7/12	8/12	9/12	10/12	11/12	12/12	13/12	14/12	15/12	TOTAL	15/12	16/12	17/12	18/12	TOTAL	12/1-16/1/82	CC	EC
R1	4	1	7	3	-	1	-	-	-	16	3	5	9	6	23	R1	542	3
R2	1	5	4	3	-	1	1	-	1	16	1	6	7	8	22	R2	603	4
R3	3	5	6	2	-	-	-	-	1	16	1	5	7	4	17	R3	512	1
R4	2	4	2	6	-	-	-	-	1	15	2	5	8	3	18	R4	449	2
R5	3	6	3	1	1	-	-	-	2	16	1	6	8	6	21	R5	413	1
TOTAL										79					101		2519	11
MEAN										15.8					20.2		503.8	2.2
Percent SURVIVAL										63.2 Percent					30.8 Percent			

Corcyra cephalonica

Date introduced: 8-11-81
Date of emergence: 7-12-81
Developmental period: 30 days

KEY

$C+\frac{E}{2}$ = C. cephalonica introduced first (25 eggs) and after 2 weeks, E. cautella introduced (25 eggs)

Table 10:

Competition in Standard Medium (limited amount of food and space).

(SET 2)

$C+\frac{E}{2}$	1ST GENERATION (C. cephalonica)								1ST GENERATION (E. cautella)						2ND GENERATION		
	DATES (Emergence)															TOTAL	
REPLICATES	3/1	4/1	5/1	6/1	7/1	8/1	9/1	TOTAL	1/11	12/1	13/1	14/1	15/1	TOTAL	10/2-17/2/82	CC	EC
R1	2	4	7	2	1	1	-	17	1	6	8	5	2	22	R1	503	3
R2	4	5	5	2	1	-	-	17	3	4	5	5	2	18	R2	353	-
R3	1	3	6	3	1	1	-	15	3	6	7	6	1	23	R3	398	1
R4	1	4	5	4	1	-	1	16	4	6	6	5	1	22	R4	545	1
R5	3	5	7	3	1	1	-	20	2	5	7	6	-	20	R5	468	1
TOTAL								85						105		2267	66
MEAN								17.5						453.4		453.4	1.2
Percent SURVIVAL								68 Percent						84 Percent			

<u>Corcyra cephalonica</u>

Date introduced: 5-12-81

Date of emergence: 3-1-81

Developmental period: 30 days

Table 11:

Competition in Standard Medium (limitdd amount of food and space).

(SET 2)

CC/EC REPLICATES	1ST GENERATION (*E. cautella*) DATES (Emergence) 30/11	1/12	2/12	3/12	4/12	5/12	6/12	7/12	8/12	TOTAL	1ST GENERATION (*C. cephalonica*) 7/12	8/12	9/12	10/12	11/12	12/12	13/12	14/12	15/12	TOTAL	2ND GENERATION 20/1-28/1	TOTAL CC	TOTAL EC
R1	1	4	7	4	3	1	1	-	-	21	2	1	4	5	2	3	2	1	1	22	R1	446	-
R2	1	1	4	6	3	3	-	-	-	18	3	1	3	4	-	3	1	-	-	15	R2	571	1
R3	1	2	5	6	5	-	-	-	-	20	1	3	5	7	-	1	-	-	-	17	R3	412	-
R4	1	2	4	8	1	2	-	-	-	19	2	3	5	7	2	-	-	-	-	19	R4	382	2
R5	1	3	6	6	4	2	-	-	-	22	1	3	4	6	2	-	2	-	-	18	R5	433	1
TOTAL										99										91		2244	4
MEAN										19.8										18.2		448.8	
Percent SURVIVAL										79.2 Perc.										72.8 Percent			

Ephestia cautella

Date introduced: 8-11-81
Date of emergence: 30-11-81
Developmental period: 23 days
Time of observation: 7.30 p.m.

KEY

EC = *E. cautella* (25 eggs) introduced, together with
CC = *C. cephalonica* (25 eggs)

Corcyra cephalonica

Date introduced: 8-11-81
Date of emergence: 7-12-81
Developmental period: 30 days

Table 12:

Competition in Standard Medium (limited amount of food and space).

(SET 2)

CC/EC	1ST GENERATION (*E. cautella*)									1ST GENERATION (*C. cephalonica*)								2ND GENERATION		
	DATES (Emergence)																	T O T A L		
REPLICATES	27/12	28/12	29/12	30/12	31/12	1/1	2/1	3/1	TOTAL	3/1	4/1	5/1	6/1	7/1	8/1	9/1	TOTAL	16/2-21/2	CC	EC
R1	1	3	5	5	3	2	-	-	19	3	2	3	5	3	1	1	18	R1	371	1
R2	1	2	6	6	4	1	1	-	21	2	3	5	6	2	-	1	19	R2	524	-
R3	1	2	4	5	4	2	-	-	18	1	2	4	4	3	-	1	15	R3	467	-
R4	1	3	6	7	3	1	-	2	21	1	4	6	5	2	2	-	20	R4	398	-
R5	1	2	5	6	5	1	-	-	21	2	4	5	7	2	-	-	20	R5	429	-
TOTAL									100								92		2189	3
MEAN									20								18.4		437.8	
Percent SURVIVAL									80								73.6			

<u>Ephestia cautella</u>

Date introduced: 5-12-81
Date of emergence: 27-12-81
Developmental period: 23 days
Time of observation: 7.30 p.m.

<u>Corcyra cephalonica</u>

Date introduced: 5-12-81
Date of emergence: 3-1-82
Developmental period: 30 days

Table 13.

Competition in Standard Medium (Abundance of food and space).

		1ST GENERATION			2ND GENERATION			3RD GENERATION		
		1ST CENSUS	TOTAL		2ND CENSUS	TOTAL		3RD CENSUS	TOTAL	
	REPLICATES	30/12/81	CC	EC	9/2/82	CC	EC	19/3/82	CC	EC
$E + \frac{C}{2}$	A1	"	22	23	"	412	679	"	927	213
	A2	"	22	23	"	510	912	"	1,002	372
$C + \frac{E}{2}$	B1	27/12/82	21	24	30/1/82	601	187	4/3/82	1,630	287
	B2	"	23	23	"	579	253	"	1,817	325
CC/EC	C1	19/12/81	22	23	29/1/82	594	652	15/3/82	1,613	643
	C2	"	22	24	"	563	625	"	1,764	592
CC_{50}		17/12/81	CC		27/1/82	CC		12/3/82	CC	
	D1	"	43		"	692		"	1,586	
	D2	"	41		"	651		"	1,750	
EC_{50}		11-12-81	EC		13/1/82	EC		16/2/82	EC	
	E1	"	46		"	945		"	4,500	
	E2	"	45		"	970		"	4,921	

Ephestia cautella

Date introduced: 8-11-81
Date of emergence: 29-11-81
Developmental period: 22 days

Corcyra cephalonica

Date introduced 8-11-81
Date of emergence: 7-12-81
Developmental period: 30 days

Table 14:

		1ST GENERATION			2ND GENERATION		
		1ST CENSUS	TOTAL		2ND CENSUS	TOTAL	
	REPLICATES	18/2/81	CC	EC	10/4/82	CC	EC
E + $\frac{C}{2}$	A1	"	15	19	"	260	42
	A2	"	16	17	"	279	35
C + $\frac{E}{2}$	B1	19/2/81	16	9	9/4/82	372	18
	B2	"	18	11	"	380	15
CC/EC	C1	31/1/82	18	7	29/3/82	410	11
	C2	"	16	8	"	365	12
CC_{50}		31/1/82	CC		28/3/82	CC	
	D1	"	29		"	427	
	D2	"	26		"	408	
EC_{50}		31/1/82	E		26/3/82	E	
	E1	"	31		"	296	
	E2	"	27		"	264	

Ephestia cautella

Date introduced: 12-12-81
Date of emergence: 21-1-82
Developmental period: 41 days

Corcyra cephalonica

Date introduced: 12-12-82
Date of emergence: 21-1-82
Developmental period: 41 days

Table 15:

Competition in broken cocoa beans (limited amount of food and space).

(SET 1)

	1ST GENERATION			2ND GENERATION	
EC_{50}	DATES (Emergence)				
Replicates	18/12	19/12-24/1	TOTAL	9/12-16/4	TOTAL
R1	-	32	32	207	207
R2	3	17	20	202	202
R3	2	22	24	118	118
R4	3	27	30	250	250
R5	3	22	25	152	152
TOTAL			131		929
MEAN			26.2		185.8

Ephestia cautella

Date introduced: 8-11-82
Date of emergence: 18-12-81
Developmental period: 41 days

Table 16:

Competition in broken cocoa beans (limited amount of food and space).

(SET 2)

	1ST GENERATION			2ND GENERATION	
EC_{50}	DATES (Emergence)				
REPLICATES	21/1	22/1-27/2/82	TOTAL	21/3/-19/6/82	TOTAL
R1	4	23	27	221	221
R2	1	25	26	173	173
R3	3	23	26	233	233
R4	2	29	31	247	247
R5	3	25	28	124	124
TOTAL			138		993
MEAN			27.6		198.6

Ephestia cautella

Date introduced: 12-12-81
Date of emergence: 21-1-82
Developmental period: 41 days

Table 17:

Competition in broken cocoa beans (limited amount of food and space)

(SET 1)

	1ST GENERATION			2ND GENERATION	
CC_{50}	DATES (Emergence)				
REPLICATES	18/12	19/12-24/1	TOTAL	9/12-8/5/82	TOTAL
R1	1	16	17	327	327
R2	4	18	22	396	396
R3	-	23	23	372	372
R4	1	21	22	354	354
R5	2	25	26	359	359
TOTAL			110	1808	1808
MEAN			22		361.6

Table 18:

Competition in broken cocoa beans (limited amount of food and space).

(SET 2)

	1ST GENERATION			2nd GENERATION	
CC_{50}	DATES (Emergence)				
REPLICATES	21/1	22/1-27/2/81	TOTAL	21/3-19/6/82	TOTAL
R1	2	23	25	375	375
R2	3	19	22	359	359
R3	2	21	23	387	387
R4	2	22	24	391	391
R5	3	20	23	342	342
TOTAL			117	1854	1854
MEAN			23.5	370.8	370.8

<u>Corcyra cephalonica</u>

Date introduced : 12-12-81
Date of emergence: 21-1-82
Developmental period: 41 days

Table 19:

Competition in broken cocoa beans (limited amount of food and space).

(SET 1)

	1ST GENERATION				2nd GENERATION		
$E + \frac{C}{2}$	DATES	(Emergence)	TOTAL		DATES (Emergence)		TOTAL
REPLICATES	18/12	19/12-24/1/82	CC	EC	9/2-8/5/82	CC	EC
R1	1	19	11	8	218	215	3
R2	2	26	16	12	175	170	5
R3	1	17	6	12	96	91	5
R4	1	15	7	9	76	74	2
R5	-	24	10	14	122	120	2
TOTAL			50	55		670	17
MEAN			10	11		134	3.4

Ephestia cautella

Date introduced: 8-11-81
Date of emergence: 18-12-81
Developmental period: 41 days

Table 20

Competition in broken cocoa beans (limited amount of food and space).

(SET 2)

	1ST GENERATION				2ND GENERATION		
$E + \frac{C}{2}$	DATES	(Emergence)	TOTAL		DATES (Emergence)	TOTAL	
REPLICATES	21/1	22/1-27/2/82	CC	EC	21/3 - 19/6/82	CC	EC
R1	1	17	8	10	227	220	7
R2	1	18	8	11	248	243	5
R3	1	29	14	16	180	168	12
R4	2	13	6	9	157	154	3
R5	2	21	9	14	180	172	8
TOTAL			45	60		957	35
MEAN			9	12		191.4	7

Ephestia cautella

Date introduced: 12-12-81
Date of emergence: 21-1-82
Developmental period: 41 days

Table 21:

Competition in broken cocoa beans (limited amount of food and space).

(Set1)

	1ST GENERATION				2ND GENERATION		
$C + \frac{E}{2}$	DATES (Emergence)		TOTAL		DATES (Emergence)	TOTAL	
REPLICATES	18/12	19/12-24/1/82	Cc	Ec	9/2-8/5/82	CC	EC
R1	4	12	14	2	317	317	-
R2	1	8	7	2	206	205	-
R3	2	9	8	3	219	218	1
R4	2	19	14	7	350	350	-
R5	1	12	13	4	312	312	-
TOTAL			56	18		1402	2
MEAN			11.2	3.6		280.4	0.4

Corcyra cephalonica

Date introduced: 8-11-81
Date of emergence: 18-12-81
Developmental period: 41 days

Table 22:

Competition in broken cocoa beans (limited amount of food and space).

(SET 2)

	1ST GENERATION				2ND GENERATION		
$C + \frac{E}{2}$	DATES (Emergence		TOTAL		DATES (Emergence)	TOTAL	
REPLICATES	21/1	22/1-27/2/82	CC	EC	21/3-19/6/82	CC	EC
R1	3	15	13	5	308	307	1
R2	3	18	17	4	360	359	1
R3	2	18	15	5	343	341	2
R4	1	13	10	4	287	287	-
R5	3	12	12	3	325	325	-
TOTAL			67	21		1619	4
MEAN			13.4	4.2		323.8	

Corcyra cephalonica

Date introduced: 12-12-81
Date of emergence: 21-1-82
Developmental period: 41 days

Table 23:

Competition in broken cocoa beans (limited amount of food and space).

(SET 1)

CC/EC	1ST GENERATION				2ND GENERATION			
	DATES	(Emergence	TOTAL		DATES	(Emergence)	TOTAL	
REPLICATES	18/12	19/12-24/1/82	CC	EC	9/2	10/2-8/5/82	CC	EC
R1	-	8	8	-	3	346	349	-
R2	2	8	7	3	2	284	286	-
R3	-	15	12	3	4	147	151	-
R4	2	7	7	2	3	124	127	-
R5	1	10	9	2	4	220	224	-
TOTAL			43	10			1137	-
MEAN			8.6	2			227.4	-

<u>*Corcyra cephalonica*/*Ephestia cautella*</u>

Date introduced: 8-11-81
Date of emergence: 18-12-81
Developmental period: 41 days

Table 24:

Competition in broken cocoa beans (limited amoung of food and space).

(SET 2

	1ST GENERATION				2ND GENERATION			
CC/EC	DATES (Emergence)		TOTAL		DATES (Emergence)		TOTAL	
REPLICATES	21/1	22/1-27/2/82	CC	EC	21/3	22/3-19/6/82	CC	EC
R1	1	11	10	2	4	357	361	-
R2	11	12	9	4	2	254	256	-
R3	2	7	7	2	4	209	213	-
R4	2	11	10	3	4	305	309	-
R5	-	11	8	3	2	182	184	-
TOTAL			44	14			1325	-
MEAN			8-8	2.8			265	-

Corcyra cephalonica/Ephestia cautella

Date introduced: 12-12-81
Date of emergence: 21-1-82
Developmental period: 41 days

Table 25:

Oviposition preferences of *E. cautella* on standard medium, broken cocoa beans and shelled groundnuts.

SET	Date introduced	Date terminated	Commodity	Larvae Petri-dish A	Larvae Petri-dish B	TOTAL
1	15-5-82	29-5-82	Std.Medium	58	68	126
			Cocoa	7	4	11
			Groundnut	5	-	5
2	15-5-82	29-5-82	Std.Medium	37	13	13
			Cocoa	-	13	13
			Groundnut	6	3	9

No. of adults: 10 males to 10 females

Duration: 2 weeks

Table 26:

Oviposition preferences of C. cephalonica on standard medium, broken cocoa beans and shelled groundnuts.

Set	Date introduced	Date terminated	Commodity	Larvae: Petri-dish A	Larvae: Petri-dish B	TOTAL
1	7-5-82	21-5-82	Std.Medium	62	28	90
			Cocoa	45	33	78
			Groundnut	1	-	1
2	7-5-82	21-5-82	Std.Med.	21	6	27
			Cocoa	3	1	4
			Groundnut	2	-	2

No. of adults: 10 males to 10 females

Duration = 2 weeks

Table 27:

Oviposition preferences of E. cautella and C. cephalonica on standard medium, broken cocoa beans and shelled groundnuts.

				C. cephalonica			E. cautella		
				Larvae			Larvae		
Set	Date introd-uced	Date termi-nated	Commodity	Petri-dish A	Petri-dish B	TOTAL	Petri-dish A	Petri-dish B	TOTAL
1	17-5-82	31-5-82	Std.Medium	4	4	8	41	33	73
			Cocoa	79	34	113	-	-	-
			Groundnut	23	5	28	-	6	6
	17-5-82	31-5-82	Std.Medium	6	1	7	108	67	175
			Cocoa	2	2	4	-	2	2
			Groundnut	7	2	9	6	12	18

No. of adults: C. Cephalonica (5 males to 5 females)

E. cautella (5 males to 5 females)

Duration: 2 weeks

Table 28:

Oviposition preferences of C. cephalonica on standard medium, broken cocoa beans and shelled groundnuts.

Set	Date Introduced	Date terminated	Commodity	Cocoon	Larvae	Adults alive	Adults dead	TOTAL (Adults)
1	20-1-82	5-5-82	Std.medium	78	12	26	183	209
			Cocoa	60	14			
			Groundnut	45	35			
2	20-1-82	5-5-82	Std.medium	81	12	30	194	224
			Cocoa	65	6			
			Groundnut	48	9			

No. of adults: 10 males to 10 females

Duration: 15 weeks

Table 29:

Oviposition preferences of E. cautella on standard medium, broken cocoa beans and shelled groundnuts.

Set	Date introduced	Date aterminated	Commodity	Cocoon	Larvae	Adults (alive)	Adults (dead
1	20-1-82	5-5-82	Std.medium	62	-	-	114
			Cocoa	29	-	-	
			Groundnut	23	-	-	
2	20-1-82	5-5-82	Std.medium	71	-	-	132
			Cocoa	34	-	-	
			Groundnut	27	-	-	

No. of adults: 10 males to 10 females
Duration: 15 weeks

Table 30:

Oviposition preferences of C. cephalonica and E. cautella on standard medium, broken cocoa beand and shelled groundnuts.

Set	Date introduced	Date terminated	Commodity	Cocoon	Larvae		Adults (alive)		Adults (dead)	TOTAL	
					CC	EC	CC	EC		EC	CC
1	20-1-82	7-5-82	St.medium	89	8	-	10	-	176	67	119
			Cocoa	61	13	-					
			Groundnut	26	7	-					
2	20-1-82	7-5-82	Std.medium	115	9	-	2	-	191	23	170
			Cocoa	57	18	-					
			Groundnut	19	4	-					

Table 31:

Egg-hatchability of E. cautella (Oviposition: 5-12-81).

		DAY / DATE			
		4, 5	6	7	
SET	REPLICATES	9-12-81	10-12-81	11-12-81	TOTAL
1.	R1	23	1	-	24
	R2	21	1	-	22
	R3	22	2	-	24
	R4	21	3	-	24
	R5	23	-	-	23
2	R1	22	-	-	22
	R2	22	1	-	23
	R3	25	-	-	25
	R4	22	2	-	24
	R5	22	1	-	23
3	R1	21	2	-	23
	R2	23	2	-	25
	R3	20	2	-	22
	R4	20	3	-	23
	R5	22	2	-	24
4	R1	22	2	-	24
	R2	23	-	-	23
	R3	23	1	-	24
	R4	21	1	-	22
	R5	22	2	-	24
5	R1	21	1	-	22
	R2	25	-	-	25
	R3	24	1	-	25
	R4	24	1	-	25
	R5	23	2	-	25
TOTAL					590
MEAN					23.6
PERCENTAGE HATCHABILITY					94.4

Table 32:

Egg-hatchability of *C. cephalonica* (Oviposition: 3-12-81).

		DAY / DATE				
		4	5	6	7	
SET	REPLICATE	6-12-81	7-12-81	8-12-81	9-12-81	TOTAL
1	R1	4	12	5	-	21
	R2	3	16	3	-	22
	R3	5	14	3	-	22
	R4	1	16	4	-	21
	R5	-	14	6	-	20
2	R1	2	12	6	-	20
	R2	1	15	4	-	20
	R3	3	18	4	-	25
	R4	1	19	1	-	21
	R5	-	19	3	-	22
3	R1	3	13	4	-	20
	R2	3	15	5	-	23
	R3	4	14	3	-	21
	R4	2	19	3	-	24
	R5	1	18	1	-	20
4	R1	1	17	3	-	21
	R2	3	15	4	-	22
	R3	3	13	5	-	21
	R4	5	16	1	-	22
	R5	4	18	2	-	24
5	R1	2	17	1	-	20
	R2	2	15	3	-	20
	R3	5	18	-	-	23
	R4	3	16	1	-	20
	R5	2	16	2	-	20
TOTAL						535
MEAN						21.4
PERCENTAGE HATCHABILITY						85.6

Table 33:

Age and Fecundity of *E. cautella*.

DATE	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	TOTAL	MEAN
5-5-82	14	12	10	15	12	20	13	17	20	12		
6-5-8-	86	74	78	82	79	76	80	73	69	75		
7-5-82	40	28	32	27	15	44	35	37	41	28		
8-5-82	10	21	39	18	29	26	23	28	30	17		
9-5-82	18	26	25	20	25	14	16	19	24	20		
TOTAL	168	161	176	162	160	180	167	174	184	152	1684	168.4

20 adults reared on 200 grams of standard medium
Pairing: 1 male to 1 female

Table 34:

Age and fecundity of <u>E</u>. <u>cautella</u>.

DATE	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	TOTAL	MEAN
11-5-82	14	17	13	12	15	17	11	10	14	12		
12-5-82	67	54	73	78	69	72	83	77	81	68		
13-5-82	43	29	38	26	33	37	41	35	32	44		
14-5-82	18	27	23	12	25	17	25	30	19	23		
15-5-82	20	24	19	22	18	26	18	16	16	22		
TOTAL	162	151	166	150	160	169	178	153	147	169	1605	160.5

20 adults reared on 200 grams of standard medium

Pairing: 1 male to 1 female

Table 35:

Age and fecundity of C. cephalonica.

DATE	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	TOTAL	MEAN
13/4/82	40	41	37	39	28	25	51	44	35	35		
14/4/82	15	30	43	33	39	43	14	27	24	19		
16/4/82	21	18	23	21	23	18	37	16	35	26		
17/4/82	17	10	13	18	19	9	26	12	24	13		
18/4/82	4	-	12	11	5	-	13	9	17	11		
TOTAL	100	123	143	154	135	121	183	132	153	108	1352	135.2

20 adults (25 eggs introduced) reared on 200 grams of standard medium.

Pairing: 1 male to 1 female

Table 36:

Age and fecundity of _C. cephalonica_.

DATE	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	TOTAL	MEAN
9/4/82	59	36	52	29	38	31	15	42	39	49		
10/4/82	13	42	17	43	27	20	47	15	43	27		
11/4/82	50	15	38	27	36	37	18	30	17	41		
12/4/82	43	14	16	12	14	23	27	25	14	36		
13/4/82	32	23	20	28	11	17	25	27	12	16		
14/4/82	18	10	9	-	9	10	12	10	8	-		
TOTAL	215	140	137	139	135	138	144	151	133	121	1453	145.3

20 adults (25 eggs introduced) reared on 200 grams of standard medium.

Pairing: 1 male to 1 female

Table 37:

Age and fecundity of E. cautella.

DATE	R1	R2	R3	R4	R5	TOTAL	MEAN	FECUNDITY PER FEMALE
15/1/82	2,850	2,160	2,510	2,801	2,015			
16/1/82	1,160	1,350	1,250	1,201	1,741			
17/1/82	1,650	1,605	1,610	1,581	1,594			
TOTAL	5,660	5,115	5,370	5,583	5,350	27,078	5415.6	108.3

200 adults (220 eggs introduced) reared on 200 grams of standard medium

Pairing: 50 males to 50 females

Table 38:

Age and fecundity of C. cephalonica.

DATE	R1	R2	R3	R4	R5	TOTAL	MEAN	FECUNDITY PER FEMALE
15-1-82	275	183	205	281	198			
16-1-82	302	369	375	341	381			
17-1-82	185	255	240	195	243			
18-1-82	72	80	77	65	84			
TOTAL	834	887	897	882	906	4406	881.2	88.1

100 adults (110 eggs introduced) reared on 200 grams of standard medium

Pairing: 10 males to 10 females

Table 39:

Competition between *E. cautella* and *C. cephalonica* for pupation sites (using corrugated cardboard with 6 pupation sites).

(SET 1)

REPLICATES	*E. CAUTELLA*	*C. CEPHALONICA*
R1	1	5
R2	1	5
R3	2	4
R4	1	5
R5	1	5
TOTAL	6	24
Percentage Success (Sites)	20.0	80.0

No. of *C. cephalonica* = 5 | No. of E. cautella = 5

Wt. of 5 larvae = 150mg | Wt of 5 larvae = 55mg

Table 40:

Competition between *E. cautella* and *C. cephalonica* for pupation sites. (Using corrugated cardboard with 6 pupation sites).

(SET 2)

REPLICATES	*E. cautella*	*C. cephalonica*
R1	2	4
R2	1	5
R3	1	5
R4	1	5
R5	1	5
TOTAL	6	24
Percentage Success (Sites)	20.0	80.0

Table 41:

Competition between E. cautella and C. cephalonica for pupation sites (Using corrugated cardboard with 11 pupation sites).

(SET 1)

REPLICATES	E. cautella	C. Cephalonica
R1	1	10
R2	*2	10
R3	1	10
R4	1	10
R5	1	10
TOTAL	(5 + 1)	50
Percentage Success (Sites)	9.1	90.9

* larvae occupying same pupation site

No. of C. cephalonica = 16
Wt. of 16 larvae = 449 mg

No. of E. cautella = 16
Wt. of 16 larvae = 123mg

Table 42:

Competition between _E. cautella_ and _C. cephalonica_ for pupation sites (Using corrugated cardboard with 11 pupation sites).

(Set 2)

REPLICATES	_E. cautella_	_C. cephalonica_
R1	1	10
R2	*2	10
R3	1	10
R4	*2	10
R5	1	10
TOTAL	(5+2)	50
Percentage Success (Sites)	9.1	90.9

* 2 larvae occupying same pupation site

No. of _C. cephalonica_ = 16

Wt. of 16 larvae = 448mg

No. of _E. cautella_ = 16

Wt. of 16 larvae = 124mg.

Irradiation of 1 day-old eggs of C. cephalonica

(Set 1)

DATE	DAY	REPLICATE	0 KRAD	5 KRAD	10 KRAD	20 KRAD	25 KRAD	30 KRAD	40 KRAD	50 KRAD	100 KRAD
21-11-81	3	R1	-	-	-	-	-	-	-	-	-
		R2	-	-	-	-	-	-	-	-	-
		R3	-	-	-	-	-	-	-	-	-
		R4	-	-	-	-	-	-	-	-	-
		R5	-	-	-	-	-	-	-	-	-
22-11-81	4	R1	5	-	-	-	-	-	-	-	-
		R2	3	1	-	-	-	-	-	-	-
		R3	2	1	-	-	-	-	-	-	-
		R4	1	1	-	-	-	-	-	-	-
		R5	3	-	-	-	-	-	-	-	-
23-11-81	5	R1	12	4	-	1	-	1	-	1	-
		R2	18	-	-	-	-	1	1	-	-
		R3	15	-	-	-	-	-	-	1	-
		R4	15	2	3	-	-	-	-	1	-
		R5	18	-	-	1	-	-	-	-	-

EGGS

Collected = 19-11-81
Irradiated = 19-11-81
Age = 1 day-old
No. of eggs in each replicate = 25

Table 43: (Contd.)

	DATE	DAY	REPLICATE	0 KRAD	5 KRAD	10 KRAD	20 KRAD	25 KRAD	30 KRAD	40 KRAD	50 KRAD	100 KRAD
	24-11-81	6	R1	2	-	-	-	-	-	-	-	-
			R2	1	-	-	-	-	-	1	1	-
			R3	3	-	-	-	-	-	-	1	-
			R4	1	-	-	1	-	-	-	-	-
			R5	-	-	-	-	-	-	-	-	-
TOTAL				103	9	3	3	-	2	2	4	-
Percentage	(HATCHED)			82.4	7.2	2.4	2.4	-	1.6	1.6	3.2	-

<u>EGGS</u>

Collected = 19-11-81
Irradiated = 19-11-81
Age = 1 day-old
No. of eggs in each replicate = 25

Table 44:

Irradiation of 1 day-old eggs of
C. cephalonica.

(Set 2)

DATE	DAY	REPLICATE	0 KRAD	5 KRAD	10 KRAD	20 KRAD	25 KRAD	30 KRAD	40 KRAD	50 KRAD	100 KRAD
13-12-81	2	R1	-	-	-	-	-	-	-	-	-
		R2	-	-	-	-	-	-	-	-	-
		R3	-	-	-	-	-	-	-	-	-
		R4	-	-	-	-	-	-	-	-	-
		R5	-	-	-	-	-	-	-	-	-
14-12-81	3	R1	-	-	-	-	-	-	-	-	-
		R2	-	-	-	-	-	-	-	-	-
		R3	-	-	-	-	-	-	-	-	-
		R4	-	-	-	-	-	-	-	-	-
		R5	-	-	-	-	-	-	-	-	-
15-12-81	4	R1	1	-	-	-	-	-	-	-	-
		R2	3	-	-	-	-	-	-	-	-
		R3	2	-	-	-	-	-	-	-	-
		R4	3	-	-	-	-	-	-	-	-
		R5	3	-	-	-	-	-	-	-	-
16-12-81	5	R1	19	2	1	-	-	-	1	-	-
		R2	14	-	-	-	-	-	-	-	-
		R3	15	1	1	-	-	-	-	-	-
		R4	13	-	-	1	-	-	-	-	-
		R5	15	-	-	-	-	-	-	-	-
17-12-81	6	R1	-	2	-	-	-	1	-	-	-
		R2	3	1	-	1	-	-	-	-	-
		R3	2	-	-	-	-	-	-	-	-
		R4	3	-	-	-	-	-	-	-	-
		R5	4	2	-	-	-	-	-	-	-
TOTAL			100	8	2	2	-	1	1	-	-
Percentage Hatched			80.0	6.4	1.6	1.6	-	0.008	0.008	-	-

Eggs

Collected = 12-12-81
Irradiated = 12-12-81
Age = 1 day-old
No. of eggs in each replicate = 25

Table 45:

Irradiation of 2 day-old eggs of
C. cephalonica.

(Set 1)

DATE	DAY	REPLICATE	0 KRAD	5 KRAD	10 KRAD	20 KRAD	25 KRAD	30 KRAD	40 KRAD	50 KRAD	100 KRAD
20-11-81	3	R1	-	-	-	-	-	-	-	-	-
		R2	-	-	-	-	-	-	-	-	-
		R3	-	-	-	-	-	-	-	-	-
		R4	-	-	-	-	-	-	-	-	-
		R5	-	-	-	-	-	-	-	-	-
21-11-81	4	R1	2	-	-	-	-	-	-	-	-
		R2	5	-	-	-	-	-	-	-	-
		R3	3	-	-	-	-	-	-	-	-
		R4	2	2	-	-	-	-	-	-	-
		R5	2	-	1	1	1	-	-	-	-
22-11-81	5	R1	15	1	2	-	-	-	-	-	-
		R2	16	-	2	1	1	-	1	-	-
		R3	17	1	-	1 -	2	-	-	-	-
		R4	15	1	-	2	-	-	-	1	-
		R5	17	1	3	-	-	-	-	-	-
23-11-81	6	R1	1	-	-	-	-	-	-	-	-
		R2	-	-	-	-	-	-	-	-	-
		R3	-	-	-	-	-	-	-	-	-
		R4	2	-	-	-	1	-	-	-	1
		R5	1	1	2	-	-	1	-	-	-
TOTAL			98	7	10	5	5	1	1	1	1
Percentage Hatched			78.4	5.6	8.0	4.0	4.0	0.008	0.008	0.008	0.008

Eggs

Collected = 18-11-81
Irradiated = 19-11-81
Age = 2 day-old
No. of eggs in each replicate = 25

Table 46:

Irradiation of 2 day-old eggs of
C. cephalonica.

(Set 2)

	DATE	DAY	REPLICATE	0 KRAD	5 KRAD	10 KRAD	20 KRAD	25 KRAD	30 KRAD	40 KRAD	50 KRAD	100 KRAD
	12-12-81	3	R1	-	-	-	-	-	-	-	-	-
			R2	-	-	-	-	-	-	-	-	-
			R3	-	-	-	-	-	-	-	-	-
			R4	-	-	-	-	-	-	-	-	-
			R5	-	-	-	-	-	-	-	-	-
	13-12-81	4	R1	3	-	-	-	-	-	-	-	-
			R2	5	-	-	-	-	-	-	-	-
			R3	1	-	-	-	-	-	-	-	-
			R4	4	-	-	-	-	-	-	-	-
			R5	3	-	-	-	-	-	-	-	-
	14-12-81	5	R1	13	2	1	-	-	-	-	-	-
			R2	12	2	-	-	-	-	-	-	-
			R3	14	1	2	-	-	-	-	-	-
			R4	13	2	1	-	-	-	-	-	-
			R5	12	2	1	-	-	-	-	-	-
	15-12-81	6	R1	2-	-	-	-	-	-	-	-	-
			R2	3	-	-	-	1	-	-	-	-
			R3	1	-	-	-	-	-	-	-	-
			R4	2	-	-	1	-	-	1	-	-
			R5	3	-	-	1	-	-	1	-	-
TOTAL				91	9	5	3	2	-	1	-	-
Percentage Hatched				72.8	7.2	4.0	2.4	1.6	-	0.008		

Eggs

Collected = 10-12-81
Irradiated = 11-12-81
Age = 2 day-old
No. of eggs in each replicate = 25

Table 47:

Irradiation of 3 day-old eggs of C. cephalonica

(Set 1)

DATE	DAY	REPLICATE	0 KRAD	5 KRAD	10 KRAD	20 KRAD	25 KRAD	30 KRAD	40 KRAD	50 KRAD	100 KRAD
20-11-81	4	R1	4	-	-	-	-	-	-	-	-
		R2	3	-	-	-	-	-	-	-	-
		R3	5	-	-	-	-	-	-	-	-
		R4	3	-	-	-	-	-	-	-	-
		R5	5	-	-	-	-	-	-	-	-
21-11-81	5	R1	13	3	2	-	-	-	-	-	-
		R2	13	1	-	-	-	-	-	-	-
		R3	16	3	1	-	-	-	-	-	-
		R4	14	2	2	-	-	-	-	-	-
		R5	16	3	1	-	-	-	-	-	-
22-11-81	6	R1	2	7	7	-	-	-	-	-	-
		R2	3	4	3	-	-	-	-	-	-
		R3	2	6	3	-	-	-	-	-	-
		R4	2	7	4	-	-	-	-	-	-
		R5	2	7	2	1	-	-	-	-	-
23-11-81	7	R1	-	-	-	3	-	-	-	1	-
		R2	-	-	-	2	-	-	-	-	-
		R3	-	-	-	1	-	1	-	-	-
		R4	-	-	-	-	1	-	-	-	-
		R5	-	-	-	1	1	-	-	-	-
TOTAL			103	43	25	8	2	1	-	1	-
Percentage Hatched			82.4	34.4	20.0	6.4	1.6	0.008		0.008	

<u>Eggs</u>

Collected = 17-11-81
Irradiated = 19-11-81
Age = 3 day-old
No. of eggs in each replicate = 25

Table 48:

Irradiation of 3 day-old eggs of C. cephalonica.

(Set 2)

DATE	DAY	REPLICATE	0 KRAD	5 KRAD	10 KRAD	20 KRAD	25 KRAD	30 KRAD	40 KRAD	50 KRAD	100 KRAD
12-12-81	4	R1	5	-	-	-	-	-	-	-	-
		R2	3	3	-	-	-	-	-	-	-
		R3	4	-	-	-	-	-	-	-	-
		R4	2	-	-	-	-	-	-	-	-
		R5	4	-	-	-	-	-	-	-	-
13-12-81	5	R1	12	10	5	1	-	-	-	-	-
		R2	14	9	4	2	-	-	-	-	-
		R3	12	5	3	2	-	-	-	-	-
		R4	16	9	2	2	-	-	-	-	-
		R5	14	11	4	1		-	-	-	-
14-12-81	6	R1	3	1	2	4	1	-	-	-	-
		R2	4	2	1	3	-	-	-	-	-
		R3	3	-	3	-	-	-	-	-	-
		R4	3	-	4	2	-	-	-	1	-
		R5	4	2	3	-	-	-	-	-	-
15-12-81	7	R1	-	-	-	-	-	-	-	-	-
		R2	-	-	-	-	-	-	-	-	-
		R3	-	-	-	-	-	-	-	-	-
		R4	-	-	-	-	-	-	-	-	-
		R5	-	-	-	-	-	-	-	-	-
TOTAL			101	49	31	17	1	-	-	1	-
Percentage Hatched			80.8	39.2	24.8	13.6	0.008	-	-	0.008	

Eggs

Collected = 9-12-81
Irradiated = 11-12-81
Age = 3 day-old
No. of eggs in each replicate = 25

-

Table 49:

Irradiation of early larvae (5 days after hatching) of *C. cephalonica*.

(Set 1)

DATE	REPLICATE	0 KRAD	5 KRAD	10 KRAD	20 KRAD	25 KRAD	30 KRAD	40 KRAD	50 KRAD	100 KRAD
11-2-82	R1 R2 R3 R4 R5	16	2	-	-	-	-	-	-	-
11-2-82	"	33	25	16	1	-	3	2	1	2
12-3-82	"	52	40	43	13	11	9	8	7	5
TOTAL		101	67	59	14	11	12	10	8	7
PERCENTAGE (EMERGENCE)		80.8	53.6	47.2	11.2	8.8	9.6	8.0	6.4	5.6
RATIO	♂/♀	48/53	27/40	14/45	5/9	7/4	16/9	12/7	3/5	3/4
SEX RATIO	♂:♀	1:1.1	1:1.5	1:3.2	1:1.8	1:8-1	1:7.1	1:7.1	1:1.6	1:1.3

<u>Early larvae</u>

Eggs collected = 11-1-82
Hatched = 15-1-82
Irradiated = 19-1-82
1st day of emergence = 11-2-82
No. of larvae in each replicate = 25
No. of larvae in 5 replicates = 125

Table 50:

Irradiation of early larvae (5 days after hatching) of <u>C. cephalonica</u>.

(Set 2)

DATE	REPLICATES	0 KRAD	5 KRAD	10 KRAD	20 KRAD	25 KRAD	30 KRAD	40 KRAD	50 KRAD	100 KRAD
5-3-82	R1 R2 R3 R5 R5	12	1	-	-	-	-	-	-	-
6-3-82	"	30	8	5	-	-	-	-	-	-
7-3-82	"	64	10	6	-	-	1	-	2	-
30-3-82	"	-	46	46	13	12	9	8	5	4
TOTAL		106	65	57	13	12	10	8	7	4
PERCENTAGE (EMERGENCE)		84.8	52.0	45.6	10.4	9.6	8.0	6.4	5.6	3.2
RATIO	♂/♀	48/58	30/35	22/35	6/7	8/4	7/3	4/4	/3	3/1
SEX RATIO	♂:♀	1:1.2	1:1.7	1:1.5	1:1.6	2:1	2:3.1	1:1	1:3.1	3:1

<u>Early larvae</u>

Eggs collected = 3-2-82
Hatched = 7-2-82
Irradiated = 11-2-82
1st day of emergenc e = 5-3-82
No. of larvae in each replicate = 25
No. of larvae in 5 replicates = 125

Table 51:

Irradiation of late larvae (5 days before pupation) of C. cephalonica.

(Set 1)

DATE	REPLICATES	0 KRAD	5 KRAD	10 KRAD	20 KRAD	25 KRAD	30 KRAD	40 KRAD	50 KRAD	100
10-1-82	R1 R2 R3 R4 R5	14	8	7	4	2	2	-	-	-
11-1-82	"	29	18	12	13	9	8	5	3	2
15-2-82	"	61	62	9	5	9	5	9	5	8
2-4-82	"	-	1	7	1	3	1	-	-	-
TOTAL		104	89	35	23	23	16	14	8	10
PERCENTAGE (EMERGENCE)		83.2	71.2	28.0	18.4	18.4	12.8	11.2	6.4	8.0
RATIO	♂:♀	54/50	51/37	18/10	12/11	9/14	7/9	6/8	1/7	3/5
SEX RATIO	♂:♀	1.1:1	1.4:1	1.8:1	1:1:1	1:1.6	1:1.3	1.3:1	1:7	1:1.7

Late larvae

Eggs collected = 10-12-81
Hatched = 14-12-81
Irradiated = 29-12-81
1st day of emergence = 10-1-82
No. of larvae in each replicate = 25
No. of larvae in 5 replicates = 125

Table 52:

Irradiation of late larvae (5 days before pupation) of *C. cephalonica*.

DATE	REPLICATES	0 KRAD	5 KRAD	10 KRAD	20 KRAD	25 KRAD	30 KRAD	40 KRAD	50 KRAD	100 KRAD
14-1-82	R1 R2 R3 R4 R5	15	12	10	7	4	2	2	1	-
15-1-82	"	32	16	8	11	9	7	8	4	1
12-2-82	"	60	62	13	7	8	8	3	5	6
5-4-82	"	-	1	-	-	1	-	-	-	-
TOTAL		107	91	31	25	22	15	13	10	7
PERCENTAGE (EMERGENCE)		85.6	72.8	24.8	20.0	17.6	12.0	10.4	8.0	5.6
RATIO	♂:♀	56/51	49/42	17/14	14/11	10/12	7/8	7/6	3/4	2/5
SEX RATIO	♂:♀	1.1:1	1.2:1	1.2:1	1.2:1	1.1:2	1:1.1	1:1	1:1.3	1:2.5

Late Larvae

Eggs collected = 12-12-81
Hatched = 16-12-81
Irradiated = 31-12-81
1st day of emergence = 14-1-82
No. of larvae in each replicate = 25
No. of larvae in 5 replicates = 125

Table 53:

Irradiation of 4 day-old pupae of C. cephalonica. (Set 1)

DATE	REPLICATES	0 KRAD	5 KRAD	10 KRAD	20 KRAD	25 KRAD	30 KRAD	40 KRAD	50 KRAD	100 KRAD
2-2-82	R1 R2 R3 R4 R5	18	10	8	5	5	3	1	-	-
3-2-82	"	22	11	11	10	9	7	6	3	-
4-2-82	"	17	9	4	7	7	5	3	5	1
15-2-82	"	15	38	8	4	6	-	-	-	-
TOTAL		92	68	31	26	27	15	14	8	1
PERCENTAGE (EMERGENCE)		73.6	54.4	34.8	20.8	21.6	12.0	11.2	6.4	0.008
RATIO	♂:♀	62/30	43/20	24/6	19/7	22/5	11/4	10/4	7/1	1/-
SEX RATIO	♂:♀	2.1:1	2.2:1	4:1	2.7:1	4:1	2.8:1	2.5:1	7:1	

4 day-old pupae

Eggs collected = 6-12-81
1st dayof pupation = 28-12-81
Irradiated = 31-12-81
1st day fof emergence = 2-2-81
No. of pupae in each replicate = 25
No. of pupae in 5 replicates = 125

Table 54:

Irradiation of 4 day-old pupae of *C. cephalonica*. (Set 2)

DATES	REPLICATES	0 KRAD	5 KRAD	10 KRAD	20 KRAD	25 KRAD	30 KRAD	40 KRAD	50 KRAD	100 KRAD
8-2-82	R1 R2 R3 R4 R5	22	12	5	7	5	2	1	-	-
9-2-82	"	19	10	10	7	9	8	3	3	1
20-2-82	"	68	49	19	13	11	2	5	3	1
TOTAL		109	71	34	27	25	12	9	6	2
PERCENTAGE (EMERGENCE)		87.2	56.8	27.2	21.6	20.0	9.6	7.2	4.8	1.6
RATIO	♂:♀	58/51	40/31	19/15	17/10	18/7	8/4	4/5	4/2	2/-
SEX RATIO	♂:♀	1:1:1	1.3:1	1.3:1	1.7:1	2.6:1	2.1	1:1.3	2:1	

4 day-old pupae

Eggs collected	=	9-12-81
1st day of pupation	=	2-2-82
Irradiated	=	5-2-82
1st day of emergence	=	8-2-82
No. of pupae in each replicate	=	25
No. of pupae in 5 replicates	=	125

Table 55:

COBALT-60 GAMMA IRRADIATION CHART

(GHANA ATOMIC ENERGY COMMISSION, KWABENYA)

Date	Fraction of Activity	Date	Fraction of Activity	Date	Fraction of Activity	Date	Fraction of Activity
1-11-81	0.2663	1-12-81	0.2633	1-1-82	0.2602	1-2-82	0.2571
2	0.2662	2	0.2632	2	0.2601	2	0.2570
3	0.2661	3	0.2531	3	0.2600	3	0.2569
4	0.2660	4	0.2630	4	0.2599	4	0.2568
5	0.2659	5	0.2629	5	0.2598	5	0.2567
6	0.2658	6	0.2628	6	0.2597	6	0.2566
7	0.2657	7	0.2627	7	0.2596	7	0.2565
8	0.2656	8	0.2626	8	0.2595	8	0.2564
9	0.2655	9	0.2625	9	0.2594	9	0.2563
10	0.2654	10	0.2624	10	0.2593	10	0.2562
11	0.2653	11	0.2623	11	0.2592	11	0.2561
12	0.2652	12	0.2622	12	0.2591	12	0.2560
13	0.2551	13	0.2621	13	0.2590	13	0.2559
14	0.2650	14	0.2620	14	0.2589	14	0.2558
15	0.2649	15	0.2619	15	0.2588	15	0.2557
16	0.2648	16	0.2618	16	0.2587	16	0.2556
17	0.2647	17	0.2617	17	0.2586	17	0.2555
18	0.2646	18	0.2616	18	0.2585	18	0.2554
19	0.2645	19	0.2615	19	0.2584	19	0.2553
20	0.2644	20	0.2614	20	0.2583	20	0.2552
21	0.2643	21	0.2613	21	0.2582	21	0.2551
22	0.2642	22	0.2612	22	0.2581	22	0.2550
23	0.2641	23	0.2611	23	0.2580	23	0.2549
24	0.2640	24	0.2610	24	0.2579	24	0.2548
25	0.2639	25	0.2609	25	0.2578	25	0.2547
26	0.2638	26	0.2608	26	0.2577	26	0.2546
27	0.2637	27	0.2607	27	0.2576	27	0.2545
28	0.2636	28	0.2606	28	0.2575	28	0.2544
29	0.2635	29	0.2605	29	0.2574		
30	0.2634	30	0.2604	30	0.2573		
		31	0.2603	31	0.2572		

Table 56:

Cobalt-60 Gamma Irradiation Chart (Ghana Atomic Energy Commission, Kwabenya)

Date	Fractions of activity
1-3-82	0.02543
2	0.02542
3	0.02541
4.	0.02540
5	0.02539
6	0.02538
7	0.02537
8	0.02536
9	0.02535
10	0.02534
11	0.02533
12	0.02532
13	0.02531
14	0.02530
15	0.02529
16	0.02528
17	0.02527
18	0.02526
19	0.02525
20	0.02524
21	0.02523
22	0.02522
23.	0.02521
24	0.02520
25.	0.02519
26.	0.02518
27	0.02517
28	0.02516
29	0.02515
30	0.02514
31	0.02513

Table 57:

Calculation of '$\underline{t}$' value for *C. cephalonica*. at Legon and Kwabenya.

Pupation variances were assumed to be equal; and a combined estimate of the variance made using pooled data, thus:

$$S^2 = \frac{1}{n_1+n_2-2}\left(\Sigma x_1^2 - \frac{(\Sigma x_1)^2}{n_1} + \Sigma x_2^2 - \frac{(\Sigma x_2)^2}{n_2}\right)$$

and then evaluated $\underline{t} = \frac{\bar{x}_1 - \bar{x}_2}{s\sqrt{\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$

entering the value obtained in the table of $\underline{t}$ at (n_1+n_2-2) degrees of freedom (ν = degrees of freedom, a = level of significance)

Treatments

1	2
Kwabenya	Legon
$\Sigma x_1 = 242$	$\Sigma x_2 = 393$
$\bar{x}_1 = 30.3$	$\bar{x}_2 = 30.2$
$\Sigma x_1^2 = 7340$	$\Sigma x_2^2 = 11891$

$$s^2 = \frac{1}{19}\left(7340 - \frac{242^2}{8} + 11891 - \frac{393^2}{13}\right)$$

$$= 1.5568$$

$S = 1.248$

$$t = \frac{0.1}{1.248\sqrt{\frac{1}{8} + \frac{1}{13}}}$$

$t_{(cal.)} = \underline{0.178}$ $\nu = 19$, $a = 0.05$

$t_{(tab.)} = 2.093$

$t_{(cal.)} < t_{(tab.)}$

∴ No significant difference between means.

Table 58:

Calculation of '*t*' value for *E. cautella* at Legon and Kwabenya.

Assumption: as in table 57

Treatment

1 Legon	2 Kwabenya
$\Sigma x_1 = 292$	$\Sigma x_2 = 173$
$\bar{x}_1^2 = 22.5$	$\bar{x}_2 = 21.6$
$\Sigma x_1^2 = 6572$	$\Sigma x_2^2 = 3751$
$n_1 = 13$	$n_2 = 8$

$$s^2 = \frac{1}{19}\left(6572 - \frac{292^2}{13} + 3751 - \frac{173^2}{8}\right)$$

$$= 23.1058$$

$$S = 4.807$$

$$t = \frac{0.9}{4.807\sqrt{\frac{1}{13} + \frac{1}{8}}}$$

$t_{(cal.)} = \underline{0.417}$ $\nu = 19$, $a = 0.05$

$t_{(tab.)} = 2.093$

$t_{(cal.)} < t_{(tab.)}$

∴ No significant difference between means.

Table 59:

Calculations of percentage adult increase or reduction of generation two (G2) over generation one (G1) in limited amount of standard medium.

EC_{50}

Set 1. $\frac{4167}{205} \times 100 = 2032.7$

Set 2. $\frac{4137}{212} \times 100 = 1951.4$

CC_{50}

Set 1. $\frac{2675}{158} \times 100 = 1693.0$

Set 2. $\frac{2476}{166} \times 100 = 1491.6$

$E + \frac{C}{2}$

Set 1. EC: $\frac{3009}{108} \times 100 = 2786$ — CC: $\frac{1475}{80} \times 100 = 1843.8$

Set 2. EC: $\frac{3091}{115} \times 100 = 2687.8$ — CC: $\frac{1441}{66} \times 100 = 1675.6$

$C + \frac{E}{2}$

Set1. CC: $\frac{2519}{79} \times 100 = 3188.6$ — EC: $\frac{11}{101} \times 100 = 10.9$

Set 2. CC: $\frac{2267}{85} \times 100 = 2667.1$ — EC: $\frac{6}{105} \times 100 = 5.7$

CC/EC

Set 1. EC: $\frac{4}{99} \times 100 = 4.0$ — CC: $\frac{2244}{91} \times 100 = 2465.9$

Set 2. EC: $\frac{3}{100} \times 100 = 3$ — CC: $\frac{2189}{92} \times 100 = 2379.3$

Table 60:

Calculations of percentage adult increase or reduction of generation two (G2) over generation one (G1) in limited amount of broken cocoa beans.

EC_{50}

Set 1. $\frac{929}{131} \times 100 = 709.2$

Set 2. $\frac{993}{138} \times 100 = 719.6$

CC_{50}

Set 1. $\frac{1808}{110} \times 100 = 1643.6$

Set 2. $\frac{1854}{117} \times 100 = 1584.6$

$E + \frac{C}{2}$

	EC	CC
Set 1.	$\frac{17}{55} \times 100 = 30.9$	$\frac{670}{50} \times 100 = 1340$
Set 2.	$\frac{35}{60} \times 100 = 58.3$	$957 \times 100 = 2126.7$

$C + \frac{E}{2}$

	CC	EC
Set 1	$\frac{1402}{56} \times 100 = 2503.6$	$\frac{2}{18} \times 100 = 11.1$
Set 2.	$\frac{1619}{67} \times 100 = 2416.4$	$\frac{4}{21} \times 100 = 19.0$

CC/EC

	CC	EC
Set 1.	$\frac{1137}{43} \times 100 = 2644.2$	$\frac{0}{10} \times 100 = 0$
Set 2.	$\frac{1325}{44} \times 100 = 3011.4$	$\frac{0}{14} \times 100 = 0$

Table 61:

Calculations of percentage adult increase or reduction of generation two (G2) over generation one (G1) and generation three (G3) over generation one (G1) in abundance of standard medium.

		G2/G1	G3/G2
EC_{50}	Set 1.	$\frac{495}{46} \times 100 = 2054.3$	$\frac{4,500}{945} \times 100 = 476.2$
	Set 2.	$\frac{970}{45} \times 100 = 2155.6$	$\frac{4.921}{970} \times 100 = 507.3$
CC_{50}	Set 1.	$\frac{692}{43} \times 100 = 1609.3$	$\frac{1.586}{692} \times 100 = 229.2$
	Set 2.	$\frac{651}{41} \times 100 = 1587.8$	$\frac{1.750}{651} \times 100 = 2.68.9$
$\frac{E + C}{2}$		EC	EC
	Set 1.	$\frac{679}{23} \times 100 = 2952.2$	$\frac{213}{679} \times 100 = 31.4$
		CC	CC
		$\frac{412}{22} \times 100 = 1872.7$	$\frac{927}{412} \times 100 = 225.0$
		EC	EC
	Set 2.	$\frac{912}{24} \times 100 = 3800$	$\frac{372}{912} \times 100 = 40.8$
		CC	CC
		$\frac{510}{22} \times 100 = 2318.2$	$\frac{1,002}{510} \times 100 = 102.0$

Table 62.

Calculations of percentage adult increase or reduction of generation two (G2) over generation one (G1) in abundance of broken cocoa beans.

EC_{50}

Set 1. $\frac{296}{31} \times 100 = 954.8$

Set 2. $\frac{264}{27} \times 100 = 977.8$

CC_{50}

Set 1. $\frac{427}{29} \times 100 = 1472.4$

Set 1. $\frac{408}{26} \times 100 = 1569.2$

$E + \frac{C}{2}$

		EC	CC
$E + \frac{C}{2}$	Set 1.	$\frac{42}{19} \times 100 = 221.1$	$\frac{260}{15} \times 100 = 1733.3$
	Set 2.	$\frac{35}{17} \times 100 = 205.9$	$\frac{279}{16} \times 100 = 1743.8$

		CC	EC
$C + \frac{E}{2}$	Set 1.	$\frac{372}{16} \times 100 = 2325$	$\frac{18}{9} \times 100 = 200$
	Set 2.	$\frac{380}{18} \times 100 = 2111.1$	$\frac{15}{11} \times 100 = 136.4$

		CC	EC
CC/EC	Set 1.	$\frac{410}{18} \times 100 = 2277.8$	$\frac{11}{7} \times 100 = 157.1$
	Set 2.	$\frac{365}{16} \times 100 = 2218.3$	$\frac{12}{8} \times 100 = 150$

Table 62 (Cont'd)

		$\frac{G2}{G1}$		$\frac{G3}{G2}$	
$C + \frac{E}{2}$	Set 1.	CC: $\frac{601}{21} \times 100$	= 2861.9	CC: $\frac{1.630}{601} \times 100$	= 271.2
		EC: $\frac{187}{24} \times 100$	= 779.2	EC: $\frac{287}{187} \times 100$	= 153.5
	Set 2.	CC: $\frac{579}{23} \times 100$	= 2517.4	CC: $\frac{1.817}{579} \times 100$	= 313.8
		EC: $\frac{253}{23} \times 100$	= 1100.0	EC $\frac{7}{8}$: $\frac{325}{579} \times 100$	= 56.13
CC/EC	Set 1.	CC: $\frac{594}{22} \times 100$	= 2700.0	CC: $\frac{1.613}{594} \times 100$	= 271.5
		EC: $\frac{652}{23} \times 100$	= 2834.8	EC: $\frac{643}{652} \times 100$	= 98.6
	Set 2.	CC: $\frac{563}{24} \times 100$	= 2345.8	CC: $\frac{1.764}{563} \times 100$	= 313.2
		EC: $\frac{625}{24} \times 100$	= 2604	EC: $\frac{592}{625} \times 100$	= 94.7

Table 63:

Results of analysis of variance on competition in standard medium (limited amount of food and space) for emerged adults of C. cephalonica. Using IBM Computer.

A N A L Y S I S   O F   V A R I A N C E
P 1, S E T 1

I N P U T   D A T A

28.	35.	25.	32.	38.
16.	16.	16.	15.	16.
17	15	17	16	15
22.	15.	17.	19.	18.
410.	631.	574.	565.	495.
265	274.	318	321.	297.
446.	571.	412.	382.	433.

L E V E L   O F   F A C T O R S

R	5
C	4
G	2

G R A N D   M E A N

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN S SQUARES	F-TEST	F-READING AT 5 PERCENT	COMMENTS
R	15726.85158	4	3931.71289	2.22131	3.26	NS
C	92548.26580	3	30849.41802	17.42910	3.49	*
RC	21794.34770	12	1816. 19555	1.02610	2.69	NS
G	1808375.75341	1	1808375.75341	1021.58420	4.75	*
RG	16413.25395	4	4103.31348	2.31826	3.26	NS
CG	78656.65643	3	26218.88286	14.81297	3.49	*
RCG	21239.94145	12	1769.99487	1.00000		
T O T A L	2054754.50292	39				

* Denotes Significant at 5 percent level
NS Denotes not significant at 5 percent level
C Denotes Corcyra Cephalonica in the various treatments
R Denotes Replicate
G Denotes Generation.

Table 64:

Results of analysis of variance on competition in standard medium (limited amount of food and space) for emerged adults of C. *cephalonica*

RANDOMISED BLOCK DESIGN

PAGE 1, SET 1

BLOCK MEANS

BLOCK NO.	MEANS
1	218.2500
2	270.0000
3	236.3750
4	224.8750
5	215.6250

TREATMENT MEANS

TREATMENT	MEAN	TREATMENT	MEAN
G1, CC	31.6000	G1, C+E/2	15.8000
G1, E+C/2	16.0000	G1, CC/EC	18.2000
G2, CC	535.0001	G2, C+E/2	503.8009
G2, E+C/2	295.0000	G2, CC/EC	448.8000

GRAND TOTAL, GT = 9321.0019

GENERAL MEAN, GM = 233.0250

CORRECTION FACTOR, CF = 2172026.5068

Table 65:

Results of analysis of variance on competition in standard medium (limited amount of food and space) for emerged adults of C. *cephalonica*

RANDOMISED BLOCK DESIGN

PAGE 1, SET 1

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	DF	SS	MS	FC		F - READING AT 0.05	0.01
BLOCKS	4	15726.5019	3931.6254	1.8517	NS	3.7390	6.5150
TREATMENTS	7	1979580.5034	282797.1883	133.1968	*	2.7640	4.2780
ERROR	28	59448.2579	2123.1518				
TOTAL	39	2054755.2529					

STANDARD ERROR/PLOT. S = 46.07766734

STANDARD ERROR/TRT. MEAN.SX = 20.60655979

STANDARD ERROR/DIFF. OF 2 TRT. MEANS. SD = 29.14207463

COEFFICIENT OF VARIATION. CV = 19.77370076 PERCENT

LSD AT 5 PERCENT = 51.3191

LSD AT 1 PERCENT = 76.4687

Table 66:

Results of analysis of variance on competition in standard medium (limited amount of food and space) for emerged adults of C. cephalonica.

ANALYSIS OF VARIANCE

P1, SET 2

INPUT DATA

32.	37.	27.	32.	38.
17.	17.	15.	16.	20.
16.	19.	17.	15.	19.
18.	19.	15.	20.	20.
506.	374.	510.	565.	521.
503.	353.	398.	546.	468.
319.	266.	263.	232.	361.
371.	524.	467.	398.	429.

LEVEL OF FACTORS

R	5
C	4
G	2

GRAND MEAN 220.07501

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F- TEST	F-READING AT 5 PERCENT	COMMENT
R	5392.40040	4	1348.10010	0.53595	3.26	NS
C	67826.07830	3	22608.69145	8.98844	3.49	*
RC	29240.78520	12	2436.73194	0.96876	2.69	NS
G	1578075.75341	1	1578075.75341	627.38891	4.75	*
RG	5207.50098	4	1301.87524	0.51758	3.26	NS
CG	55426.65635	3	18475.55082	7.34524	3.49	*
RCG	30183.68363	12	2515.30713	1.00000		
TOTAL	1771352.25341	39				

* Denotes Significant at 5 percent level

NS Denotes not significant at 5 percent level

Table 67:

Results of analysis of variance on competition in standard medium (limited amount of food and space) for emerged adults of C. cephalonica.

RANDOMISED BLOCK DESIGN

PAGE 1, SET 2

BLOCK MEANS

BLOCK NO.	MEANS
1	222.7500
2	201.1250
3	214.0000
4	228.0000
5	234.5000

TREATMENT MEANS

TREATMENT	MEAN	TREATMENT	MEAN
G1, CC	33.2000	G1, C+E/2	17.0000
G1, E+C/2	17.2000	G1, CC/EC	18.4000
G2, CC	495.2000	G2, C+E/2	453.6000
G2, E+C/2	288.2000	G2, CC/EC	437.8000

GRAND TOTAL, GT = 8803.0019

GENERAL MEAN, GM = 220.0750

CORRECTION FACTOR, CF = 1937320.2529

Table 68:

Results of analysis of variance on competition in standard medium (limited amount of food and space) for emerged adults of C. cephalonica.

RANDOMISED BLOCK DESIGN

PAGE 1, SET 2

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	DF	SS	MS	FC		F - READING AT 0.05	F - READING AT 0.01
BLOCKS	4	5392.5009	1348.1252	0.5840	NS	3.7390	6.5150
TREATMENT	7	1701328.2534	243046.8754	105.2924	*	2.7640	4.2780
ERROR	28	64632.5079	23000.3037				
TOTAL	39	1771353.2534					

STANDARD ERROR/PLOT.S = 48.04480753

STANDARD ERROR/TRT. MEAN, SX = 21.48629003

STANDARD ERROR/DIFF. OF 2 TRT. MEANS, SD = 30.38620381

COEFFICIENT OF VARIATION, CV = 21.83110813 PERCENT

LSD AT 5 PERCENT = 53.5101

LSD AT 1 PERCENT = 79.7333

Table 69:

Results of analysis of variance on competition in standard medium (limited amoung of food and space) for emerged adults of E. cautella

ANALYSIS OF VARIANCE

P 2, SET 1

INPUT DATA

37.	40.	49.	37.	42.
16.	23.	20.	24.	25.
23.	22.	17.	18.	21.
21.	18.	20.	19.	22.
695.	874.	976.	763.	859.
607.	659.	530.	811.	402.
3.	4.	1.	2.	1.
0.	1.	0.	2.	1.

LEVEL OF FACTORS

R	5
E	4
G	2

GRAND MEAN 192.62503

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F-TEST	F-READING AT 5 PERCENT	COMMENTS
R	10119.25197	4	2529.81299	0.53252	3.26	NS
E	1401167.50292	3	467055.81335	98.31512	3.49	*
RE	61379.94541	12	5114.99513	1.07670	2.69	NS
G	1114558.25341	1	1114558.25341	234.61419	4.75	*
RG	10579.15041	4	2644.78760	0.55672	3.26	NS
EG	1298497.50292	3	432832.43823	91.11111	3.49	*
REG	57007.21102	12	4750.60059	1.00000		
TOTAL	3953307.50585	39				

* Denotes significant at 5 percent level
NS Denotes not significant at 5 percent level
E Denotes Ephestia Cautella in the various treatements

Table 70:

Results of analysis of variance on competition on standard medium (limited amount of food and space) for emerged adults of E. *cautella*.

RANDOMISED BLOCK DESIGN

PAGE 2, SET 1

BLOCK MEANS

BLOCK NO.	MEANS
1	175.2500
2	205.1250
3.	201.6250
4	209.5000
5	171.6250

TREATMENT MEANS

TREATMENT	MEAN	TREATMENT	MEAN
G1, EC	41.0000	G1, E+C/2	21.6000
G1, C+E/2	20.2000	G1, CC/EC	20.0000
G2, EC	833.4000	G2, E+C/2	601.8000
G2, C+E/2	2.2000	G2, CC/EC	0.8000

GRAND TOTAL, GT = 7705.0009

GENERAL MEAN, GM = 192.6250

CORRECTION FACTOR, CF = 1484175.7529

Table 71:

Results of analysis of variance on competition in standard medium (limited amount of food and space) for emerged adults of E. cautella.

RANDOMISED BLOCK DESIGN

PAGE 2, SET 1

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	DF	SS	MS	FC		F - READING AT 0.05	0.01
BLOCKS	4	10119.2519	2529.8129	0.5492	NS	3.7390	6.5150
TREATMENTS	7	3814223.0058	544889.0017	118.3000	*	2.7640	4.2780
ERROR	28	128967.7658	4605.9912				
TOTAL	39	3953310.0058					

STANDARD ERROR/PLOT, S = 67.86744707

STANDARD ERROR/TRT. MEAN, SX = 30.35124592

STANDARD ERROR/DIFF. OF 2 TRT. MEANS, SD = 42.92314156

COEFFICIENT OF VARIATION, CV = 35.23293314 PERCENT

LSD AT 5 PERCENT = 75.5876

LSD AT 1 PERCENT = 112.6302

Table 72:

Results of analysis of variance on competition in standard medium (limited amount of food and space) for emerged adults of E. cautella.

ANALYSIS OF VARIANCE

P 2, SET 2

INPUT DATA

45.	38.	38.	45.	46.
24.	23.	25.	20.	23.
22.	18.	23.	22.	20.
19.	21	18.	21.	21.
801.	635.	960.	863.	878.
500.	680.	830.	683.	398.
3.	0.	1.	1.	1.
1.	0.	2.	0.	0.

LEVEL OF FACTORS

R	5
E	4
G	2

GRAND MEAN 194.22500

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F-TEST	F-READING AT 5 PERCENT	COMMENTS
R	24297.60160	4	6074.40040	1.17693	3.26	NS
E	1412582.50292	3	470860.81335	91.23097	3.49	*
RE	63569.16415	12	5297.43067	1.02639	2.69	NS
G	1123925.75341	1	1123925.75341	217.76461	4.75	*
RG	24772.00395	4	6193.00098	1.19991	3.26	NS
EG	1304215.25341	3	434738.37573	84.23211	3.49	*
REG	61936 .34384	12	5161.19532	1.00000		
TOTAL	4015295.50683	39				

* Denotes significant at 5 percent level
NS Denotes not significant at 5 percent level

Table 73:

Results of analysis of variance on competition in standard medium (limited amount of food and space) for emerged adults of E. cautella.

RANDOMISED BLOCK DESIGN

PAGE 2, SET 2

BLOCK MEANS

BLOCK NO.	MEANS
1	176.8750
2	176.8750
3.	237.1250
4.	206.8750
5.	173.3750

TREATMENT MEANS

TREATMENT	MEAN	TREATMENT	MEAN
G1, EC	42.4000	G1, E+C/2	23.0000
G1, C+E/2	21.0000	G1, CC/EC	20.0000
G2, EC	827.4000	G2, E+C/2	618.2000
G2, C+E/2	1.2000	G2, CC/EC	0.6000

GRAND TOTAL, GT = 7769.0009

GENERAL MEAN, GM = 194.2250

CORRECTION FACTOR, CF = 1508934.2529

Table 74:

Results of analysis of variance on competition in standard medium (limited amount of food and space) for emerged adults of E. cautella.

RANDOMISED BLOCK DESIGN

PAGE 2, SET 2

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	DF	SS	MS	FC		F-READING AT 0.05	F-READING AT 0.01
BLOCKS	4	24297.5039	6074.3759	1.1317	NS	3.7390	6.5150
TREATMENTS	7	3840723.0058	548674.7514	102.2304	*	2.7640	4.2780
ERROR	28	150277.0316	5367.0361				
TOTAL	39	4015297.5058					

STANDARD ERROR/PLOT, S = 73.26005572

STANDARD ERROR/TRT. MEAN, SX = 32.76289376

STANDARD ERROR/DIFF. OF 2 TRT. MEANS, SD = 46.33372507

COEFFICIENT OF VARIATION, CV = 37,71916970 PERCENT

LSD AT 5 PERCENT = 81.5936

LSD AT 1 PERCENT = 121.5796

Table 75:

Results of analysis of variance on competition in broken cocoa beans (limited amount of food and SPACE) for emerged adults of C. cephalonica.

ANALYSIS OF VARIANCE

P3, SET I

INPUT DATA

17.	22.	23.	22.	26.
14.	7.	8.	14.	13.
11.	16.	6.	7.	10.
8.	7.	12.	7.	9.
327.	396.	372.	354.	359.
317.	205.	218.	350.	312.
215.	170.	91.	74.	120.
349.	286.	151.	127.	224.

LEVEL OF FACTORS

R	5
C	4
G	2

GRAND MEAN 131.90002

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F-TEST	F-READING AT 5 PERCENT	COMMENTS
R	10590.60158	4	2647.65039	1.46168	3.26	NS
C	75624.40643	3	25208.13285	13.91658	3.49	*
RC	24401.58598	12	2033.46533	1.12260	2.69	NS
G	565964.12670	1	565964.12670	312.45031	4.75	*
RG	10404.90041	4	2601.22510	1.43605	3.26	NS
CG	61651.50791	3	20550.50395	11.34526	3.49	*
RCG	21736.48052	12	1811.37329	1.00000		
TOTAL	770373.37646	39				

* Denotes significant at 5 percent level

NS Denotes not significant at 5 percent level

Table 76:

Results of analysis of variance on competition in broken cocoa beans (limited amount of food and space) for emerged adults of C. cephalonica.

RANDOMISED BLOCK DESIGN

PAGE 3, SET 1

BLOCK MEANS

BLOCK NO.	MEANS
1	157.2500
2	138.6250
3	110.1250
4	119.3750
5	134.1250

TREATMENT MEANS

TREATMENT	MEAN	TREATMENT	MEAN
G1, CC	22.0000	G1, C+E/2	11.2000
G1, E+C/2	10.0000	G1, CC/EC	8.6000
G2, CC	361.6000	G2, C+E/2	280.4000
G2, E+C/2	134.0000	G2, CC/EC	227.4000

GRAND TOTAL, GT = 5276.0009

GENERAL MEAN, GM = 131.9000

CORRECTION FACTOR, CF = 695904.5014

Table 77:

Results of analysis of variance on competition in broken cocoa beans (limited amount of food and space) for emerged adults of C. cephalonica.

RANDOMISED BLOCK DESIGN

PAGE 3, SET 1

ANALYSIS OF RVARIANCE

SOURCE OF VARIATION	DF	SS	MS	FC		F- READING AT 0.05	F- READING AT 0.01
BLOCKS	4	10590.6269	2547.6567	1.3111	NS	3.7390	6.5150
TREATMENTS	7	703240.1267	100462.8595	49.7490	*	2.7640	4.2780
ERROR	28	56543.0079	2019.3930				
TOTAL	39	770373.7514					

STANDARD ERROR/PLOT,S = 44.93766030

STANDARD ERROR/TRT. MEAN, SX = 20.09673313

STANDARD ERROR/DIFF. OF 2 TRT. MEANS, SD = 28.42107014

COEFFICIENT OF VARIATION, CV = 34.06948861 PERCENT

LSD AT 5 PERCENT = 50.0494

LSD AT 1 PERCENT = 74.5768

Table 78:

Results of analysis of variance on competition in broken cocoa beans (limited amount of food and space) for emerged adults of _C. cephalonica_.

ANALYSIS OF VARIANCE

P3 SET 2

INPUT DATA

25.	22.	23.	24.	23.
13.	17.	15.	10.	12.
8.	8.	14.	6.	9.
10.	9.	7.	10.	8.
375.	359.	387.	391.	342.
307.	359.	341.	287.	325.
220.	243.	168	154.	172.
361.	256.	213.	309.	184.

LEVEL OF FACTORS

R	5
C	4
G	2

GRAND MEAN 150.65002

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F-TEST	F-READING AT 5 PERCENT	COMMENT
R	4510.60059	4	1127.65014	1.25874	3.26	NS
C	52196.10165	3	17398.69926	19.42145	3.49	*
RC	11657.40041	12	971.44995	1.08439	2.69	NS
G	750760.12670	1	750760.12670	838.04297	4.75	*
RG	4289.00098	4	1072.25024	1.19690	3.26	NS
CG	38585.80479	3	12861.93362	14.35725	3.49	*
RCG	10750.19143	12	895.84924	1.00000		
TOTAL	872749.00170	39				

* Denotes significant at 5 percent level
NS Denotes not significant at 5 percent level

Table 79:

Results of analysis of variance on competition in broken cocoa beans (limited amount of food and space) for emerged adults of C. cephalonica.

RANDOMISED BLOCK DESIGN

PAGE 3, SET 2

BLOCK MEANS

BLOCK NO.	MEANS
1	164.8750
2	159.1250
3	146.0000
4	148.8750
5	134.3750

TREATMENT MEANS

TREATMENT	MEAN	TREATMENT	MEAN
G1, CC	23.4000	G1, C+E/2	13.4000
G1, E+C/2	9.0000	G1, CC/EC	8.8000
G2, CC	370.8000	G2, C+E/2	323.8000
G2, E+C/2	191.4000	G2, CC/EC	264.6000

GRAND TOTAL, GT = 6026.0009

GENERAL MEAN, GM = 150.6500

CORRECTION FACTOR, CF = 907816.8767

Table 80:

Results of analysis of variance on competition in broken cocoa beans (limited amount of food and space) for emerged adults of C. cephalonica

RANDOMISED BLOCK DESIGN

PAGE 3, SET 2

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	DF	SS	MS	FC		F- READING AT 0.05	F- READING AT 0.01
BLOCKS	4	4510.7509	1127.6877	1.1827	NS	3.7390	6.5150
TREATMENTS	7	841542.1264	120220.2970	126.0902	*	2.7640	4.2780
ERROR	28	26696.5039	953.4465				
TOTAL	39	872749.3767					

STANDARD ERROR/PLOT, S = 30.87792973

STANDARD ERROR/TRT. MEAN, SX = 13.80902865

STANDARD ERROR/DIFF. OF 2 TRT. MEANS, SD = 19.52891926

COEFFICIENT OF VARIATION, CV = 20.49646764 PERCENT

LSD AT 5 PERCENT = 34.3904

LSD AT 1 PERCENT = 51.2438

Table 81:

Results of analysis of variance on competition on broken cocoa beans (limited amount of food and space) for emerged adults of *E. cautella*.

A N A L Y S I S O F V A R I A N C E

P 4, S E T 1

I N P U T D A T A

32.	20.	24.	30.	25.
8.	12.	12.	9.	14.
2.	2.	3.	7.	4.
0.	3.	3.	2.	2.
207.	202.	118.	250.	152.
3.	5.	5.	2.	2.
0.	1.	1.	0.	0.
0.	0.	0.	0.	0.

L E V E L O F F A C T O R S

R	5
E	4
G	2

G R A N D M E A N 29.05000

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F-TEST	F-REATING AT 5 PERCENT	COMMENT
R	1329.65014	4	332.41253	1.08905	3.26	NS
E	79172.31268	3	26390.76958	86.46215	3.49	*
RE	4488.95020	12	374.07916	1.22556	2.69	NS
G	13468.90041	1	13468.90041	44.12717	4.75	*
RG	1241.85010	4	310.46252	1.01714	3.26	NS
EG	50391.50791	3	16797.16801	55.03133	3.49	*
REG	3662.75049	12	305.22918	1.00000		
T O T A L	153755.87542	39				

* Denotes significant at 5 percent level

NS Denotes not significant at 5 percent level

Table 82:

Results of analysis of variance on competition in broken cocoa beans (limited amount of food and space) for emerged adults of E. cautella.

RANDOMISED BLOCK DESIGN

PAGE 4, SET 1

BLOCK MEANS

BLOCK NO.	MEANS
1	31.5000
2.	30.6250
3.	20.7500
4	37.5000
5	24.8750

TREATMENT MEANS

TREATMENT	MEAN	TREATMENT	MEAN
G1, EC	26.2000	G1, E+C/2	11.0000
G1, C+E/2	3.6000	G1, CC/EC	2.0000
G2, EC	185.8000	G2, E+C/2	3.4000
G2, C+E/2	0.4000	G2, CC/EC	0.0000

GRAND TOTAL, GT = 1162.0002

GENERAL MEAN, GM = 29.0500

CORRECTION FACTOR, CF = 33756.1016

Table 83:

Results of analysis of variance on competition in broken cocoa beans (limited amount of food and space) for emerged adults of _E_. _cautella_.

RANDOMISED BLOCK DESIGN

PAGE 4, SET 1

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	DF	SS	MS	FC		F- READING AT 0.05	F- READING AT 0.01
BLOCKS	4	1329.6564	132.4141	0.9908	NS	3.7390	6.5150
TREATMENTS	7	143032.7191	20433.2422	60.9066	*	2.7640	4.2780
ERROR	28	9393.5644	335.4844				
TOTAL	39	153755.9379					

STANDARD ERROR/PLOT, S = 18.31623464

STANDARD ERROR/TRT. MEAN, SX = 8.19126894

STANDARD ERROR/DIFF. OF 2 TRT. MEANS, SD = 11.58420183

COEFFICIENT OF VARIATION, CV = 63. 05071268 PERCENT

LSD AT 5 PERCENT = 20.3997

LSD AT 1 PERCENT = 30.3969

Table 84:

Results of analysis of variance on competition in broken cocoa beans (limited amount of food and space) for emerged adults of *E. cautella*.

ANALYSIS OF VARIANCE

P4 SET 2

INPUT DATA

27.	26.	26.	31.	28.
10.	11.	16.	9.	14.
5.	4.	5.	4.	3.
2.	4.	2.	3.	3.
221.	173.	233.	247.	124.
7.	5.	12.	3.	8.
1.	1.	2.	0.	0.
0.	0.	0.	0.	0.

LEVEL OF FACTORS

R	5
E	4
G	2

GRAND MEAN 31.75000

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF GREEDOM	MEAN SQUARES	F-TEST	F-READING AT 5 PERCENT	COMMENTS
R	1293.75024	4	323.43756	1.03967	3.26	NS
E	89711.70333	3	29903.89849	96.12338	3.49	*
RE	4026.05029	12	335.50421	1.07845	2.69	NS
G	16160.40041	1	16160.40040	51.94699	4.75	*
RG	1295.85010	4	323.96252	1.04135	3.26	NS
EG	57910.60166	3	19303.53520	62.05011	3.49	*
Error RCG+R+RC+RG	3733.15039	12	311.09588	1.00000		
TOTAL	174131.46917	39				

* Denotes significant at 5.percent level
NS Denotes not significant at 5 percent level

Table 85:

Results of analysis of variance on competition in broken cocoa beans (limited amount of food and space) for -emerged adults of E. *cautella*

RANDOMISED BLOCK DESIGN

PAGE 4, SET 2

BLOCK MEANS

BLOCK NO.	MEANS
1	34.1250
2	28.0000
3	37.0000
4	37.1250
5	22.5000

TREATMENT MEANS

TREATMENT	MEAN	TREATMENT	MEAN
G1, EC	27.6000	G1, E+C/2	12.0000
G1, C+E/2	4.2000	G1, CC/EC	2.8000
G2, EC	199.6000	G2, E+C/2	7.0000
G2, C+E/2	0.8000	G2, CC/EC	0.0000

GRAND TOTAL, GT = 1270.0002

GENERAL MEAN, GM = 31.7500

CORRECTION FACTOR,CF = 40322.5079

Table 86:

Results of analysis of variance on competition in broken cocoa beans (limited amount of food and space) for emerged adults of *E. cautella*.

PAGE 4, SET 2

RANDOMISED BLOCK DESIGN

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	DF	SS	MS	FC		F-READING AT 0.05	F-READING AT 0.01
BLOCKS	4	1293.7502	323.4375	1.0001	NS	3.7390	6.5150
TREATMENTS	7	163782.7191	23397.5273	72.3496	*	2.7640	4.2780
ERROR	28	9055.0644	323.3951				
TOTAL	39	174131.5316					

STANDARD ERROR/PLOT, S = 17.98319249

STANDARD ERROR/TRT. MEAN, SX = 8.04232790

STANDARD ERROR/DIFF. OF 2 TRT. MEANS, SD = 11.37356760

COEFFICIENT OF VARIATION, CV = 56.63996896

LSD AT 5 PERCENT = 20.0288

LSD AT 1 PERCENT = 29.8442

Table 87:

Results of analysis of variance on competition in standard medium (Abundance of food and space) for emerged adults of C. cephalonica

A N A L Y S I S   O F   V A R I A N C E

P 5   S E T 1

I N P U T   D A T A

43.	41.
21.	23.
22.	22.
22.	22.
692.	651.
601.	579.
412.	510.
594.	563.
1586.	1750.
1630.	1817.
927.	1002.
1613.	1764.

L E V E L   O F   F A C T O R S

R	2
C	4
G	3

G R A N D   M E A N   764.45837

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F-TEST	F-READING AT 5 PERCENT	COMMENTS
R	14065.04299	1	14065.04299	8.89731	5.99	*
C	396976.12573	3	132325.37536	83.70681	4.76	*
RC	411.45837	3	137.15280	9.08676	4.76	NS
G	9010846.02734	2	4505423.01367	2850.05518	5.14	*
RG	27553.8598	2	13776.54299	8.71481	5.14	*
CG	448661.75085	6	74776.95330	47.30265	4.28	*
RCG	9484.91799	6	1580.81958	1.00000		
T O T A L	9907994.02343	23				

* Denotes significant at 5 percent level
NS Denotes not significant at 5 percent level

Table 88:

Results of analysis of variance on competition in standard medium (Abundance of food and space) for emerged adults of E. cautella.

A N A L Y S I S   O F   V A R I A N C E

P 5   S E T 2

I N P U T   D A T A

46.	45.
23.	24.
24.	23.
23.	24.
945.	970.
679.	912.
187.	253.
652.	625.
4500.	4921.
213.	372.
287.	325.
643.	592.

L E V E L   O F   F A C T O R S

R	2
E	4
G	3

G R A N D   M E A N   721.16674

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F-TEST	F-READING AT 5 PERCENT	COMMENTS
R	31104.00395	1	31104.00395	3.61151	5.99	NS
E	11397106.02734	3	3799035.00683	441.10949	4.76	*
RE	30398.00395	3	10132.66799	1.17651	4.76	NS
G	8496442.02343	2	4248221.01171	493.26483	5.14	*
RG	20108.25395	2	10054.12697	1.16739	5.14	*
EG	17141988.04687	6	2856997.50683	331.72863	4.28	*
REG	51674.72666	6	8612.45510	1.00000		
T O T A L	37168816.10937	23				

* Denotes significant at 5 percent level

NS Denotes not significant at 5 percent level

Table 89:

Results of analysis of variance on competition in broken cocoa beans (Abundance of food and space) for emerged adults of E. cautella.

ANALYSIS OF VARIANCE

P6 SET 1

INPUT DATA

31.	27.
19.	17.
9.	11.
7.	8.
296.	264.
42.	35.
18.	15.
11.	12.

LEVEL OF FACTORS

R	2
E	4
G	2

GRAND MEAN 51.37500

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F-TEST	F-READING AT 5 PERCENT	COMMENTS
R	121.00001	1	121.00001	3.06976	10.13	NS
E	57506.25790	3	19168.75395	486.31085	9.28	*
RE	224.50003	3	74.83334	1.89852	9.28	NS
G	19881.00395	1	19881.00395	504.38061	10.13	*
RG	90.25001	1	90.25001	2.28964	10.13	NS
EG	43598.50791	3	14532.83400	368.69769	9.28	*
REG	118.25001	3	39.41667	1.00000		
TOTAL	121539.76583	18				

* Denotes significant at 5 percent level
NS Denotes not significant at 5 percent level

Table 90:

Results of analysis of variance on competition in broken cocoa beans (Abundance of food and space) for emerged adults of E. cautella.

A N A L Y S I S   O F   V A R I A N C E

P 6   S E T   2

I N P U T   D A T A

29.	26.
16.	18.
15.	16.
18.	16.
427.	408.
372.	308.
260.	279.
410.	365.

L E V E L   O F   F A C T O R S

R	2
C	4
G	2

G R A N D   M E A N   190.93753

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F-TEST	F-READING AT 5 PERCENT	COMMENTS
R	95.06251	1	95.06251	0.52843	10.13	NS
C	14005.18947	3	4668.39649	25.95055	9.28	*
RC	703.18762	3	234.39584	1.30295	9.28	NS
G	471625.62573	1	471625.62573	2621.65967	10.13	*
RG	76.56251	1	76.56251	0.42559	10.13	NS
CG	11141.68947	3	3713.89600	20.64470	9.28	*
RCG	539.68762	3	179.89584	1.00000		
T O T A L	498187.00073	15				

* Denotes significant at 5 percent level

NS Denotes not -significant at 5 percent level

Table 91:

Calculation of χ^2 value for E. cautella and C. cephalonica (CC/EC) (larvae) from data on oviposition preferences.

χ^2 is computed from the general formala $\chi^2 = \sum (0-E)^2/E$,

where 0 is an observed frequency, and E. is the corresponding expected one. The value obtained is entered in table of at (n-1) degrees of freedom, where n = the number of class frequencies compared i.e. the number of items in the sum. In testing for association, in which there are more than two categories of classification, the number of degrees of freedom is given by (c-1)(r-1) where c and r represent columns and rows respectively.

Thus from table 16:

$$\chi^2 = \frac{43.1^2}{81.4} + \frac{-35.9^2}{36.9} + \frac{-6.9^2}{18.9} + \frac{-42.6^2}{50.1} + \frac{6.9^2}{11.6}$$

$$= 22.8 + 34.9 + 2.5 + 36.2 + 57.0 + 4.1$$

$$= \underline{157.5} \quad \text{with } (3-1)(2-1) = 2 \text{ degrees of freedom.}$$

This value corresponds to a probability of less than 0.001.

∴ Highly significant association.

Table 92:

Calculation of χ^2 value for E. cautella (larvae) from data on oviposition preferences.

From table 17:

$$\chi^2 = \frac{40^2}{29.5} + \frac{-17.5^2}{22.5} + \frac{-22^2}{29.5}$$

$$= 54.23 + 13.61 + 16.41$$

$$= \underline{84.25} \quad \text{with } (3-1) = 2 \text{ degrees of freedom.}$$

This value corresponds to a probability of less than 0.001.

∴ Highly significant association.

Table 93:

Calculation of χ^2 value for C. cephalonica (larvae) from data on oviposition preferences.

From table 18:

$$\chi^2 = \frac{24.83^2}{33.67} + \frac{7.33^2}{33.67} + \frac{-32.17^2}{33.6}$$

$$= 18.31 + 1.60 + 30.74$$

$$= 50.65 \text{ with } (3-1) = 2 \text{ degrees of freedom.}$$

$$\chi^2_{(2)} = 50.65, \quad P < 0.001$$

∴ Highly significant association.

Table 94:

Calculation of χ^2 value for C. cephalonica (cocoon) from data on oviposition preferences.

From table 19:

$$\chi^2 = \frac{16.67^2}{62.83} + \frac{-0.33^2}{62.83} + \frac{-16.33^2}{62.83}$$

$$= 4.42 + 1.73 + 4.24$$

$$= \underline{10.39} \text{ with } (3-1) = 2 \text{ degrees of freedom.}$$

$$\chi^2_{(2)} = 10.39, \quad P < 0.01$$

∴ Significant association.

Table 95:

Calculation of χ^2 value for E. cautella (cocoon) from data on oviposition preferences.

From table 20:

$$\chi^2 = \frac{25.5^2}{41} + \frac{-9.5^2}{41} + \frac{-16^2}{41}$$

$$= 15.86 + 2.20 + 6.24$$

$= \underline{24.3}$ with $(3-1) = 2$ degrees of freedom.

$\chi^2_{(2)} = 24.3, \quad P < 0.001$

$\therefore$ Highly significant association.

Table 96:

Calculation χ^2 value for C. cephalonica and E. cautella (cocoon) from data on oviposition preferences.

From table 21:

$$\chi^2 = \frac{42.83^2}{62.17} + \frac{-3.17^2}{62.17} + \frac{-39.67^2}{62.17}$$

$$= 29.51 + 0.16 + 25.3$$

$$= \underline{54.93} \text{ with } (3-1) = 2 \text{ degrees of freedom.}$$

$$\chi^2_{(2)} = 54.93, \quad P < 0.001$$

$\therefore$ Highly significant association.

Average HT/electronic hygrometer readings
at 7.30 pm.

(Set 1)

Standard Medium
(limited amount of food and space)

23-11-81

28°C/79.5% RH	-	CC
28°C/78.5% "	-	$C + \frac{E}{2}$
28°C/79.5% "	-	EC
28°C/79.5% "	-	$E + \frac{C}{2}$
28°C/79.5% "	-	CC/EC

27-11-81

31°C/82% RH	-	CC
31°C/82% "	-	$C + \frac{E}{2}$
31°C/80% "	-	EC
31°C/78.5% "	-	$E + \frac{C}{2}$
31°C/78.5% "	-	CC/EC

29-11-81

32°C/72% RH	-	CC
32°C/72% "	-	$C + \frac{E}{2}$
32°C/72% "	-	$E + \frac{C}{2}$
32°C/72% "	-	EC
32°C/72% "	-	CC/EC

Broken cocoa beans
(limited amount of food and space)

23-11-81

28°C/78.5% RH	-	CC/EC
28°C/78.5% "	-	$C + \frac{E}{2}$
28°C/78.5% "	-	$E + \frac{C}{2}$
28°C/78.5% "	-	CC
28°C/78.5% "	-	EC

27-11-81

31°C/78.5%RH	-	CC/EC
31°C/78.0% "	-	$C + \frac{E}{2}$
31°C/78.5% "	-	$E + \frac{C}{2}$
31°C/78.5% "	-	EC
31°C/78.0% "	-	CC

29-11-81

32°C/71% RH	-	CC/EC
32°C/71.5% "	-	$C + \frac{E}{2}$
32°C/71% "	-	$E + \frac{C}{2}$
32°C/71% "	-	CC
32°C/71% "	-	EC

Average HT/electronic hygrometer readings
at 7.30 p.m.

(Set 1)

Cages
Standard Medium
(Abundance of food and space)

23-11-81

28°C/78%RH	-	CC
28°C/78% "	-	EC
28°C/77.5% "	-	C + $\frac{E}{2}$
28°C/78% "	-	E + $\frac{C}{2}$
28°C/78% "	-	CC/EC

27-11-81

31°C/78% RH	-	CC
31°C/77.5% "	-	CC/EC
31°C/78.5% "	-	C + $\frac{E}{2}$
31°C/77% "	-	E + $\frac{C}{2}$
31°C≠77.5% "	-	EC

29-11-81

31°C/71% RH	-	EC
31°C/71% "	-	CC
31°C/70% "	-	CC/EC
31°C/70% "	-	E + $\frac{C}{2}$
31°C/71% "	-	C + $\frac{E}{2}$

Cages
Broken cocoa beans
(Abundance of food and space)

23-11-81

28°C/78.5% RH	-	EC
28°C/78% "	-	CC/EC
28°C/78.5% "	-	C + $\frac{E}{2}$
28°C/78.5% "	-	E + $\frac{C}{2}$
28°C/78% "	-	CC

27-11-81

31°C/77% RH	-	CC/EC
31°C/77.5% "	-	E + $\frac{C}{2}$
31°C/77.5% "	-	C + $\frac{E}{2}$
31°C/77.5% "	-	CC
31°C/77% "	-	EC

29-11-81

31°C/70.5% RH	-	CC/EC
31°C/71% "	-	C + $\frac{E}{2}$
31°C/71% "	-	E + $\frac{C}{2}$
31°C/70.5% "	-	EC
31°C/71% "	-	CC

Average HT/electronic hygrometer readings
at 7.30 p.m.

(Set 1)

Standard medium
(limited amount of food and space)

4-12-81		
30°C/80% RH	-	CC
30°C/80% "	-	C + $\frac{E}{2}$
30°C/80% "	-	E + $\frac{C}{2}$
30°C/80% "	-	CC/EC
30°C/80% "	-	EC
5-12-81		
30°C/80% RH	-	CC
30°C/80% "	-	EC
30°C/80% "	-	CC/EC
30°C/80% "	-	C + $\frac{E}{2}$
30°C/80% "	-	E + $\frac{C}{2}$ $\frac{C}{2}$
15-12-81		
30°C/88% RH	-	EC
30°C/88% "	-	E + $\frac{C}{2}$
30°C/88% "	-	C + $\frac{E}{2}$
30°C/88% "	-	CC/EC
30°C/88% "	-	CC
26-12-81		
30°C/84% RH	-	EC

Broken cocoa beans
(limited amount of food and space)

4-12-81		
30°C/80% RH	-	CC/EC
30°C/80% "	-	E + $\frac{C}{2}$
30°C/80% "	-	C + $\frac{E}{2}$
30°C/80% "	-	CC
30°C/80% "	-	EC
5-12-81		
30°C/80% RH	-	EC
30°C/80% "	-	C + $\frac{E}{2}$
30°C/80% "	-	E + $\frac{C}{2}$
30°C/80% "	-	CC/EC
30°C/80% "	-	CC
15-12-81		
30°C/84% RH	-	EC/CC
30°C/84% "	-	C + $\frac{E}{2}$
30°C/84% "	-	E + $\frac{C}{2}$
30°C/84% "	-	EC
30°C/84% "	-	CC
26-12-81		
30°C/84% RH	-	C + $\frac{E}{2}$

Average HT/electronic hygrometer readings
at 7.30 p.m.

(Set 1)

Cages

Standard Medium
(Abundance of food and space)

4-12-81

30°C/80% RH	-	CC
30°C/80% "	-	$E + \frac{C}{2}$
30°C/80% "	-	$C + \frac{E}{2}$
30°C/80% "	-	EC
30°C/80% "	-	CC/EC

5-12-81

30°C/80% RH	-	$E + \frac{C}{2}$
30°C/80% "	-	$C + \frac{E}{2}$
30°C/80% "	-	CC/EC
30°C/80% "	-	CC
30°C/80% "	-	EC

15-12-81

30°C/84% RH	-	EC/CC
30°C/84% "	-	$C + \frac{E}{2}$
30°C/84% "	-	$E * \frac{C}{2}$
30°C/84% "	-	CC
30°C/84% "	-	EC

26-12-81

30°C/84% RH	-	$C + \frac{E}{2}$
30°C/84% "	-	$E + \frac{C}{2}$
30°C/84% "	-	CC/EC
30°C/84% "	-	EC
30°C/84% "	-	CC

Cages

Broken cocoa beans
(Abundance of food and space)

4-12-81

30°C/80% RH	-	EC
30°C/80% "	-	$C * \frac{E}{2}$
30°C/80% "	-	CC/EC
30°C/80% "	-	$E + \frac{C}{2}$
30°C/80% "	-	CC

5-12-81

30°C/80% RH	-	CC
30°C/80% "	-	$E + \frac{C}{2}$
30°C/80% "	-	$C + \frac{E}{2}$
30°C/80% "	-	CC/EC
30°C/80% "	-	EC

15-12-81

30°C/84% RH	-	CC
30°C/84% "	-	CC/EC
30°C/84% "	-	$C + \frac{E}{2}$
30°C/84% "	-	$E + \frac{C}{2}$
30°C/84% "	-	EC

26-12-81

30°C/84% RH	-	CC
30°C/84% "	-	EC
30°C/84% "	-	$C + \frac{E}{2}$
30°C/84% "	-	CC/EC
30°C/84% "	-	$E + \frac{C}{2}$

Average HT/electronic hygrometer readings at 7.30 p.m.

(Set 2)

Cages

Standard Medium
(limited amount of food and space)

5-12-81

30°C/80% RH	-	EC
30°C/80% "	-	CC/EC
30°C/80% "	-	$E + \frac{C}{2}$
30°C/80% "	-	CC
30°C/80% "	-	$C + \frac{E}{2}$

10-12-81

30°C/86% RH	-	EC
30°C/86%"	-	CC/EC
30°C/86% "	-	$C + \frac{E}{2}$
30°C/86% "	-	$E + \frac{C}{2}$
30°C/86% "	-	CC

15-12-81

30°C/88% RH	-	$C + \frac{E}{2}$
30°C/88% "	-	$E + \frac{C}{2}$
30°C/88% "	-	CC/EC
30°C/88% "	-	EC
30°C/88% "	-	CC

19-12-81

30°C/84% RH	-	EC
30°C/84% "	-	CC
30°C/84% "	-	$E + \frac{C}{2}$
30°C/84% "	-	$C + \frac{E}{2}$

Standard Medium
(abundance of food and space)

5-12-81

30°C/80% RH	-	EC
30°C/80% "	-	$C + \frac{E}{2}$
30°C/80% "	-	$E + \frac{C}{2}$
30°C/80% "	-	CC/EC
30°C/80% "	-	CC

10-12-81

30°C/84% RH	-	CC
30°C/84% "	-	EC
30°C/84% "	-	$C + \frac{E}{2}$
30°C/84% "	-	$E + \frac{C}{2}$
30°C/84% "	-	CC/EC

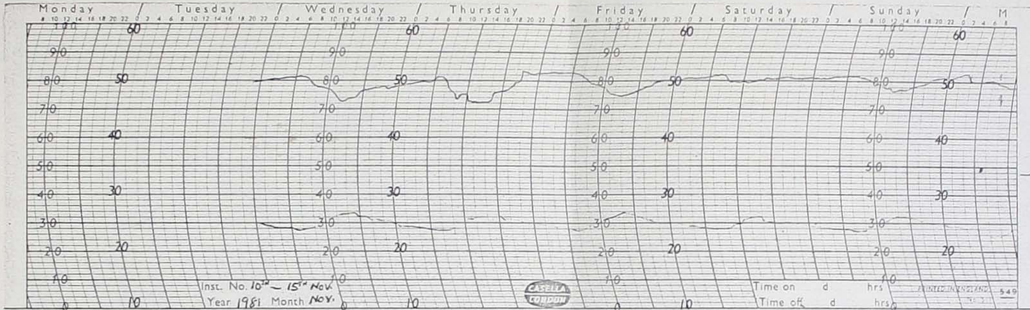
15-12-81

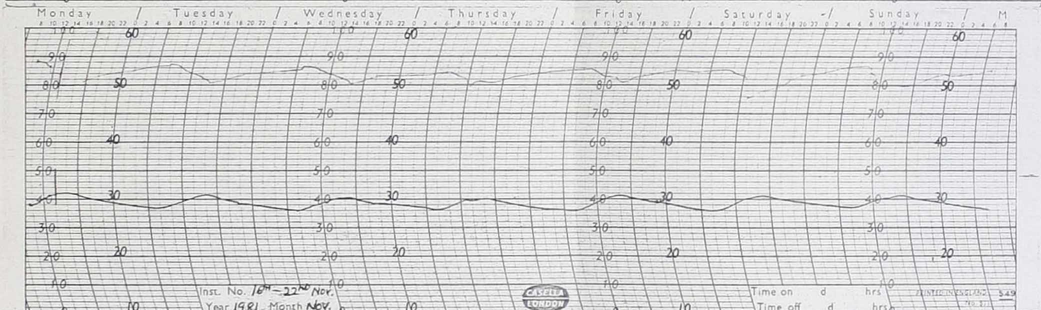
30°C/84% RH	-	CC
30°C/84% "	-	$E + \frac{C}{2}$
30°C/84% "	-	CC/EC
30°C/84% "	-	$C + \frac{E}{2}$
30°C/84% "	-	EC

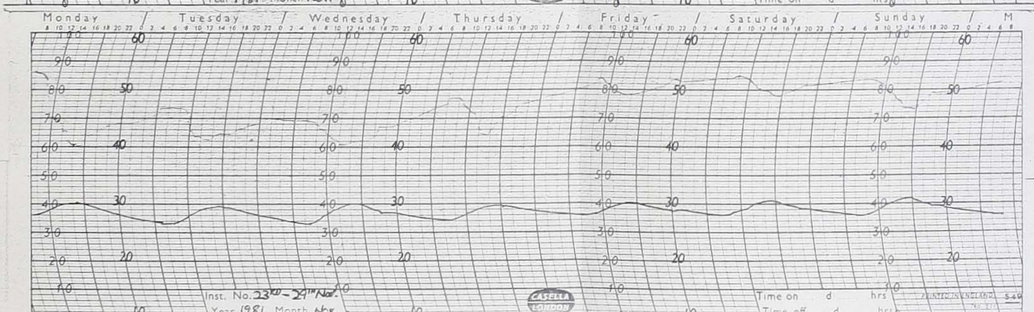
19-12-81

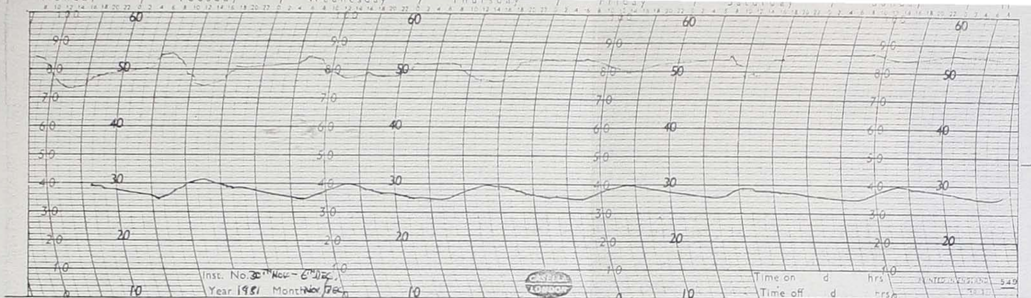
30°C/84% RH	-	CC
30°C/84% "	-	$E + \frac{C}{2}$
30°C/84% "	-	$C + \frac{E}{2}$
30°C/84% "	-	CC/EC

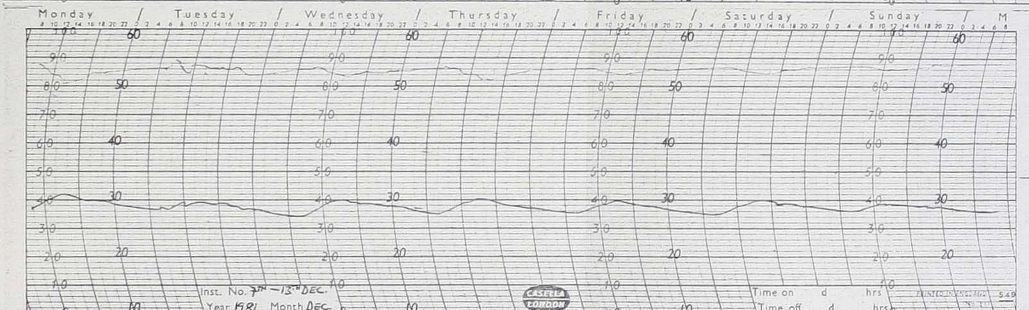
Readings of ambient temperature and
humidity recorded by
thermohygrograph

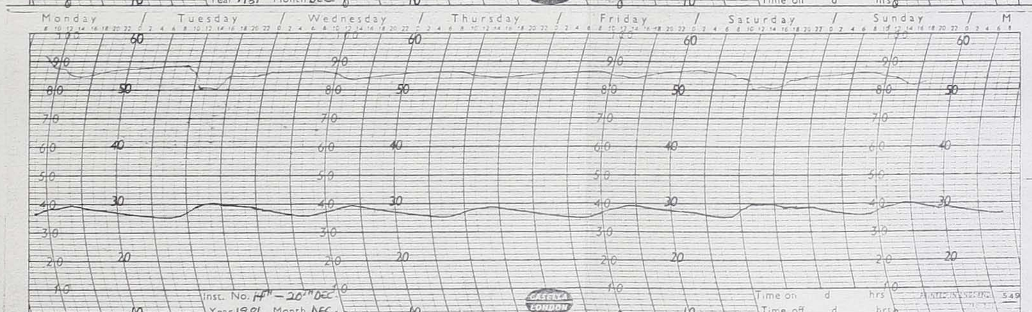

Monday / Tuesday / Wednesday / Thursday / Friday / Saturday / Sunday / M
Inst. No. 10TH – 15TH NOV.
Year 1981 Month NOV.
CASELLA LONDON
Time on d hrs
Time off d hrs
549

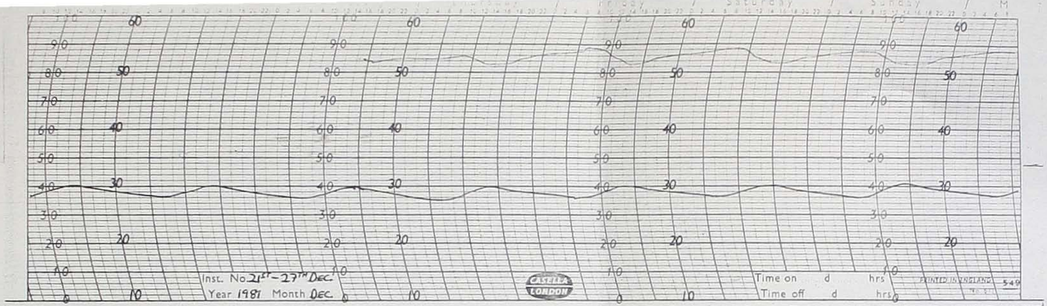

Monday / Tuesday / Wednesday / Thursday / Friday / Saturday / Sunday / M
Inst. No. 16TH – 22ND NOV.
Year 1981 Month NOV.
CASELLA LONDON
Time on d hrs
Time off d hrs
549

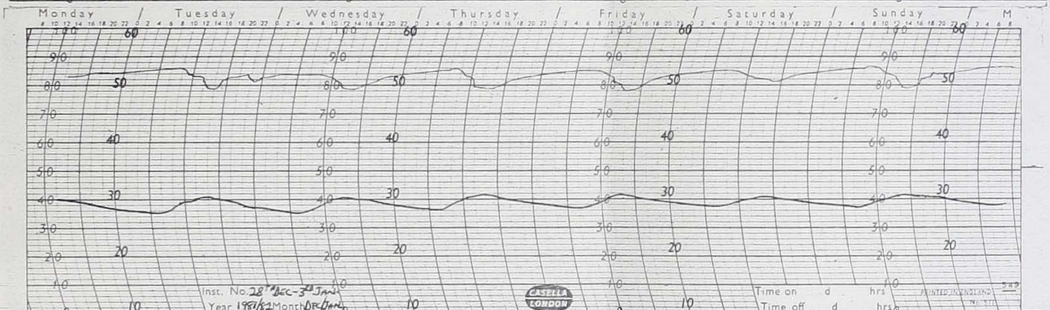

Monday / Tuesday / Wednesday / Thursday / Friday / Saturday / Sunday / M
Inst. No. 23RD – 29TH NOV.
Year 1981 Month NOV.
CASELLA LONDON
Time on d hrs
Time off d hrs
549

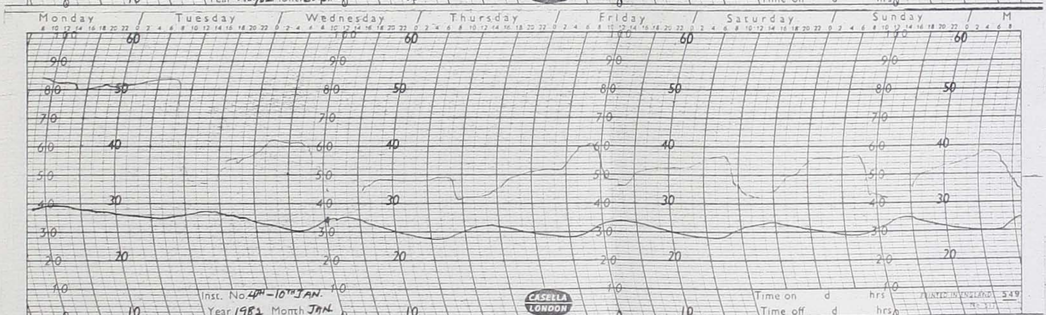

Inst. No. 30th Nov – 6th Dec.
Year 1981 Month Nov/Dec
CASELLA LONDON
Time on d hrs
Time off d hrs
549

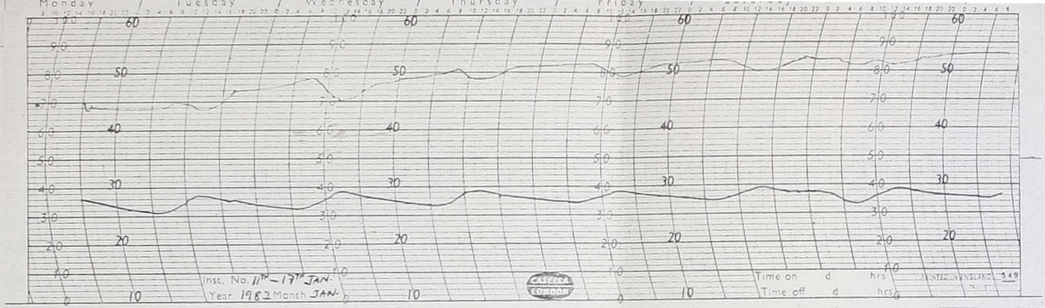

Monday / Tuesday / Wednesday / Thursday / Friday / Saturday / Sunday / M
Inst. No. 7th – 13th DEC.
Year 1981 Month DEC
CASELLA LONDON
Time on d hrs
Time off d hrs
549

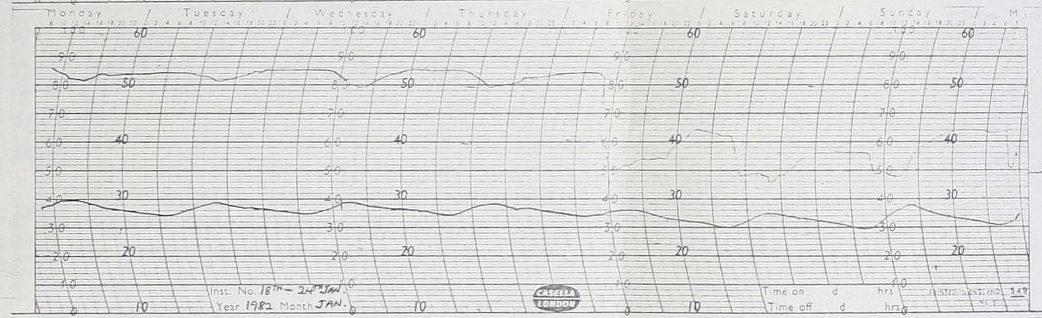

Monday / Tuesday / Wednesday / Thursday / Friday / Saturday / Sunday / M
Inst. No. 14th – 20th DEC.
Year 1981 Month DEC.
CASELLA LONDON
Time on d hrs
Time off d hrs
549

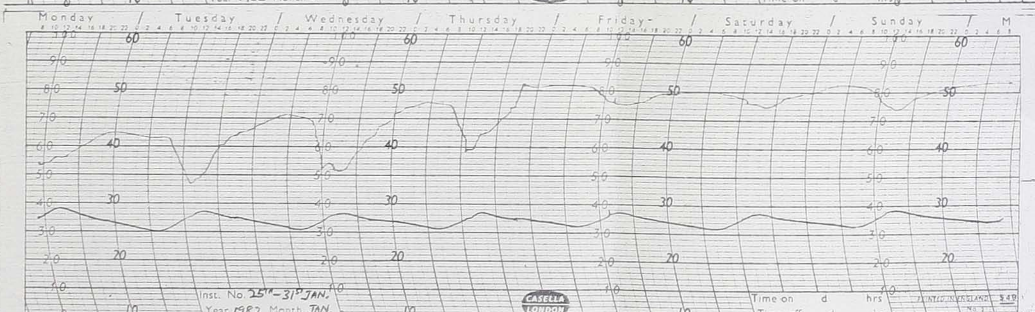

Inst. No. 21ST – 27TH DEC.
Year 1981 Month DEC.
CASELLA LONDON
Time on d hrs
Time off d hrs
PRINTED IN ENGLAND
549

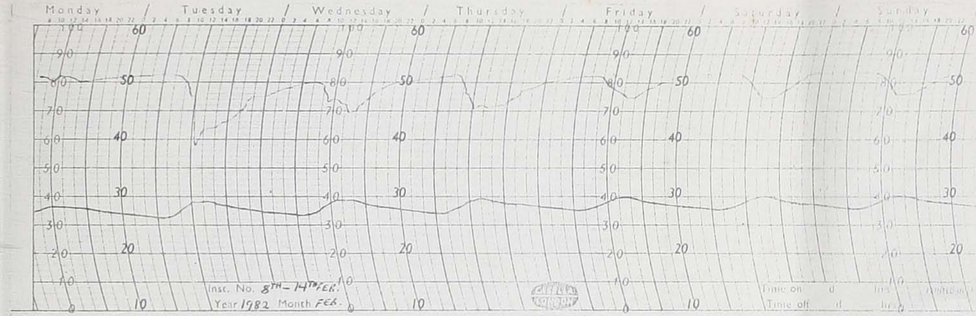

Monday / Tuesday / Wednesday / Thursday / Friday / Saturday / Sunday / M
Inst. No. 28TH DEC – 3RD JAN.
Year 1981/82 Month DEC/JAN.
CASELLA LONDON
Time on d hrs
Time off d hrs
PRINTED IN ENGLAND
549

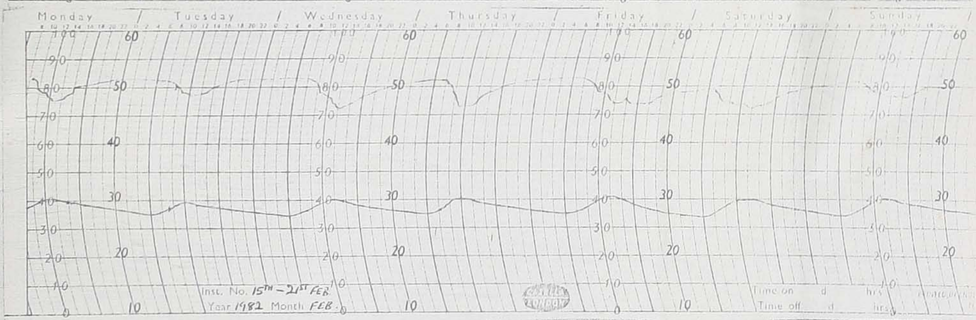

Monday / Tuesday / Wednesday / Thursday / Friday / Saturday / Sunday / M
Inst. No. 4TH – 10TH JAN.
Year 1982 Month JAN.
CASELLA LONDON
Time on d hrs
Time off d hrs
PRINTED IN ENGLAND
549

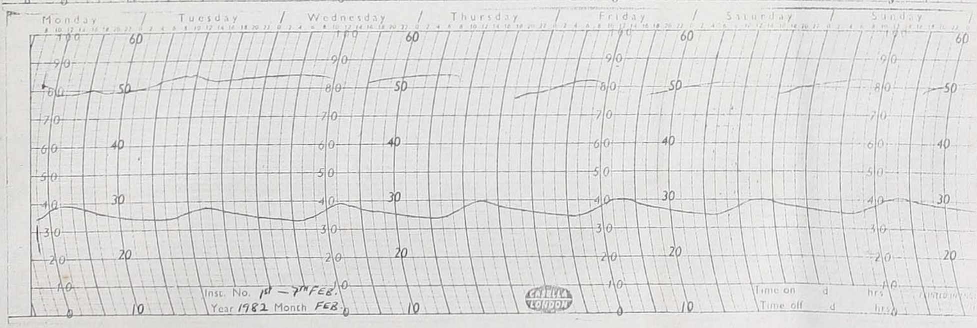

Monday / Tuesday / Wednesday / Thursday / Friday
Inst. No. 11TH – 17TH JAN.
Year 1982 Month JAN.
Time on d hrs
Time off d hrs
PRINTED IN ENGLAND 549

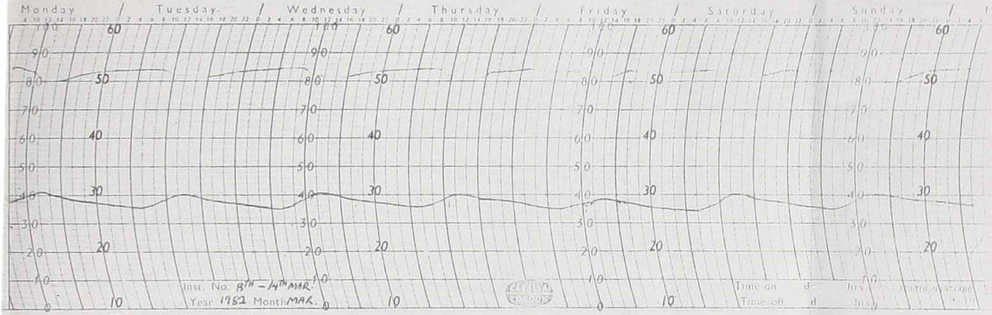

Monday / Tuesday / Wednesday / Thursday / Friday / Saturday / Sunday / M
Inst. No. 18TH – 24TH JAN.
Year 1982 Month JAN.
Time on d hrs
Time off d hrs
PRINTED IN ENGLAND 549

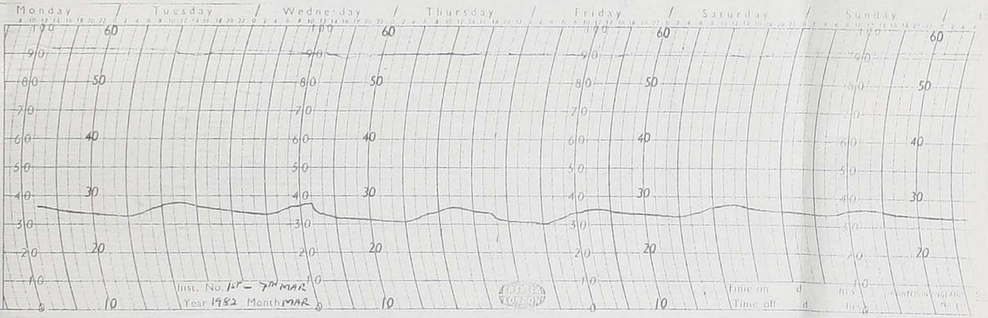

Monday / Tuesday / Wednesday / Thursday / Friday / Saturday / Sunday / M
Inst. No. 25TH – 31ST JAN.
Year 1982 Month JAN.
Time on d hrs
Time off d hrs
PRINTED IN ENGLAND 549

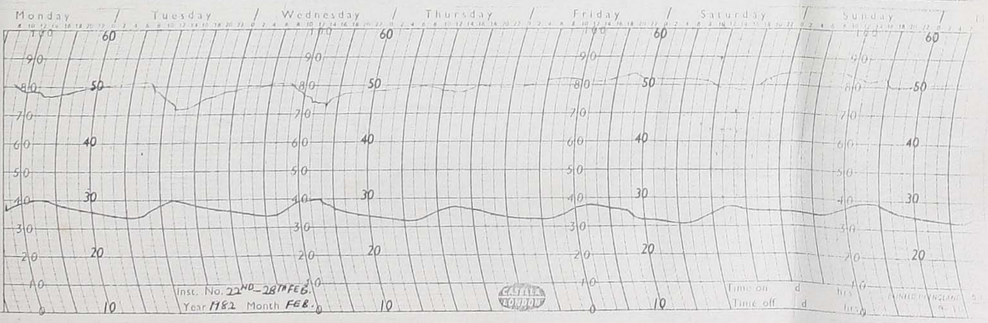

Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Insc. No. 8TH – 14TH FEB.
Year 1982 Month FEB.
CASELLA LONDON
Time on d hrs
Time off d hrs

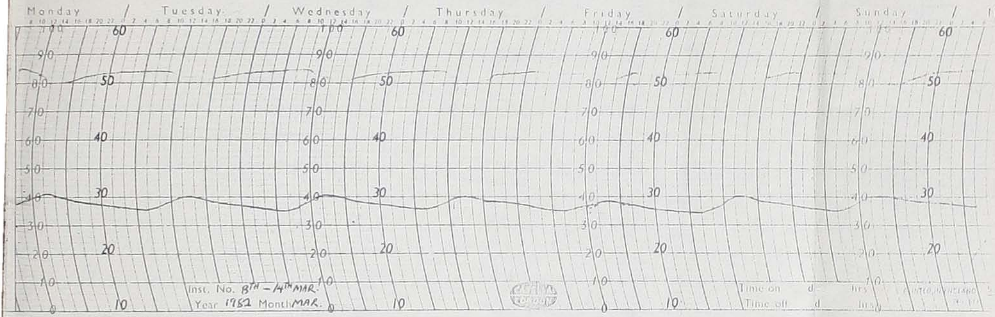

Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Insc. No. 15TH – 21ST FEB.
Year 1982 Month FEB.
CASELLA LONDON
Time on d hrs
Time off d hrs

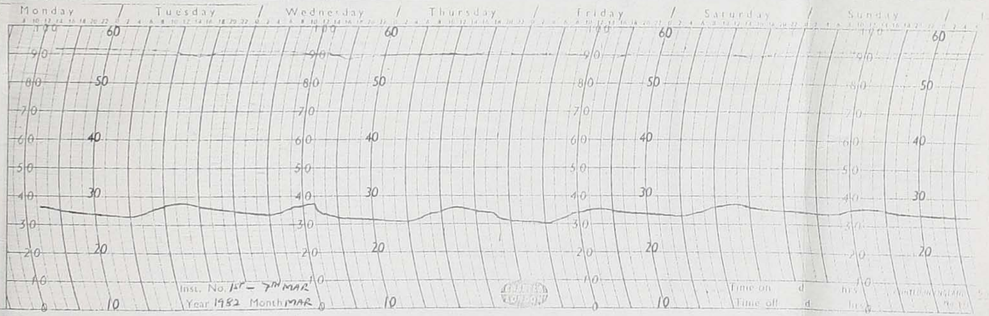

Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Insc. No. 1st – 7TH FEB.
Year 1982 Month FEB.
CASELLA LONDON
Time on d hrs
Time off d hrs

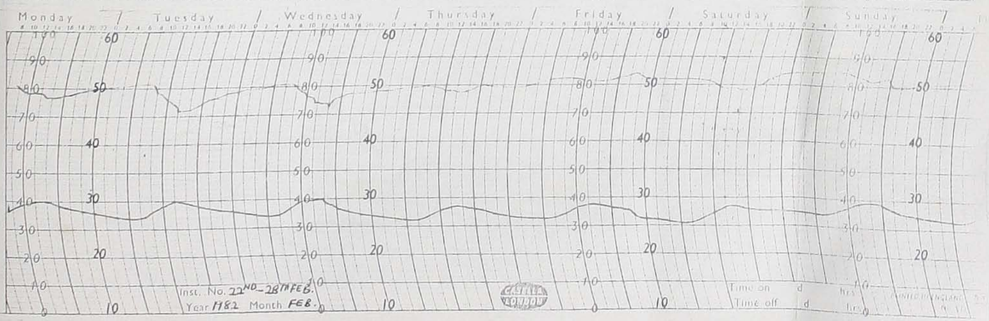

Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Inst. No. 8TH – 14TH MAR.
Year 1982 Month MAR.
Time on d hrs
Time off d hrs

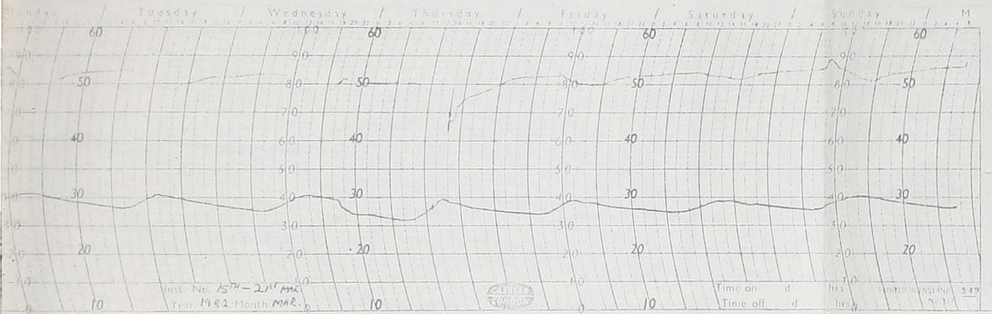

Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Inst. No. 1ST – 7TH MAR
Year 1982 Month MAR
Time on d hrs
Time off d hrs

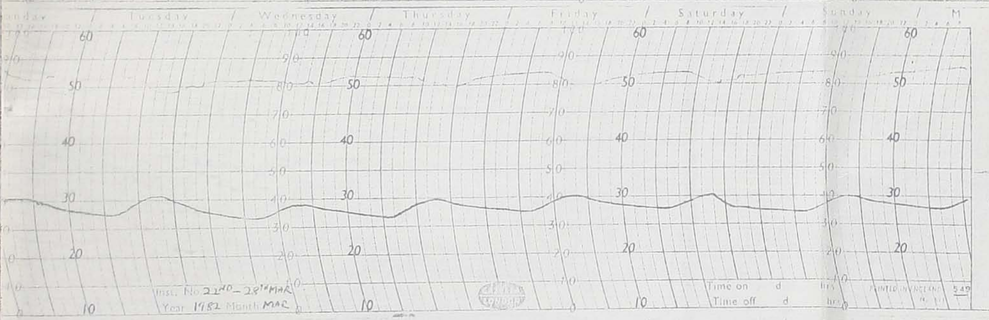

Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Inst. No. 22ND – 28TH FEB.
Year 1982 Month FEB.
Time on d hrs
Time off d hrs

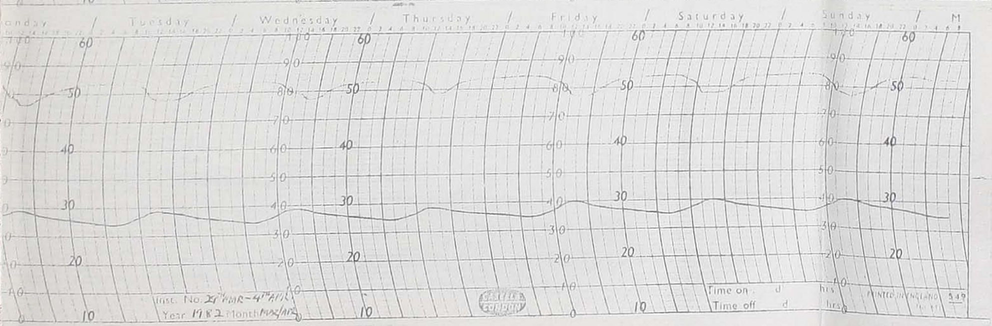

Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Inst. No. 8TH – 14TH MAR.
Year 1982 Month MAR.
Time on d hrs
Time off d hrs

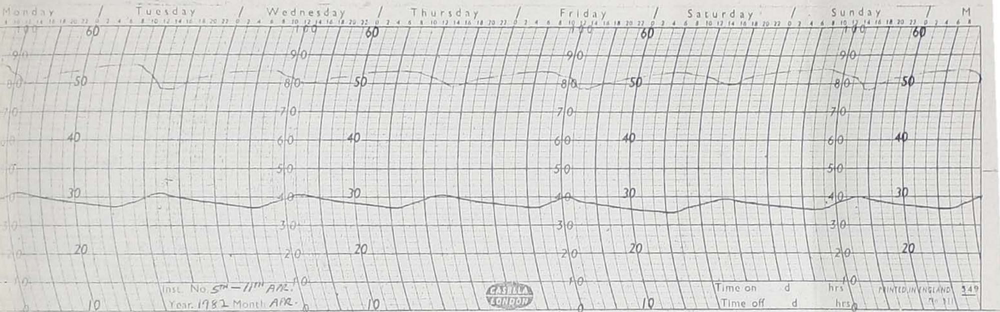

Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Inst. No. 1ST – 7TH MAR
Year 1982 Month MAR
Time on d hrs
Time off d hrs


Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Inst. No. 22ND – 28TH FEB.
Year 1982 Month FEB.
Time on d hrs
Time off d hrs

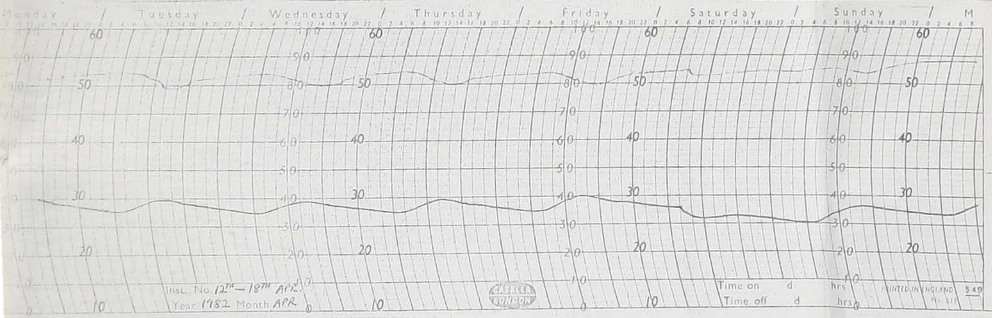

Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Inst. No. 15TH – 21ST MAR.
Year 1982 Month MAR.
Time on d hrs
Time off d hrs
PRINTED IN ENGLAND 549


Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Inst. No. 22ND – 28TH MAR
Year 1982 Month MAR
Time on d hrs
Time off d hrs
PRINTED IN ENGLAND 549

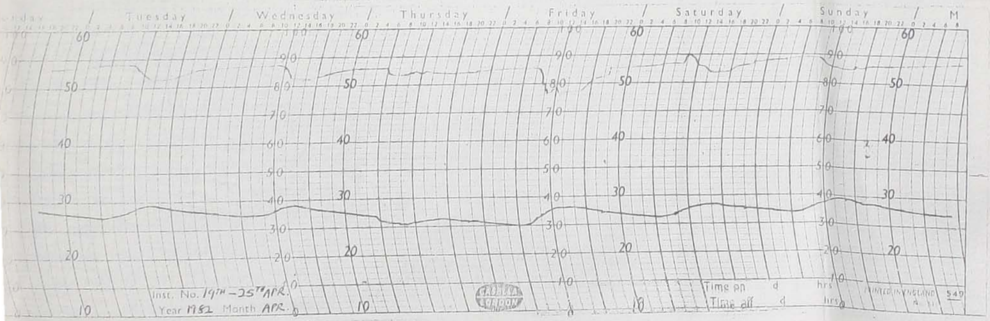

Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Inst. No. 29TH MAR – 4TH APR
Year 1982 Month MAR/APR
Time on d hrs
Time off d hrs
PRINTED IN ENGLAND 549



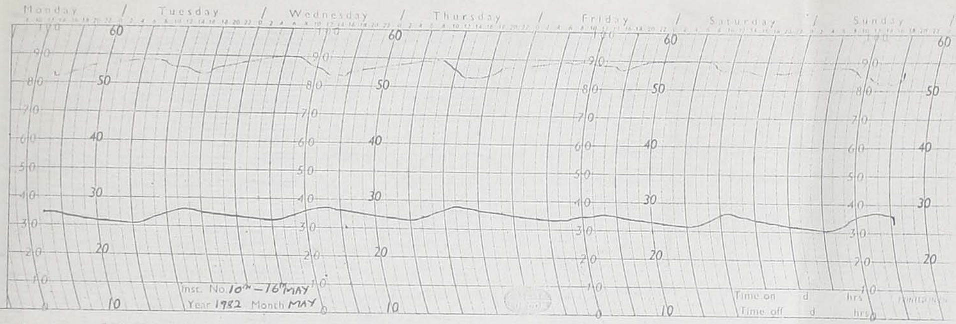
Monday / Tuesday / Wednesday / Thursday / Friday / Saturday / Sunday / M
Inst. No. 5TH – 11TH APR.
Year 1982 Month APR.
CASELLA LONDON
Time on d hrs
Time off d hrs
PRINTED IN ENGLAND
549

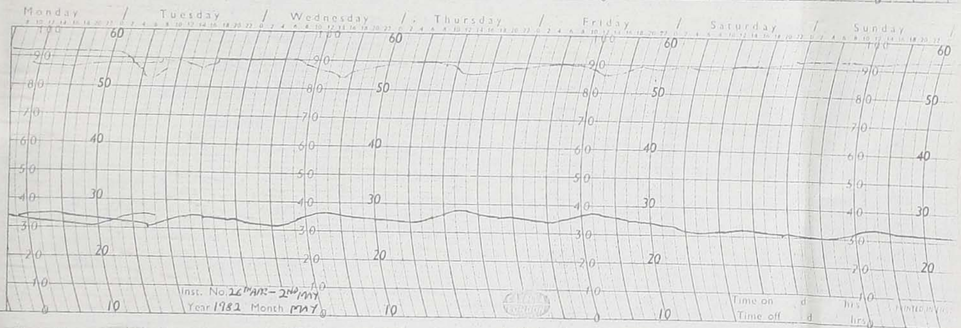


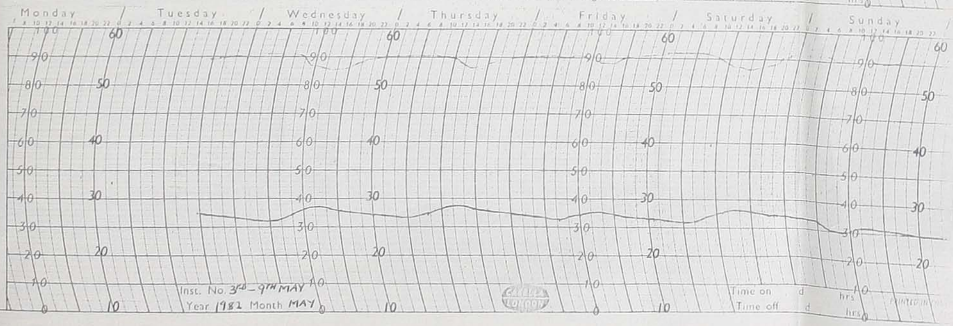
Monday / Tuesday / Wednesday / Thursday / Friday / Saturday / Sunday / M
Inst. No. 12TH – 18TH APR.
Year 1982 Month APR.
CASELLA LONDON
Time on d hrs
Time off d hrs
PRINTED IN ENGLAND
549

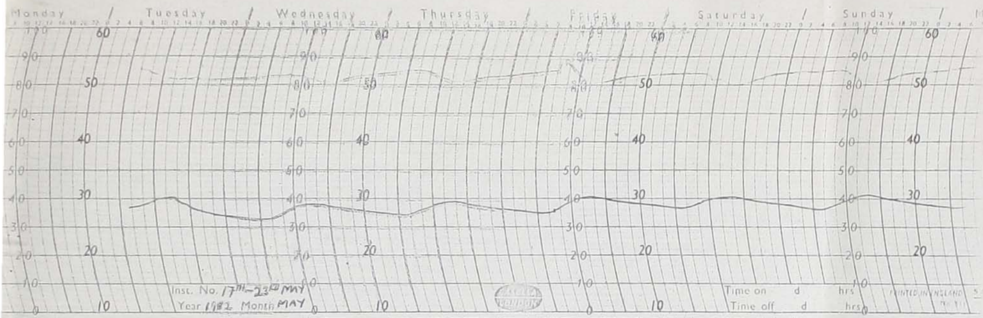


Tuesday / Wednesday / Thursday / Friday / Saturday / Sunday / M
Inst. No. 19TH – 25TH APR.
Year 1982 Month APR.
CASELLA LONDON
Time on d hrs
Time off d hrs
PRINTED IN ENGLAND
549

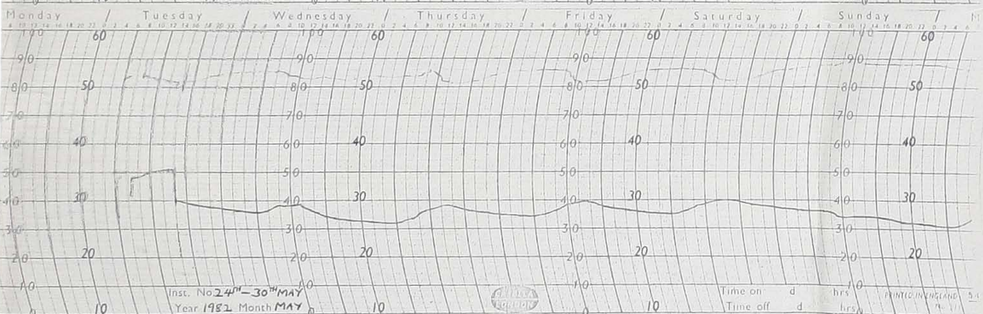

Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Inst. No. 10th – 16th MAY
Year 1982 Month MAY
Time on d hrs
Time off d hrs


Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Inst. No. 26th APR – 2nd MAY
Year 1982 Month MAY
Time on d hrs
Time off d hrs

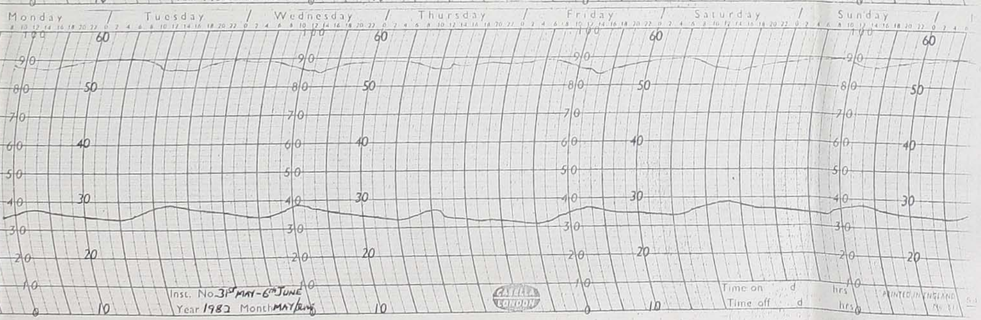

Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Inst. No. 3rd – 9th MAY
Year 1982 Month MAY
Time on d hrs
Time off d hrs



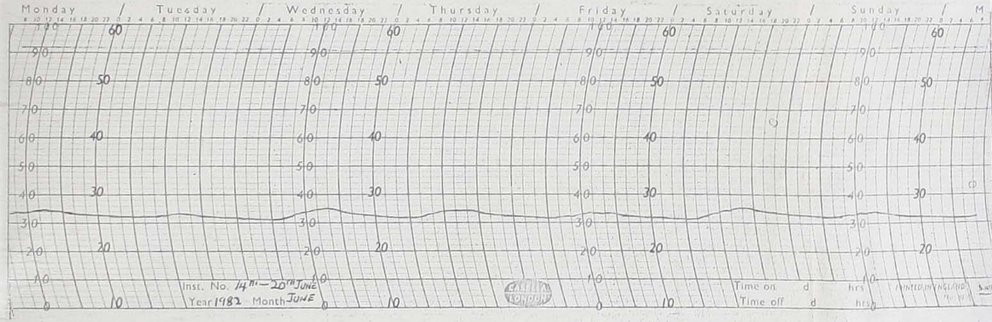
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Inst. No. 17TH–23RD MAY
Year 1982 Month MAY
CASELLA LONDON
Time on d hrs
Time off d hrs
PRINTED IN ENGLAND

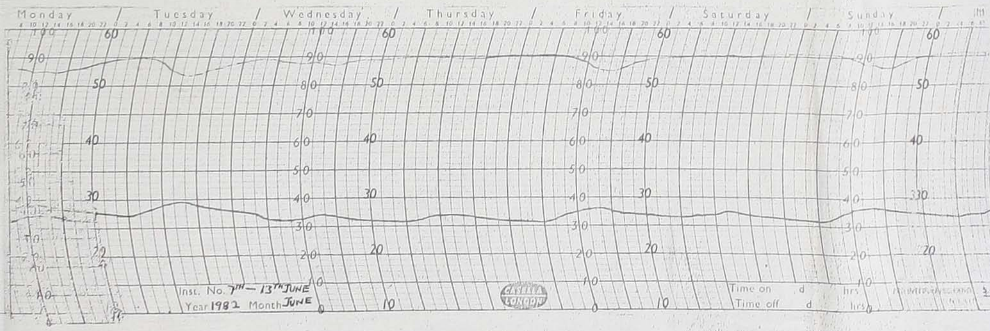


Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Inst. No 24TH–30TH MAY
Year 1982 Month MAY
CASELLA LONDON
Time on d hrs
Time off d hrs
PRINTED IN ENGLAND



Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Inst. No 31ST MAY-6TH JUNE
Year 1982 Month MAY/JUNE
CASELLA LONDON
Time on d hrs
Time off d hrs
PRINTED IN ENGLAND


Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Inst. No. 14TH—20TH JUNE
Year 1982 Month JUNE
CASELLA LONDON
Time on d hrs
Time off d hrs
PRINTED IN ENGLAND


Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Inst. No. 7TH — 13TH JUNE
Year 1982 Month JUNE
CASELLA LONDON
Time on d hrs
Time off d hrs