

**ASSESSMENT OF THE DAMAGE CAUSED BY *CORCYRA
CEPHALONICA* (STAINTON) (LEPIDOPTERA:
PYRALIDAE) AND *ARAECERUS FASCICULATUS*
(DEGEER) (COLEOPTERA: ANTHRIBIDAE) TO STORED
COCOA BEANS IN GHANA**

By

William Azalekor (B.Sc.)

A thesis presented in partial fulfillment of the requirements for the degree of
Master of Philosophy in Entomology in the University of Ghana, Legon.

Insect Science Programme *
University of Ghana
Legon



February, 1999

*Joint interfaculty international programme for the training of entomologists in West Africa.
Collaborating Departments: Zoology (Faculty of Science) & Crop Science (Faculty of Agriculture).

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ABSTRACT

The damage caused by *Corcyra cephalonica* and *Araecerus fasciculatus* to cocoa beans was studied at the Research Department of Quality Control Division of COCOBOD, Tema. The study included breeding of the two insects on cocoa beans to investigate the biology, fecundity and progeny production of the two insect species. The free fatty acid level of cocoa beans was also determined and the change in this level due to insect damage was calculated with respect to undamaged ones. The contaminants produced by these insects were also determined. *Araecerus fasciculatus* did not breed on cocoa beans but *C. cephalonica* bred well on cocoa beans. Ten *C. cephalonica* larvae produced 608 adults after four months storage. *C. cephalonica* bred better on crushed cocoa than whole cocoa beans. Developmental period of 33.8 days was recorded on crushed cocoa beans while 37.9 days were recorded on whole cocoa beans. Fecundity of *C. cephalonica* was also higher on crushed cocoa beans compared to whole cocoa beans, laying 174 and 141 eggs, respectively.

There was significant difference between the survival and establishment of *C. cephalonica* and *A. fasciculatus* and hence the damage caused. *C. cephalonica* produced the highest quantity of contaminants of 77.2 g when alone and 67.8 g when introduced with *A. fasciculatus*. The highest percentage seed damage and weight loss of 46.7 and 13.3% were caused by *C. cephalonica* when alone, respectively. The actual percentage seed damage and weight loss attributable to *A. fasciculatus* were 0.1 and 0.9%, respectively. There was correlation between insect density and damage caused. The free fatty acid level of cocoa beans was increased by 0.17% and 0.13% when infested by *C. cephalonica* and *A. fasciculatus*, respectively.



DECLARATION

I hereby declare that, this work is my own research conducted at the Research Department of the Quality Control Division of COCOBOD. Other researchers have been duly honoured for their references cited. No part of this work has been presented for any degree anywhere.



WILLIAM AZALEKOR

(STUDENT)

DANIEL OBENG-OFORI, Ph.D
(PRINCIPAL SUPERVISOR)

DAVID WILSON, Ph.D
(CO-SUPERVISOR)

DEDICATION

This thesis is dedicated to my parents: Yao Azalekor Seworvi and Abla Mewornowovor Fiakuna. For all I am and hope to be I owe it to them.



ACKNOWLEDGEMENT

This thesis could not have been produced without the unfailing love and care of God Almighty.

I extend my heartfelt gratitude to my supervisor, Dr. D. Obeng-Ofori for his advice, guidance and commitment to the work. My sincere thanks go to co-supervisor Dr. D. Wilson who also showed much commitment to the work.

I sincerely thank also Mr. William Anthony Jonfia-Essien who was more or less a co-supervisor. He was so helpful to me during the laboratory work and offered technical advice. I have to also mention Mr. Ambitey, the Head of Research Department of Quality Control Division laboratory who approved my application to carry out the research there and ensured that equipment needed for the work was made available to me. I am grateful to him. I thank Messers Owusu, Botwe, Frimpong, Gyan, Kotey, Seth Ofori and sister Comfort, Ayi and Emma workers of the QCD research laboratory for their assistance in diverse ways.

I would also like to say a very big thank you to Mr. Bernard Agyeman-Boateng and Mr. Asante who helped immensely during data analysis. I also thank brothers, Daniel Mensah Brande, Patrick Frederick Azalekor, John Azalekor and Peter Azalekor for their encouragement and financial support.

My final thanks go to all my course mates and friends especially Patrick Ayeh Kumi.

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CHAPTER ONE

INTRODUCTION

Cocoa is one of the major foreign exchange earners in Ghana. In 1997 /98 cocoa season, Ghana earned approximately five hundred thirty million dollars (\$530,182,801.78) from the export cocoa (Cumulative Records, 1998). Ghana's cocoa is mainly exported but part is used locally. Some of the finished products of cocoa include cocoa powder such as Milo, bournvita etc. cocoa, butter chocolate and other by-products. Cocoa bean is generally grouped into (a) fine grade from the Criollo or Trinitario trees. (b) bulk cocoa grade from the Amelanado, Amazonia and hybrid trees (Wood and Lass, 1986). Fine cocoa is produced in Papua New Guinea, Samoa, Sri Lanka, Trinidad and some West Indian countries. Bulk cocoa, which is about 90-95% of the World production, is produced in countries like Brazil, Cote d'Ivoire, Cameroun, Nigeria and Ghana (Wood and Lass, 1986). Of the bulk cocoa, Ghana's cocoa is the premier grade on the world market and offers consistently, good quality and flavour for milk chocolate (Wood and Lass, 1986), hence the number of awards won by Ghana's Golden Tree chocolate (Wood and Las. 1986).

The cocoa industry in Ghana faces a lot of pest problems. Pests attack cocoa from the farm to storage. These pests include fungi, rodents and various insects. They cause considerable damage to the cocoa beans leading to reduction in quality and marketability. Insects that infest stored cocoa beans in Ghana include *Ephestia cautella*, *Lasioderma serricornis*, *Cryptolestes sp.*, *Tribolium castaneum*, *Trogoderma granarium* with *Corcyra*



Cephalonica and *Araecerus fasciculatus* being among the most serious pests currently in Ghana (Wood and Lass, 1986).

In Belgium, *A. fasciculatus* has been documented as one of the major pests of stored cocoa beans (Janssens *et al.*, 1990). On high value commodities like cocoa and coffee, the contamination caused by the presence of *A. fasciculatus* is usually of great importance than the actual damage it causes. This is because of the standard set by the World market for these products. It is believed that *A. fasciculatus* pierces the shells of stored cocoa beans and predisposes it to the attack by other insects (Wood and Lass, 1986).

Corcyra cephalonica is also a serious pest of cocoa beans (Allotey, 1986) and is spreading to other important commodities in the West African subregion (Allotey and Kumar, 1985; Allotey, 1991). During feeding, the larvae produce silken threads which develop into dense webbing (Prevelt, 1946). These silken threads may also form galleries (Ayyar, 1934; Cormona, 1958; Piltz, 1977). In heavy infestation, the product becomes tightly matted together with webbings, larval galleries, cocoons excreta and frass (Kamel and Hassanein, 1967; Cormona, 1958). Feeding outside the grains or beans cause the product to stick into clumps, which contain both intact and broken beans, exuviae, silken threads, dust and detritus.

The International Cocoa Standards (ICS) regards cocoa bean with any form of insect infestation as defective (Anon. 1970). The ICS also defines grading limits in relation to damage. For example, cocoa with not more than 3% insect damage, slaty beans, flat or germinated beans, 3% fungal infection is graded I. Those with not more than 6% of insect

damage, 4% slatiness, flat or germinated beans and 8% fungal infection are graded II. Any thing more than this is considered substandard and not marketable (Rene, 1992).

Corcyra cephalonica and *A. fasciculatus* contaminate products to produce off scent and loss in weight. This is unacceptable to the International Cocoa Standards.

Insect infestation may also cause increase in free fatty acid (FFA) level for oily seeds (Appert, 1992). An increase in FFA level for cocoa bean renders it unsuitable for chocolate and cocoa butter production (Anon, 1970).

No work has been done on the assessment of damage caused by *C. cephalonica* and *A. fasciculatus* to cocoa beans, increase in the level of free fatty acid due to their damage, and the breeding of the two insect species on cocoa beans in Ghana.

OBJECTIVE

This research work was formulated with the following objectives: (a) to assess the damage caused by *C.cephalonica* and *A. fasciculatus* singly, and in combination with each other, on stored cocoa beans. (b) to determine the change in free fatty acid level of cocoa beans due the infestation of the two insect species. (c) to determine the potential of cocoa beans as standard breeding medium for *C. cephalonica* and *A. fasciculatus*

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1.1 TAXONOMY OF *C. CEPHALONICA*

The rice moth; *Corcyra cephalonica* (Stainton) belongs to the subfamily Galleriinae, family Pyralidae and the order Lepidoptera. In the adult stage, the hind-wings are greyish-brown or pale brown with a darker brown thin vague line along the wing veins. The wings have fringes of hairs along the margins. The wing span is usually about 15-25 mm. When the insect is viewed from above, the adults have distinct “shoulder” and rather broad wings. This distinguishes *C. cephalonica* from other stored product moths (Hodges, 1979; Haines and Hodges, 1991). The labial palps which point forward or downward in the females, are also pointed and long but very short, blunt and inconspicuous in the male (Haines and Hodges, 1991).

The larvae are greyish or creamy white except for the head capsule and the prothoracic tergite which are brown. There is a conspicuous seta above each spiracle and on the eighth abdominal segment (Haines and Hodges 1991). The spiracles of the larvae of this species are thickened on the posterior rim. This differentiates them from the larvae of other stored product moths.

2.1.2 DISTRIBUTION AND ECONOMIC IMPORTANCE OF *C. CEPHALONICA*.

Corcyra.cephalonica is found throughout the humid tropics and the subtropics. It is more widespread and common in Africa than suspected (Hodge,1979; Haines and Hodges,1991;). *C. cephalonica* is the most important pest of stored cocoa in Ghana today (Allotey, 1985). It is spreading fast onto other West African foodstuffs like maize and groundnut (Allotey and Kumar, 1985; Allotey, 1991). Produce attacked includes rice, maize, wheat, sorghum, coffee etc. (Cox *et. al.*, 1981; Allotey and Kumar, 1985). Prior to 1957, *C. cephalonica* was virtually absent in West Africa (WASPRU, 1958; Allotey and Kumar, 1985). However, it has assumed cosmopolitan status (Ayyar, 1934; Pruthi and Singh, 1945; Rao, 1954; Grist and Lever, 1969).

As far back as 1959, *C.cephalonica* was firmly established on groundnut in Nigeria (Smith, 1963; Prevett, 1964; Riley, 1969; Adeyemi, 1968; Cornes, 1973). The increasing importance of *C.cephalonica* as a pest of stored products in W. Africa in the past decades is believed to be due to import of low grade rice from the far East (Allotey, 1985). Of the moths associated with imported stored products in Britain, *C. cephalonica* is second only to *Ephestia cautella* (Walker) both in frequency and importance (Freeman, 1976). *C. cephalonica* causes damage by causing weight loss and contamination in most cases. The larvae attack loosely stored products and prefer milled products to whole ones. In the presence of milled products, they do not bore into intact products but feed on crushed particles (Pajni and Gill, 1974). Each larva gives about 4-6 clumps. It is established that a single larva, completing its development in 250 g of rice, contaminated 7 g by forming

clumps (Prevett, 1964). When more than 10 larvae were developing in 250 g, a change in colour of the rice was noticed together with unpleasant odour (Prevett, 1964).

2.1.3 LIFE HISTORY AND BEHAVIOUR OF *C. CEPHALONICA*

Corcyra.cephalonica is able to breed on a wide range of food products with varying developmental periods (Carmona, 1958; Hodges, 1979; Allotey, 1991)

It is known to survive and breed on a variety of stored foods such as cereals, pulses and oil seeds (Hodges, 1979; Cox *et. al.*, 1981; Osman, 1984; Allotey and Kumar, 1985; Krishna and Mishra, 1985). This probably contributes to its cosmopolitan distribution.

Allotey (1982) recorded *C. cephalonica* adult emergence of 64.5% on a standard medium comprising wheat bran /maize /glycerol; 8:8:1 w/w and 46% on cocoa beans under ambient laboratory conditions. The survival rate of an insect on its host depends on how effective or nutritious the host serves as food for the insect. Survival rate of *C. cephalonica* from egg to adult on both maize and groundnut had been reported to be 70% (Allotey, 1991). 69% and 48% on millet and sorghum, respectively (Osman, 1984) Russell *et. al.* (1980) noted that at 28°C and 70% r.h., the percentage survival rates of the larvae of the African strain of *C. cephalonica* to adult on millet and sorghum were 36% and 58%, respectively. The developmental period of *C. cephalonica* from egg to adult varies from one food to another. Allotey (1991) recorded 38 and 35.5 days on maize and groundnut respectively. The developmental period was found to be 60 and 63 days on maize flour and whole maize grains, respectively (Carmona, 1958). The developmental

period on pulses is slower than on cereals. Fifty days was recorded on chickpeas while 78 days on black bean flour (Hodges, 1979).

Corcyra.cephalonica develops faster on whole forms of some products and on flour forms of others. For instance, development is faster on whole sorghum than its flour (Rao, 1954; Uberoi, 1961). However, on wheat flour and maize flour the developmental periods were shorter than on the whole forms; 66, 60, and 76 days, respectively (Cormona, 1958). *C. cephalonica* only develops within the temperature range of 60 and 75°C (Shazali and Smith, 1986).

Sexual activity takes place 15-30 minutes after emergence (Ayyar, 1934). However, sexual activity can be put off several hours and only begins a night following the emergence (Pajni and Gill, 1974). Females mate only once, while males are promiscuous (Carmona, 1958). Subramanyan and Sreeramalu (1969) noted that females mate only once within the limit of 1-2 days. After this period, if there is no copulation the females begin to lose interest in mating. Sex ratio is normally 1:1.

Oviposition begins about two hours after emergence and reaches its maximum on the second and third days (Pajni and Gill, 1974). Mean value of about 153.6 and 209.87 eggs were recorded on maize and groundnut, respectively (Allotey, 1991). The eggs are sticky and usually laid on the food or among the sack fibres (Haines and Hodges, 1991). They take about 4 days to hatch. On crushed sorghum the eggs took a mean of 4.3 days to hatch at temperature of 25°C and

r.h of 40%. At 30°C and 70% r.h on the same food the mean incubation period was 4.1 days (Shazali and Smith, 1986).

Corcyra cephalonica has mean egg hatchability of about 70 – 85% (Hodges, 1979; Allotey, 1986). Larval developmental period of *C. cephalonica* was recorded to be 27.8 and 26.5 days at 25°C and 60%r.h and 30°C and 60% r.h respectively, on crushed sorghum (Shazali and Smith, 1986). Shazali and Smith (1986) recorded the pupal developmental period of this insect as 13.9 and 8.9 days at 25°C and 60% r.h. and 30°C and 60% r.h., respectively on the same food medium.

2.1.4 CONTROL OF *C. CEPHALONICA*

For successful storage of produce, it is essential to control insect pests. The control measures normally used include physical, hygienic, biological, chemical etc. These are used to manipulate the storage environment to make it less favourable for the insects (Allotey, 1991). Contact insecticides and fumigants have been widely used method to control storage pests. Due to the fact that *C. cephalonica* attacks mostly consumables, restrictions have been placed on the types of pesticides to use to control them (Entwistle, 1972).

Pyrethrins of plant origin are accepted by consumer countries of cocoa and coffee for the control of *C. cephalonica* and other pests. This is because such pyrethrins have low mammalian toxicity, breakdown rapidly, unstable to sunlight and hydrolyse easily by alkalis (Entwistle, 1972).

Synthetic pyrethroid, fenvalerate (at 0.02 and 0.03%) and deltamethrin (at 0.002 and 0.003%) have been found to be highly toxic to the larvae of *C. cephalonica* compared to 66.7% mortality produced by malathion after 96 hours of exposure (Mishra *et. al.*, 1988). Between 48 and 72-hours, deltamethrin was the most effective compound (Mishra *et. al.*, 1988). On the basis of LC_{50} s, deltamethrin was the most toxic compound followed by cypermethrin and permethrin when these chemicals were tested against the larvae and adults of *C. cephalonica* and *Ephestia cautella*. Deltamethrin was also more toxic than DDT, lindane, Malathion, and etrimfos against these pests (Yadav, 1987). However, DDT is no used. Etrimfos and deltamethrin were judged to be superior for large-scale use especially as wettable powders and suitable for subtropical conditions (Yadav, 1987).

Fumigation with methyl bromide at 24 g/m^2 for 18 hours was effective against most stored produce insects including *C. cephalonica* larvae in cups and adults in gunnysacks. Fumigating with methyl bromide at 16 g/m^3 for three days under vacuum conditions or with phosphine at 1.0 g a.i/m^3 for three days under normal atmosphere was safe, economical, quick and effective, giving 100% mortality of larvae and eggs of *C. cephalonica* (Rao, *et.al.*:1991). The fumigants: aluminum phosphide (phosphine), ethylene dibromide, methyl iodide and ethyl formate were also found to be effective against eggs and larvae of *C. cephalonica* (Bowry, 1985).

Chander and Ahmed (1986) recorded that powdered rhizomes of *Acorus calamus* mixed with samples of wheat grains at 1, 2 and 5% w/w were lethal to first instar larvae of *C.*

cephalonica in treated grains. They also reported that the powdered leaves of *Clerodendrum inerme*, *Tylophora asthmatica* and *Justicia betonica* reduced adult emergence of *C. cephalonica* by 91, 78, and 54% respectively, at 1% w/w. Petroleum extract of water hyacinth (*Eichhornia crassipes*) effectively controlled the larval stage of this pest (Rani and Jamil, 1989). Rathod and Neelagund (1992) reported that *Bacillus cereus* is an effective alternative pathogen to *B. thuringiensis* against *C. cephalonica*.

The use of ^{60}Co Gamma radiation, chemosterilants like metapa and hempa to control *C. cephalonica* have been reported by Lorenzo (1986) and Reddy and Shama (1986), respectively.

2.2.1 TAXONOMY OF THE COFFEE BEAN WEEVIL, *ARAECERUS FASCICULATUS* (DEGEER) (COLEOPTERA: ANTHRIBIDAE)

Araecerus fasciculatus (Degeer) is the only member of this family that attacks stored products (Haines and Hodges, 1991).

The adult is moderately large (3-5 mm) and dull brown to grey brown in colour (Wrigley, 1988; Haines and Hodges, 1991). The prothorax and the elytra bear many small patches, which are dark. This gives the insect an atomized appearance. The elytra are slightly shorter than the abdominal segment. This leads to one abdominal segment getting exposed.

The antennae in the matured adults are long, thin and end in three thick blackish joints. These antennae are held forward. The head is somewhat pointed with prominent eyes.

The larva is about 4.5-6 mm long. It is white with an ochre head, narrow, apodal and hairy (Wrigley, 1988).

2.2.2 DISTRIBUTION AND ECONOMIC IMPORTANCE OF *A. FASCICULATUS*

Araecerus fasciculatus is found in most tropical regions of the world (Mphuru, 1974; Haines and Hodges, 1991). It was thought to have originated from India, East Indies etc. However, its occurrence is now more or less cosmopolitan (Mphuru 1974). Degeer first described *Araecerus fasciculatus* in 1775. Lucas in 1861 recorded it boring into branches of Chinese ginger in France. Now, *A. fasciculatus* is distributed worldwide in U.S.A, Brazil, St.Helena, Persia, Japan, Nigeria, Ghana, Kenya, etc. (Sayed, 1935; Mphuru, 1974). This insect is known to attack coffee, cherries, coffee beans, copra, millet, cassava chips, maize, sorghum, groundnut, rice etc (Mphuru, 1974; Wrigley, 1988; Appert, 1991). *A. fasciculatus* was recorded damaging the boll and seeds of cotton plant in Africa (Zacher, 1913), attacking cocoa in the Gold Coast during the drying stage and then in stores (Patterson, 1928), on cocoa pods in Nigeria (Lamborn, 1914), in coffee berries in the Dutch East Indies (Friederichs, 1925) where it also attacked Brazil nuts (Gater, 1925).

It is a very important pest of prepared and stored coffee. In several South American countries, it is a serious pest, causing considerable damage to harvested coffee (Wrigley, 1988). Presently, *A. fasciculatus* is a serious problem to the cocoa industry in Ghana. It infests cocoa beans of high moisture content. This insect causes damages to stored produce by feeding on the germ thereby reducing their viability. It also feeds on the cotyledon and either reduces the product into powder or causes loss in weight to the produce (Appert, 1992). Both the adult and the larvae cause damage to stored produce.

The larvae live inside the grain or bean for their entire development, consuming about a third of the grain or bean (Cotterell, 1934). There is usually one larva per seed. A serious attack of cocoa by this insect is an indication of the fact that the beans are not adequately dried (Jonfia-Essien per comm.). This is because *A. fasciculatus* attacks products of high moisture content. This pest causes severe quantitative damage to cassava chips (Haines *et. al*, 1991).

2.2.3 BIOLOGY OF *A. FASCICULATUS*

This pest establishes successfully on the host food materials that it attacks and reproduces successfully. The adult of this pest is a good flyer. It lays its eggs in the field and in the warehouse when the produce is in storage. The eggs are laid on the seeds (Appert, 1992). Cabal Concha (1956) reported 50 eggs per female on stored coffee. However, Cotterell (1934) recorded 5-6 per female eggs on cocoa beans. The eggs are laid singly on each seed (Wrigley, 1988). Egg laying starts immediately after copulation (Appert, 1992). However, Cotterell (1934) noted that when the adults emerge on cocoa beans, it takes them 2 days to start laying eggs.

The eggs take about a week to hatch. The larvae live within the seeds and feed on the cotyledon. There is always one larva per seed. When developing in cocoa beans one larva eats up to about one third of the interior of the bean (Cotterell, 1934). When the larva is within

the seed it digs tunnels and fills the seed with its dejecta and produces hidden infestation. The larvae pupate within the seed. The larval period is about one and half months while the pupation takes period is about 6-9 days (Wrigley, 1988).

The total developmental period from egg to adult has been reported to be between 46 and 66 days at 28°C and 76-80% r.h (Cabal Concha, 1952). Rene (1992) reported a rather shorter developmental period of 29-40 days also on coffee at 25-30°C and 70% r.h. It has been shown that on maize the insect develops most quickly at a high moisture content; development is however, severely affected by low humidities (Allotey, 1991).. All stages, except the pupae die when the r.h. is lower than 60%; and at 27°C the developmental period increases from 29 to 57 days on maize when the r.h. is reduced from 100% to 60% (Sayed, 1935; 1940). Adults live for more than 17 weeks, but longevity is severely reduced at low humidities (Allotey, 1991). Each adult emerges from a hole 0.4mm in diameter. The sex ratio is 1:1 for the adults that have emerged.

2.2.4 CONTROL OF *A. FASCICULATUS*

Chemicals are widely used to control *A. fasciculatus*. Lavabre (1970) advised that in cases of slight attack of *A. fasciculatus*, the produce should be dusted or sprayed with insecticides like pirimiphos-methyl (Actellic). However, in cases of severe attack, control can only be achieved through fumigation under polyethylene cover or using low pressure equipment with methyl bromide (Lavabre, 1970).

Dusts containing 2% malathion or 1% tetrachlorvinphos are effective against *A. fasciculatus* when applied at the rates of 8 and 20 ppm even after 210 days (Bitran, 1974b)

Malathion and Phoxim (Volaton) both with low mammalian toxicity when used as 50% emulsion concentrates in 0.25% solution give adequate protection to coffee stored in bags (Chacko *et al.* 1979). Fumigation has been the most widely used control measure against *A. fasciculatus*. Fumigating with dichlorvos (DDVP) at a rate of 50 g / m³ or with three tablets of phostoxin/ m³ effectively controlled the pest (Lin, 1976). A complete control of all the stages of *A. fasciculatus* was achieved when the jute sacks or the paper bags used to store coffee was fumigated for 48 hours or 72 hours with phosphine at 0.5 g and 0.4 g active ingredients /m³, respectively or for 24 hours with 20 ml methyl bromide /m³ (Bitran, 1974a).

2.3 0.DAMAGE AND LOSS ASSESSMENT

Damage refers to the superficial evidence of deterioration, for example, holed or broken grains or beans from which loss may result. Loss on the other hand is a measurable decrease of food, which may be quantitative, or qualitative (Boxall, 1986; Appert, 1992). From the above, it can be said that losses come as a result of damage. Loss can be defined as any change in the availability, edibility, wholesomeness or quality of food that prevent it from being consumed or utilised by people (Boxall, 1986). Losses may be direct or indirect depending on whether the food disappeared by spillage or consumed by birds, insects or rodents. Or whether the quality of the food was lowered to warrant people's refusal to eat it (Boxall, 1986). Boxall (1986) categorised the losses into (a) weight loss (b) quality loss (c) nutritional loss (d) loss of seed viability (e) commercial loss.

2.3.1 WEIGHT LOSS

Reduction in weight is obvious but does not always indicate loss. This may be due to reduction in moisture content (mc) of produce. True weight loss may result from the feeding of insects, rodents and birds or spillage (Boxall, 1986). When grains or beans are eaten by insects, the insect themselves, their remains, moults, frass and the dust resulting from their feeding activity must be considered when estimating weight loss (Appert, 1992). At times loss due to insect infestation manifests in grain as increase in weight of the produce. This is because the powdery residue or the impurity produced by the insects are more hygroscopic and absorbs more moisture from the atmosphere (Hall, 1970). Produce experience varying degrees of weight loss due to the way they are handled in storage. For instance, there was a report that within 12 months of storage in the Democratic Republic of Congo loss

in weight of about 50% was recorded for sorghum, 20% for beans and 15% for groundnut (CCT/CSA, 1957).

Hodges (1983) reported 9-34% weight loss in stored maize in Tanzania due to the destructive pest *Prostaphanus truncatus*. Hall (1970) also recorded 20% loss in weight of maize in Ghana due to *Sitophilus zeamais*. He also recorded 5% loss in weight of maize in Uganda due to attack by *Tribolium castaneum*.

2.3.2 QUALITATIVE LOSS

Qualitative loss is subjective in that it is assessed according to consumers taste and criteria used by local traders. Generally, quality is assessed and products graded on basis of appearance, shape, size, smell, flavour, etc. (Boxall, 1986; Appert, 1992).

Foreign bodies normally reduce the quality of produce. Foreign bodies may be in the form of elements such as those that can be removed or contaminants such as those that cannot be removed. Foreign bodies like insect fragments, frass, excreta, pebble etc can be eliminated. However, soluble excretions of pests, pathogens, pesticide residue etc can not easily be removed.

In cases where the seeds are attacked by insects, the level of free fatty acids (FFA) increases. This causes the produce to go rancid and becomes unsuitable for processing (Howe, 1952; Pingale et al., 1954; Hayward, 1955; Wood and Lass, 1986; Appert, 1992)

2.3.3 NUTRITIONAL LOSS

This loss represents reduction in food value of the produce as a result of a reduction of protein, carbohydrate and vitamin content in the product. The effect of insect infestation on the nutritional value of produce varies with composition of the product affected and the species of insect (Hall, 1970). This is because different insects prefer parts of products with various compositions. For instance, weevils which feed mainly on carbohydrate portion of produce, remove considerable amount of the caloric potential with a little portion of vitamins and proteins removed.

In cereals, proteins and vitamins are found in the germ, hence pests that feed on the germ cause considerable loss in these nutrients. On the other hand, nutrients are virtually uniformly distributed throughout pulses. Hence beetle infestation, which can lead to about 50% of loss in weight, may lead to about 25% loss in dry matter and hence about 12% loss of available protein (Hall, 1970).

Nutrient loss may be proportionately larger due to selective feeding by pests (Boxall, 1986). When grains are attacked by insect species which feed selectively on the germ leaving the endosperm almost untouched, food loss is not apparent, weight loss is also very small compared to loss of vitamin etc (Hall, 1970)

Nevertheless, over drying or cover-exposure to sunlight also destroys certain nutrients, especially vitamins. High temperatures during artificial drying cause loss of thiamin content in rice (Christensen, 1974). Pingale et al (1954) reported that losses of thiamin in

rice stored for eight months were 10-15% greater in infested than in uninfested.

2.3.4 LOSS OF SEED VIABILITY

Loss of seed viability relates to loss in seed germination. Loss of seed viability has serious repercussions on the amount of food available the following year for the family and sometime even nationally (Boxall, 1986; Appert, 1992). Loss in seed viability may be due to both internal and external factors. Physical factors such as light, moisture and temperature are important in causing losses in viability (Hall, 1970). Excessive respiration and insect infestation are also some of the main cause of loss in seed viability.

Chemical factors in genetic constitution of the seed and chemicals used to control infestation and infection may affect seed viability (Hall, 1970; Boxall, 1986). Caswell and Clifford (1960) showed that maize fumigated with chlorinated hydrocarbons adversely affect viability and growth of the resultant seedlings.

2.3.5 COMMERCIAL LOSS

Commercial loss occurs directly as a result of any of the losses discussed or indirectly as the cost of preventive or remedial actions required, including that of the necessary equipment (Boxall, 1986; Appert, 1992). Commercial loss encompasses monetary loss and loss of goodwill. Monetary loss occurs when the producer sells his crop, because he is unable to store it, during the period of plenty and therefore sells the crop or the produce at a lower price.

2.3.6.0 LOSS ASSESSMENT

Loss assessment in stored foodstuff is a necessary step that helps to ascertain the effectiveness of a specific storage method in reducing losses during storage. It also helps determine effectiveness of protectants used to reduce pest attack. Loss or damage assessment also helps determine economic threshold of pests in storage.

Damage can be assessed by calculating the percentage of damaged grains, percentage weight loss or change in nutrients of the product concerned. There is some sort of correlation among the number of insect present in stored produce, the percentage of insect damage and percentage weight loss (Hall, 1970). Davies (1960) reported that 10% bored samples of maize represented 2.7% loss in weight in Uganda. In India, Rao et al, (1958) found out that the percentage of sorghum grains holed by weevils was two to three times the percentage weight loss. These values show that the percentage of holed grains or beans do not give even rough estimate of percentage loss in weight. The same applies to change in nutrient content. For this reason, procedures had been set or developed to provide these estimates. There are two main methods of loss assessment. These are simple and complex methods (Boxall, 1986). The simple methods include (a) Count and weigh method (b) Converted percentage method. The complex methods are (a) volumetric method (b) Thousand grain mass method.

Adams and Schulten (1978) suggested three methods of determining losses in grains or beans. These are (a) the volumetric method (b) the gravimetric or count and weigh

method and (c) the converted percentage damage method

2.3.6.1 VOLUMETRIC METHODS

This method is also called bulk density or standard volume weight (SVW) method and was first proposed by Adams (1976). This compares the weight of standard volume of damaged and undamaged grains. Rawnsley (1969), working in Ghana, developed a method that involved collecting a sample of maize cobs, shelling and separating the grains into damaged and undamaged fractions. After measuring the weight and volume occupied by each fraction, the litre weight was then calculated. The percentage weight loss was then calculated using the following formula:

$$\% \text{Wt. loss} = \frac{(W_a - W_b) \times 100 - L_b}{W_a \times L_a \times L_b}$$

Where W_a = Litre weight of undamaged grains

W_b = litre weight of undamaged grains

L_b = litre weight of damaged grains

L_a = Volume (litres) of damage grains

Other workers like Schulten (1972) used similar methods for the determination of percentage weight loss. Factors like change in shape of damaged grains or beans (hollowed), changes in moisture content of product etc. affect the efficiency of this method. Due to these defects of the method, modifications like expressing all weight measurement in dry weight and elimination of different volumes occupied by the same

quantity of grains or beans at different moisture contents were made. Thus the dry weights of standard volume of the reference sample of grain or beans at different levels of moisture content are calculated and plotted. This curve then serves as a baseline for further determinations (Boxall, 1986).

However, the volumetric method can still be used when loss estimate are to be made in the middle of storage period when baseline curve had not been previously determined. An artificial baseline curve is then determined using undamaged grains in storage.

2.3.6.2 COUNT AND WEIGH OR GRAVIMETRIC METHOD

This method provides an estimate of loss where no baseline data is determined at the beginning of the storage period, and when equipment is lacking. The method requires calculation of (i) the proportion by weight of grain damaged by insect (ii) percentage of damaged grains. The proportion by weight of damaged grains is calculated from mean weight of damaged and undamaged grains as follows:

$$\frac{\text{Mean weight of undamaged grain} - \text{mean weight of damaged grains}}{\text{Mean weight of undamaged grains}}$$

(Boxall, 1986). This average weight loss per a damaged grain is then multiplied by percentage of damaged grains in the sample to obtain the percentage weight loss. This is also expressed in the formula;

$$\text{Percentage weight loss} = \frac{[U/N_u - D/N_d] \times N_d / N_u + N_d \times 100}{U/N_u}$$

Where U = Weight of undamaged grains

D = Weight of damaged grains

N_u = Number of undamaged grains

N_d = Number of damaged grains

When insects feed preferentially on larger grains, then the percentage weight loss may be negative. This formula is similar to the one proposed by De Luca (1969):

$$\%Wt \text{ loss} = \frac{U_a - D_a \times N_d \times 100}{U_a N}$$

Where U_a = average weight of an undamaged grain

D_a = the average weight of a damaged grain

N = total number of grains

N_d = Number of damaged grains

The Commission for Evaluation of Losses published a modification of the basic formula which incorporated the calculation of the average grain, weight due to insects attack, and percentage of damaged grains (Anon, 1969):

$$\%Wt \text{ loss} = \frac{UN_d - DN_u \times 100}{UN}$$

Where U and D are weights of undamaged and damaged grains respectively. N = total number of grains. This formula was described by Adams and Schulten (1978) as count and weigh method except that N was expressed as (N_u + N_d). They recommended that 100-1000 grains should be used in this method but did not give how the grain should be taken. However experience shows that about 500 grains should be used, and at least three replicates must be used (Boxall, 1986).

2.3.6.3 CONVERTED PERCENTAGE DAMAGE METHOD

This method is a simple one which relates damage with losses. Parkin (1956) recommended that in order to achieve an assessment of losses, laboratory studies should first be undertaken to determine the relationship between damage and weight loss, including a correction for hidden infestation. Other workers like Schulten (1969) used the relationship between percentage damage and weight loss to obtain estimates of storage losses. This method is very suitable for assessing losses caused by grain boring insects; where hidden infestation is high.

Once the relationship between percentage damage and weight loss has been established, a conversion factor can be calculated and subsequently used to determine weight loss in other samples of the same type of product (Boxall, 1986). This relationship can be established by the count and weigh method.

The conversion factor is calculated from the formula:

$$\text{Conversion factor} = \frac{\% \text{ damaged grains}}{\% \text{ weight loss}}$$

For accuracy, a sample of grain with 10% or more damaged grains is used for the determination of the correction factor. With this correction factor, the percentage weight loss of samples of 500 - 1000 grains is determined by counting and expressing the damaged portion as a percentage of the total number of grains. The most important step to take when using this method is to use emergence hole than number of damaged grains when assessing damage. This is because in products like the pulses more than one insect

might develop and feed in a single big grain, all consuming about the same amount of food (Boxall, 1986). From the calculated conversion factor, percentage weight loss then becomes:

$\frac{\% \text{ damaged grain}}{\text{conversion factor}}$

2.3.6.4 THE THOUSAND GRAIN MASS METHOD

This method overcomes the drawbacks of the Volumetric and Gravimetric methods. This method is modified from a standard procedure of determining the weight of one thousand grains known as the thousand grain mass (TGM) method. The TGM technique was proposed to take account of variations in grain size and difficulties in obtaining representative samples (Proctor and Rowley, 1983).

The TGM is the mean grain weight multiplied by 1000 and corrected to a dry weight. This is done by counting and weighing. The sample is not adjusted by a specific weight or number of grains, hence no clear-cut bias (Boxall, 1986). The determination of TGM is done at the beginning of storage and comparison made with subsequent determinations throughout the season. The weight of the sample of the grain is then calculated as follows:

$$\frac{\text{Initial TGM} - \text{Sample TGM} \times 100}{\text{Initial TGM}}$$



With all TGM calculated on dry basis, then the dry weight TGM can be obtained directly using the formula:

$$M_D = \frac{10m(100 - H)}{N}$$

Where m = mass (weight) of grain in sample

N = Number of grains in the sample

H = moisture content of sample

M_D = TGM (dry basis)

In using the thousand grain mass method, samples collected must be as representative of the bulk as possible. Otherwise, the proportion of grains of different sizes must be taken into account, hence the application of the multiple TGM method (Boxall, 1986). In this multiple TGM method grains are separated into groups of equal sizes. Thereafter, count and weigh method is applied and TGM calculated for each group (Boxall, 1986).

The potential weight of each size group is calculated as follows:

$$W_p = \frac{M_1 \times M_x}{M_x}$$

Where M_1 = initial TGM

M_x = Sample TGM for a grain size group

The percentage loss is then calculated from the formula:

$$\frac{W_p(\text{large}) + W_p(\text{small}) - W_x(\text{large}) + W_x(\text{small})}{(W_p(\text{large}) + W_p(\text{small}))} \times 100$$

W_x = Weight of grain size group

W_p = Potential weight

Or simply

$$\frac{\text{Potential Sample weight} - \text{actual sample weight}}{\text{Potential Sample weight}}$$

The latest method in use is the FAO (1985) method. In this method, counting and weighing of damaged and undamaged grains or beans are made. Percentage loss in weight is calculated using the following formula:

$$\% \text{ Wt loss} = \frac{UaN - (D + U) \times 100}{UaN}$$

Where U = weight of undamaged grains in the sample

D = Weight of damaged grains in the sample

Ua = Average weight of one undamaged grain

N = total number of grains

2.4 .0 BIOCHEMICAL CHANGES IN STORED PRODUCE

When grains are stored, some changes or modifications take place in their biochemical moieties. These changes affect the quality of the products. Some of these changes involve carbohydrates, nitrogenous compounds and lipids (Christensen, 1974).

2.4.1 CARBOHYDRATES

Alpha- and beta-amylases attack the starches of grain and grain products during storage and convert them into dextrans and maltose. Amylase activity in wheat has been shown by Popv and Timofeev (1933) to increase during the early stages of storage. Ramstad and Geddes (1942) found a marked increase in reducing sugars in stored soybeans with more than 15% moisture content. This increase is followed by an equally significant decrease in non-reducing sugars

Bottomley et al (1950, 1952) demonstrated a marked disappearance of non-reducing sugars in corn stored under conditions favouring deterioration. Glass et al (1959) carried out laboratory studies on aerobic and anaerobic storage of wheat and found that changes in both reducing and non-reducing sugars occur in each condition even as mould growth was prevented under anaerobic conditions. The decrease in non-reducing sugars was almost exactly compensated for by the increase in reducing sugars. However, Pixton and Hill (1967) reported that storage of sound wheat for six years reduced the total sugar content, especially the non-reducing sugars.

Taufel et. al., (1960) reported that on qualitative and quantitative bases legumes (including soybean) contain carbohydrates like fructoses, glucose, raffinose, stachyose and verbascose. However, during storage of these legumes for one month there was practically no change in the contents of the lower carbohydrates.

2.4.2 CHANGES IN NITROGENOUS COMPOUNDS

According to Pixton and Hill (1967), wheat stored which had been for eight years, crude protein remained unchanged. Daftary *et.al*, (1970) found protein content in wheat to be slightly, but consistently, higher in mould-damaged samples than in corresponding sound samples. The relative increase on a percentage basis can be explained by respiration loss of carbohydrates. The longer the storage of produce the greater the decrease in hydrophilic characteristics and aggregation of the protein molecules (Kozlova and Nekrasov, 1956). The deterioration of gluten was always greater for lower quality grain which had been severely dried after harvest or fumigated (Kozhova and Nekrasov, 1956).

Proteolytic enzymes in grain and in organisms associated with grain hydrolyze the proteins into polypeptide and finally into amino acids. These changes are slow and difficult to measure except in advanced stage of deterioration (Zeleny and Coleman, 1939). Amino acid content of corn (maize), measured by titratmetric method and expressed as the number of milligrams of potassium hydroxide required to neutralize the free carboxyl groups in 100g of corn was found to be in the neighbourhood of 110 mg in

mature corn and as high as 320 mg in severely damaged corn (Zeleny and Coleman, 1939).

2.4.3 CHANGES IN LIPIDS

Deteriorative changes in grain fats or oils may be oxidative, resulting typically in rancid flavours and odours, or hydrolytic, resulting in the production of free fatty acids (Christensen, 1974). Grains contain fairly active antioxidants and the fats in unbroken kernels of grains are effectively protected against effects of oxygen in the air. As a result, the development of oxidative rancidity is rarely a problem in grain storage, although it is a serious problem in the storage of grain oils and of milled products (Christensen, 1974). Whole wheat, for example can be kept for only a relatively short time because it readily becomes rancid, regardless of its moisture content (Zeleny, 1954).

Fat hydrolysis takes place much more rapidly than protein or carbohydrate hydrolysis in stored grain. For this reason, the free fatty acid content of grain has been proposed as a sensitive deterioration parameter (Christensen, 1974). The free fatty acid content of damaged palm kernel was found by Allotey (1988) to be higher than that of the undamaged ones and above the acceptable 4.75% level (Kuku, 1983). The higher free fatty acid in palm kernels, especially in damaged kernels can be attributed mostly to activities of the insects present in the experimental jars (Allotey, 1988).

Mouldiness and high moisture are prerequisite for increase in free fatty acid content of oil seeds (Cornelius, 1966). The presence of insects' frass speeds up lypolysis which leads to increase in free fatty acid of oil seeds such as groundnuts (Halliday, 1968).

The length of storage is important in determining the effect of any factor on a produce (Allotey, 1988). The deterioration of wheat during storage is generally accompanied by decreases in petroleum ether-extractable lipids. A thousand-fold increase in mould count was accompanied by a 20% reduction in free lipids (Pomeranz *et al.*, 1956). Pomeranz and Daftary (1965) studied the changes in lipids of soft and hard wheat stored at elevated moisture levels and higher temperatures and found an increase in mould count from 1000 to about 2,000,000 per grain. This was accompanied by a 40% decrease in total lipid content. Out of this decrease in lipids, 25% was non-polar lipids. It was also found that damaged wheat contained only about one third as much polar lipids as sound wheat.

Grain deterioration was accompanied by rapid disappearance of glycolipids and phospholipids (Christensen, 1974). The breakdown of polar lipids was more rapid and extensive than formation of free fatty acid or disappearance of triglycerides (Pomeranz and Daftary, 1965). Morrison (1963) followed changes in free fatty acids of wheat flours of 13 to 14% moisture in storage. He found that palmitic, oleic, linoleic, and linolenic acids were liberated at a steady rate in proportions close to those of the total lipids.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 STUDY SITES

The experiments were carried out at the Controlled Temperature room (CTR) maintained at 25-31°C and 60-73% r.h. at the Research Department of Quality Control Division of COCOBOD, Tema and in the physiology laboratory at the Zoology Department, University of Ghana, Legon. The arrangement of the cocoa beans in mini jute sacks was similar to those at the warehouse at the ports awaiting export (Plate 4). The CTR was fogged with coopex smoke generator before the experimental cocoa beans were stacked in.

3.2 EXPERIMENTAL DESIGN

The experimental design was completely randomised design (CRD). Where the minijute sacks containing the cocoa beans were stacked in 4 groups. Each group contained three treatments and a control. Each treatment, together with the control had 5 replicates. The treatments were assigned randomly because the CTR is of uniform conditions.

3.3 COCOA BEANS USED FOR THE STUDY

Three bags of cocoa beans were provided by COCOBOD for the study. These beans were fumigated with phosphine gas for about five days before they were used. The beans were sorted out to remove all the defective ones(plate 5). Only undamaged beans were used for the various treatments. Two kilogrammes of beans were weighed into mini jute sacks (16 cm x 30 cm) and the sacks were stacked in the controlled temperature room (CTR).

3.4 CULTURING OF INSECTS

The culture jars and petri dishes used in this study were sterilised in a hot box oven at 60°C for 3 hours before experimentation. *A. fasciculatus* and *C. cephalonica* used were collected from the cocoa sheds at Tema port and reared in the CTR at 31-35°C and 70-75 r.h. *Araecerus fasciculatus* was collected by sieving samples of 1 cocoa arriving at the port with a sieve of mesh size 4 mm. The insects were picked with a brush from a basin underneath the sieve and reared on cassava chips. (Haines and Hodges, 1991). Three batches of cassava chips with 7.5, 8.0 and 8.5% moisture contents were prepared following the method of Dent (1991):

$$\text{Wt. of water to add (g)} = \text{wt. of cassava chips (g)} \times \frac{[\text{required \% mc} - \text{initial \% mc}]}{(100 - \text{required mc})}$$

mc =moisture content.

Fifty newly emerged adults of *A. fasciculatus* of mixed- sex were introduced into each batch of cassava chips. This is because sex ratio is assumed to be 1:1. The culture jars; (19 cm deep x 11 cm diameter) were covered with muslin cloth held in place by rubber bands to allow for aeration (plate 1).

The sets-up were put into trays filled with white oil to prevent entry of crawling insects and left for six weeks. Some of the cassava chips were taken every week and examined for the development of the insect. The time interval within which larvae and newly emerged adults were seen were noted. At the end of six weeks, newly emerged adults that were observed were collected with the aid of pooter and put into Petri dishes in batches of 10.

Corcyra cephalonica was collected from the cocoa sheds at Tema port using pooter or mouth aspirator. The warehouse was disturbed by beating the sacks of stacked cocoa causing them to fly from their resting sites. They were then caught and sent to the CTR and reared on finely ground maize, wheat bran and glycerol in the ratio of 8:8:1 (w/w) (Amoako-Atta and Partida, 1979). The finely ground maize and wheat bran were mixed completely by stirring equal weights of each before glycerol was added. This medium was put into kilner jars, 19 cm deep with a diameter of 11 cm. The jars were placed in metallic trays filled with white oil to avoid the entry of crawling insects. Fifty newly emerged *C. cephalonica* adults were introduced into each culture jar. The jars were covered with muslin cloth held in place by rubber bands (plate 1). The cultures were kept in the CTR (31-35°C and 70-75% r.h). The cultures were kept for five weeks but monitored weekly for the various developmental stages. Fresh medium was periodically added to the culture to ensure adequate source of food for the insects.

When the insects started emerging, the females were collected and egg-laying apparatus (Allotey and Goswani 1990) was set up (plate 3). This consists of cylindrical disk 4 cm deep with a diameter of 7 cm and covered with glass plate 8 cm square with wire gauze in the middle of the plate. The discs were placed in 10 cm petri dishes lined with filter papers. One newly emerged *C. cephalonica* female was introduced into each of these egg-laying apparatus and left overnight. Eggs were laid on the filter papers and the adults were gently removed with forceps. Finely ground maize was placed in each disc for the newly

atched larvae to feed on in order to avoid egg cannibalism (Allotey and Goswani, 1990; Allotey and Morris, 1993).

The first instar larvae (0-12 hrs) of *C. cephalonica* obtained from the egg laying apparatus were counted with the aid of horse brush into Petri dishes in batches of 10 ready to be introduced into cocoa beans in mini jute sacks.

All the culture jars and Petri dishes used in this study were sterilised in a hot box oven at 60°C for 3 hrs before experimentation.

3.5 INSECT SURVIVAL AND DAMAGE ASSESSMENT

The mini jute sacks containing 2 kg of cocoa beans were sealed at both ends. They were then arranged into four groups of 20 mini jute sack each as replicates. Each group stack had three treatments and a control. There were five replicates for each treatment as well as the controls. The whole arrangement was done on a wooden shelf (plate 4). Temporary holes were created by means of forceps on the mini jute sacks and 10 insects of each species were introduced separately into each sack.

In another set of mini jute sacks 10 jute containing 2 kg cocoa beans insects of both species were introduced. After this the holes were sealed. The insects were introduced by means of horse brush. The set-ups were left for four months and five sacks were opened at the end of each month. The content was poured on serially arranged sieves with mesh sizes of 5.6 mm, 2.0 mm, 1.0 mm and 0.5 mm. This arrangement allowed for separation of insects, contaminants comprising feeding residue, frass and fragments, and cocoa beans. The contaminants were removed, critically observed and weighed.

The dead and live insects were counted. The cocoa beans were also separated into damaged and undamaged portions. Each category of beans from each sack was counted and weighed. The percentage of damaged beans was calculated as follows:

$$\% \text{ of damaged beans} = \frac{\text{number of damaged beans}}{\text{total number of beans}}$$

The percentage weight loss was calculated following FAO (1985) methods.

$$\% \text{ Wt loss} = \frac{UaN - (U + D) \times 100}{UaN}$$

Where U_a = Average weight of one undamaged bean

U = Weight of undamaged beans

D = Weight of damaged beans

N = Total Number of beans

3.6 ASSESSMENT OF CHANGES IN FREE FATTY ACID (FFA) LEVEL OF COCOA BEANS

After separating the cocoa beans in each replicate into damaged and undamaged lots, 20 g samples were taken from each lot. These were sent to the Crop Science Department, Faculty of Agriculture University of Ghana. Each sample was put into a metallic dish and placed in an oven at 145°C for 10 minutes (Rene, 1992). After roasting, the shells on the cocoa beans were peeled off manually. Each sample was ground with electronic mill into

fine particle sizes. The powdered cocoa beans were then taken to the physiology laboratory of Zoology Department, University of Ghana, Legon for extraction.

Eighteen grammes of the powdered beans was poured into 100 cm³ beaker and 50 cm³ of n-hexane was added. The mixtures were stirred with glass rod, covered and left for 4.5 hours. They were stirred intermittently during the 4.5 hour period. The mixtures were filtered using filter papers fitted into a funnel (Allotey, 1988). Four grammes of NaOH pellets was weighed and dissolved in 1000 cm³ of distilled water to prepare 0.1 M solution of NaOH. 1 cm³ portions of the prepared 0.1 M NaOH were pipetted and titrated against the filtrates using phenolphthalein as indicator. The phenolphthalein was prepared by dissolving 1 mg of phenolphthalein crystals in 5 cm³ of methylated spirit. 45 cm³ of CO₂ free distilled water was added to the mixture and 0.05 cm³ of 0.1 M NaOH was dropped into the resultant solution.

The molarity or concentration of the free fatty acid in 18 g of powdered cocoa beans was determined using the mole concept, where the endpoint was compared with the volume and concentration of acid used. A factor of 28.2 g was used to multiply the concentration and the result divided by the weight of the cocoa powder to obtain the % FFA value (Annon, 1958). The equation $\text{RCOOH} + \text{NaOH} \rightleftharpoons \text{RCOONa} + \text{H}_2\text{O}$ was used to calculate the concentration of the FFA. The end point is reached when the colour changed from pink to whitish.

3.7 BREEDING TRIALS OF *C. CEPHALONICA* AND *A. FASCICULATUS*.

Araecerus fasciculatus and *C. cephalonica* were reared on crushed and whole cocoa beans to determine their breeding efficiency on this produce. The set-ups were in two batches. For the first batch, 100 g of each medium was put into 9 cm deep with 8 cm diameter kilner jars. Ten first instar larvae (0-12 hrs) of *C. cephalonica* and 10 newly emerged adults of *A. fasciculatus* were introduced into each jar separately. There were 18 replicates for each insect species and breeding medium. These treatments were kept for 3 months. At the end of each month, six of the replicates from each treatment for each insect were examined and the dead or live insects found were counted.

For the second batch, 10 g of both crushed and whole cocoa beans were put into glass vials (25 cm dia x 7.6 cm deep) separately. One newly hatched larva of *A. fasciculatus* collected by breaking through cassava chips and first instar larva of *C. cephalonica* obtained from egg laying apparatus were introduced. There were 20 replicates in each case. The set-ups were monitored and the larval period, pupal period and whole life cycle were determined.

Araecerus fasciculatus could not survive because the cocoa beans used had moisture contents outside the preferred range of the insect species. Hence, the larval period, pupal period, whole life cycle, fecundity, oviposition period and adult longevity was studied for *C. cephalonica* only. All the females of *C. cephalonica* that emerged from this study

were put into egg laying apparatus. The oviposition period and the number of eggs laid were determined.

Twenty adults were also kept singly in 20 vials each and monitored till they died to determine adult longevity. All the vials and kilner jars used in this experiment were sterilised in hot box 60°C for three hours before they were used. They were all kept on wooden trays raised at the corners with corks placed in oil during the experiment to prevent the entry of crawling insects.

3.8 ANALYSIS OF DATA

The data collected was entered on excel. The percentage damage caused and percentage weight loss were transformed using arcsine. Insect numbers was transformed using square root of (x+1). The data was analysed using analysis of variance. The means were separated using Fisher's mean separation.



Plate 1



Plate 2



Plate 3



Plate 4

Plate 1. Culturing of insects for experimental work

Plate 2. Breeding of *A. fasciculatus* and *C. cephalonica* on cocoa beans

Plate 3. Egg laying apparatus for *C. cephalonica*

Plate 4. Arrangement of mini jute sacks in the CTR for the experiment



Plate 5. Researcher sorting and counting damaged and undamaged beans

CHAPTER FOUR

4.0 RESULTS

4.1 SURVIVAL AND ESTABLISHMENT OF INSECTS ON COCOA BEANS

During the storage period of the cocoa beans, significant differences were observed among the mean number of insects that survived and established on the various treatments (Table 1) (see Appendix 1). Insect survival and establishment increased over time for all the treatments. Significant ($P = 0.00$) interaction of insect survival and establishment was also observed.

The highest number of insects (488.6) survival was recorded in the fourth month on cocoa infested with *C. cephalonica* (C). No insect was recorded in the first month in the control.

Table 1 Mean number of insects recorded on different treatments of cocoa beans

Treatment	Mean number of insects \pm SE*			
	Month 1	Month 2	Month 3	Month 4
Control	0.00 ^a	8.0 \pm 2.3 ^a	43.6 \pm 7.8 ^b	278.8 \pm 9.6 ^c
A	9.6 \pm 0.4 ^a	9.6 \pm 0.2 ^a	59.2 \pm 8.9 ^b	323.8 \pm 24.7 ^{ef}
C	7.4 \pm 0.3 ^a	97.2 \pm 3.6 ^c	218.2 \pm 10.8 ^d	488.6 \pm 24.7 ^g
CA	10.4 \pm 0.8 ^a	35.4 \pm 1.2 ^b	318.4 \pm 2.0 ^{ef}	382.0 \pm 4.3 ^{ef}

Control = cocoa beans without any insect introduced onto them.

A = cocoa beans infested with *A. fasciculatus*.

C = cocoa beans infested with *C. cephalonica*

CA = cocoa beans infested with *A. fasciculatus* and *C. cephalonica* in combination.

*Values are means of five replicates.

Means followed by the different letter(s) in both columns and rows are significantly different from each other at

P < 0.05 at 0.05, Fisher's test.

4.2 CONTAMINANTS PRODUCED BY THE INSECTS ON COCOA BEANS

The insects produced contaminants through their biological processes. Contaminants such as powdery residue of damaged beans was produced through their feeding, frass through their defecation, insect fragments through moulting and death, and silken threads and cocoons through reproduction (Table 2).

The variation of the contaminants increased with time. At the end of the first month, only few contaminants were produced. The control beans had virtually no contaminants. Cocoa beans infested with *C. cephalonica* alone and those infested with combination of *C. cephalonica* and *A. fasciculatus* had powdery residue, frass, insect fragments and silken threads. Cocoa beans treated with *A. fasciculatus* alone had only powdery residue, frass and insect fragments.

At the end of the second month, the amount and type of contaminants increased. The control had powdery residue, frass and insect fragments, while the other treatments had silken thread in addition to the first month's contaminants. At the end of the third and fourth months, pungent odour was produced in addition to matting or clumping of the other contaminants and fibre from the jute sacks (Table 2).

Table 2 Contaminants produced by *C. cephalonica* and *A.*

Treatment	month1	Month 2
		Insect fragment, Powdery residue and frass
Control	Nil	
A	Insect fragment, Powdery residue and frass	Powdery residue, frass, insect fragment, and silken thread
C	Powdery residue, frass, insect fragment, and silken thread	Powdery residue, frass, insect fragment, and silken thread
CA	Powdery residue, frass, insect fragment, and silken thread	Powdery residue, frass, insect fragment, and silken thread
	Control= Cocoa beans.	without any insect introduced
	A= Cocoa beans infested	with <i>A. fasciculatu</i>
	C= Cocoa beans infested.	With <i>C. cephalonica</i>
	CA= Cocoa beans.	infested with <i>C. cephalonica</i> and <i>A. fasciculatus</i> combined.

b

fasciculatus on cocoa beans**Month 3**

Powdery residue, insect fragm-

ent, frass, cocoon, silken thread,
pungent smell and matted fibre

with other contaminants

Powdery residue, insect fragm-
ent, frass, cocoon, silken thread,pungent smell and matted fibre
with other contaminantsPowdery residue, insect fragm-
ent, frass, cocoon, silken thread,
pungent smell and matted fibre
with other contaminantsPowdery residue, insect fragm-
ent, frass, cocoon, silken thread,
pungent smell and matted fibre
with other contaminants

on them.

Month 4

Powdery residue, insect

fragment, frass, cocoon,
silken thread, pungentsmell and matted fibre with
other contaminantsPowdery residue, insect
fragment, frass, cocoon,silken thread, pungent
smell and matted fibre with
other contaminantsPowdery residue, insect
fragment, frass, cocoon,
silken thread, pungent
smell and matted fibre with
other contaminantsPowdery residue, insect
fragment, frass, cocoon,
silken thread, pungent
smell and matted fibre with
other contaminants

4.3 WEIGHT OF CONTAMINANTS PRODUCED BY THE INSECTS ON COCOA BEANS

Significant ($P = 0.00$) differences were observed in the weight of contaminants produced by the insects on the various treatments over the period of the experiment. The weight of contaminants produced increased with time. Significant ($P = 0.00$) interaction existed between weight of contaminants produced by the insects and time.

The highest weight of contaminant of 77.17 g was produced in the cocoa beans infested with *C. cephalonica* in the fourth month (Table 3) and no contaminant was in the control beans in the first month. However, in the subsequent months, the control became contaminated by the activities of *C. cephalonica* since the set up is a laboratory simulation of the warehouse conditions gave room for free movement of the insects.

Table 3 Weight of contaminants produced by the insects on cocoa beans

Treatment	Mean weight (g) of contaminants produced \pm SE*			
	Month 1	Month 2	Month 3	Month 4
Control	0.00 ^a	0.65 \pm 0.19 ^a	3.60 \pm 0.62 ^b	32.86 \pm 2.44 ^g
A	0.13 \pm 0.08 ^a	0.21 \pm 0.06 ^a	4.68 \pm 0.50 ^c	42.12 \pm 5.16 ⁱ
C	1.46 \pm 0.15 ^a	10.18 \pm 0.58 ^c	34.20 \pm 1.88 ^h	77.17 \pm 0.61 ^k
CA	1.26 \pm 0.15 ^a	5.66 \pm 0.36 ^d	24.98 \pm 1.37 ^f	67.79 \pm 1.16 ^j

Control = Cocoa beans without any insect introduced.

A = Cocoa beans infested with *A. fasciculatus*.

C = Cocoa beans infested with *C. cephalonica*.

CA = Cocoa beans infested with *A. fasciculatus* and *C. cephalonica* combined.

*Values are means of five replicates.

Means followed by different letter(s) in both columns and rows are significantly different from each other at $p < 0.05$, Fisher's test.

4.4 DAMAGE ASSESSMENT

The percentage damage and weight loss caused by *C. cephalonica* and *A. fasciculatus* to cocoa beans during the four months' storage period was significantly different (Tables 4 and 5) (Appendix 4). There was significant percentage damage and weight loss to cocoa beans during the four months of storage due to *C. cephalonica* and *A. fasciculatus* infestation. Tables 4 and 5) (Appendix 4). Percentage damage and weight loss also increased with time the lowest damage was recorded in the first month and the highest in the fourth month. Damage was lowest on control cocoa beans. The highest damage was recorded on cocoa beans infested with *C. cephalonica*. This treatment recorded 44.72% and 13.34% for percentage damage and percentage weight loss at the fourth month, respectively (Tables 4 and 5). In addition, the cocoa beans got clumped together especially in the third and fourth months (plates 8 & 9) as opposed to the holed beans which were apart in the first and second months (plates 6 & 7).

Table 4 Percentage damage caused by *C. cephalonica* and *A. fasciculatus* to cocoa beans

Treatment	Percentage damaged beans \pm SE*			
	Month 1	Month 2	Month 3	Month 4
Control	0.00 ^a	1.16 \pm 0.51 ^a	6.04 \pm 1.55 ^b	25.97 \pm 1.95 ^d
A	0.87 \pm 0.20 ^a	1.46 \pm 0.33 ^a	14.45 \pm 3.56 ^c	28.03 \pm 3.41 ^{de}
C	2.33 \pm 0.22 ^a	13.25 \pm 0.64 ^c	30.02 \pm 2.06 ^e	44.72 \pm 2.19 ^f
CA	2.33 \pm 0.51 ^a	7.96 \pm 1.4 ^b	22.15 \pm 4.04 ^d	35.18 \pm 0.76 ^c

Control = Cocoa beans without any insect on it.

A = Cocoa beans infested with *A. fasciculatus*.

C = Cocoa beans infested with *C. cephalonica*.

CA = Cocoa beans infested with *C. cephalonica* and *A. fasciculatus*

*Values are means of five replicates.

Means followed by the different letter(s) in both columns and rows are significantly

different from each other at $P < 0.05$, Fisher's test.

Table 5 Percentage weight loss caused by *C. cephalonica* and *A. fasciculatus* to cocoa beans

Treatment	Percentage weight loss \pm SE*			
	Month 1	Month 2	Month 3	Month 4
Control	0.00 ^a	0.29 \pm 0.19 ^a	1.48 \pm 0.53 ^{ab}	5.14 \pm 0.58 ^d
A	0.06 \pm 0.20 ^a	0.09 \pm 0.02 ^a	1.34 \pm 0.40 ^{ab}	5.29 \pm 1.08 ^d
C	0.59 \pm 0.27 ^a	2.82 \pm 0.88 ^{bc}	3.24 \pm 0.62 ^c	13.34 \pm 1.05 ^f
CA	0.53 \pm 0.19 ^a	1.22 \pm 0.31 ^{ab}	2.75 \pm 0.50 ^{bc}	8.09 \pm 0.43 ^e

Control = Cocoa beans without any insect on it.

A = Cocoa beans infested with *A. fasciculatus*.

C = Cocoa beans infested with *C. cephalonica*.

CA = Cocoa beans infested with *C. cephalonica* and *A. fasciculatus*

*Values are means of five replicates.

Means followed by the different letter(s) in both columns and rows are significantly different from each other at $P < 0.05$, Fisher's test

4.5 THE RELATIONSHIP BETWEEN INSECT DENSITY AND DAMAGE CAUSED

Defining the relationship between pest densities and damage is a very important basis for sound pest management (Stern *et. al*; 1973). As a result of this, a correlation test was conducted on percentage bean weight loss and percentage beans damaged for each month using insect density as an independent variable.

It was observed that, there was positive correlation for both percentage weight loss and percentage damage against insect numbers (Table 6). There was smooth correlation between insect number and percentage of damaged beans, but this relationship fluctuated for percentage weight loss and insect numbers.

The correlation between insect number and percentage damage was significant ($P = 0.05$) for all the months (Table 6) (Appendix 5). However, this relation was not significant for ($P = 0.05$) insect numbers and percentage weight loss in the first month.

Table 6 Correlation among insect number, percentage damage and percentage weight loss

Correlation coefficient (R).		
Insect numbers	%damage	%weight loss
I ₁	0.509	0.356
I ₂	0.740	0.789
I ₃	0.750	0.573
I ₄	0.938	0.565

I₁ - I₄ = Insect number in the 1st-4th month.

R > 0.444 have P < 0.05 and these are significant.

20 sample were used for each parameter.

4.6 FREE FATTY ACID LEVEL OF COCOA BEANS AFTER INFESTATION BY *C. CEPHALONICA* AND *A. FASCICULATUS*

Infestation by the two insects increased the free fatty acid value of cocoa beans. It was observed that significant ($p = 0.00$) differences existed among the percentage free fatty acid (FFA) values of the various treatments. The percentage FFA value of each treatment increased significantly ($p = 0.00$) with time (Table 7) (Appendix 6).

The percentage FFA values recorded ranged from 0.42% to 0.61%. The lower FFA was recorded in the first month while the highest was in the fourth month. The lowest value of 0.42% was recorded in the control while the highest value of 0.61% was in the cocoa beans damaged by *C. cephalonica*.

The increase in the %FFA value of damaged beans with respect to the control beans was highest for beans damaged by *C. cephalonica*. However, there was no significant ($p = 0.00$) difference in the increase in %FFA values of the undamaged beans selected from the various treatments as compared to those from the control. (Figure 1).

Table 7 Percentage of free fatty acid level of cocoa beans infested by *C. cephalonica* and *A. fasciculatus*

Treatment	Percentage free fatty acid value \pm SE			
	Month 1	Month 2	Month 3	Month 4
Control	0.420 \pm 0.00 ^a	0.424 \pm 0.00 ^a	0.426 \pm 0.00 ^a	0.436 \pm 0.00 ^a
AD	0.516 \pm 0.04 ^b	0.472 \pm 0.00 ^a	0.544 \pm 0.00 ^b	0.570 \pm 0.00 ^b
AU	0.420 \pm 0.00 ^a	0.428 \pm 0.00 ^a	0.426 \pm 0.00 ^a	0.440 \pm 0.00 ^a
CD	0.488 \pm 0.02 ^a	0.586 \pm 0.00 ^b	0.574 \pm 0.00 ^b	0.610 \pm 0.00 ^c
CU	0.420 \pm 0.00 ^a	0.428 \pm 0.00 ^a	0.430 \pm 0.00 ^a	0.440 \pm 0.00 ^a
CAD	0.446 \pm 0.01 ^a	0.570 \pm 0.00 ^b	0.570 \pm 0.00 ^b	0.596 \pm 0.01 ^c
CAU	0.424 \pm 0.00 ^a	0.430 \pm 0.00 ^a	0.424 \pm 0.00 ^a	0.440 \pm 0.00 ^a

Means followed by the same letter in both column and rows are not significantly different from each other at 0.05 level Fisher's test.

Control = Cocoa without any insect introduced on it.

AD = by Cocoa beans damaged by *A. fasciculatus*

Au = Cocoa beans undamaged by *A. fasciculatus*

CD = Cocoa beans damaged by *C. cephalonica*

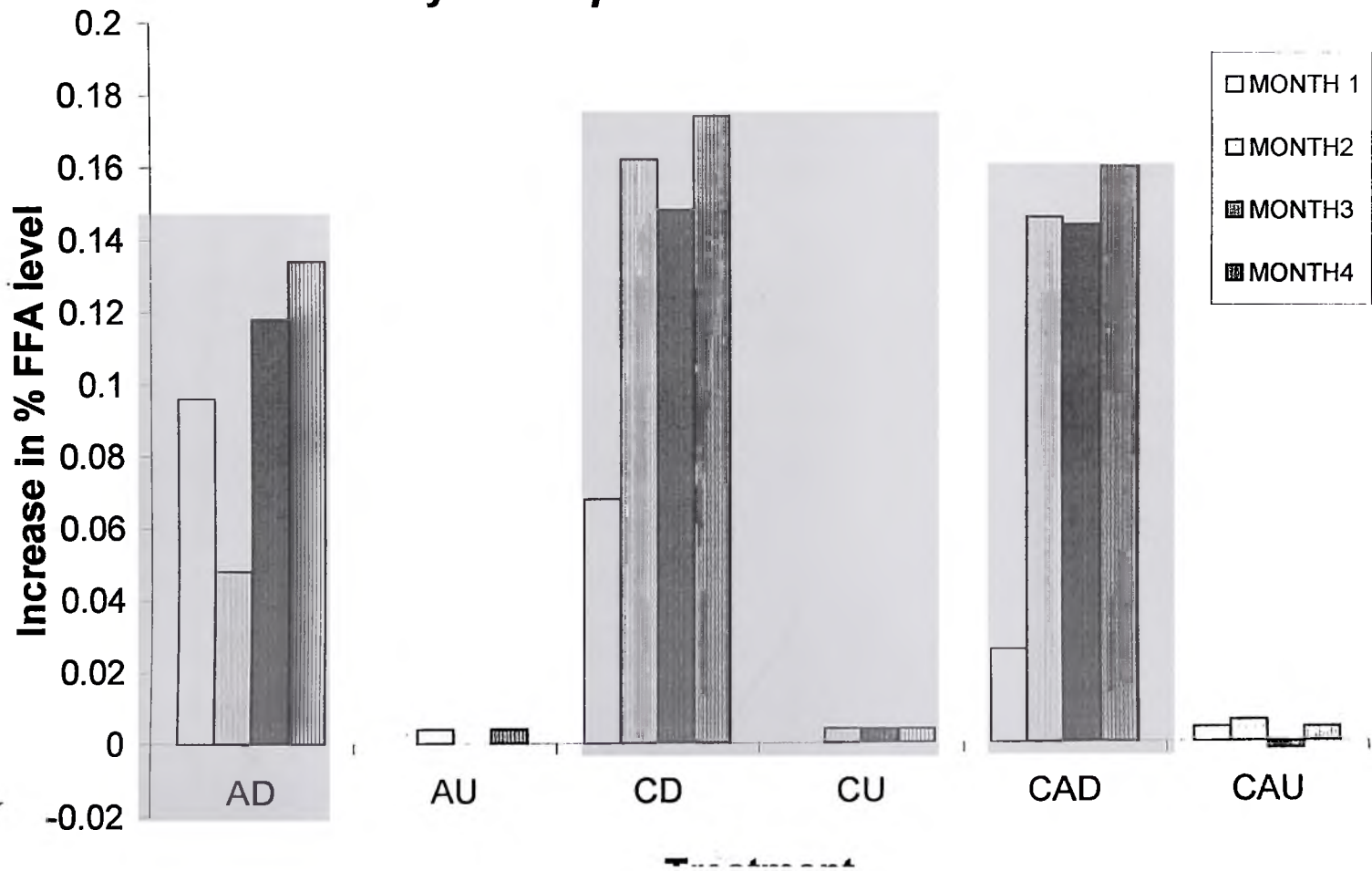
CU = by Cocoa beans undamaged by *C. cephalonica*

CAD = Cocoa beans damaged by *C. cephalonica* and *A. fasciculatus* combined

CAU = Cocoa beans undamaged by *C. cephalonica* and *A. fasciculatus* combined

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Fig 1 Increase in % FFA level of cocoa beans after infestation by *C. cephalonica* and *A. fasciculatus*.



4.7 BREEDING OF *A. FASCICULATUS* AND *C. CEPHALONICA* ON COCOA BEANS

The rate at which *C. cephalonica* reproduced and multiplied on cocoa beans was significantly ($P= 0.05$) different for each form of the beans. It was also observed that the multiplication rate was dependent on time (Table 8) (Appendix 7).

The number of progeny produced by a female *C. cephalonica* on cocoa beans ranged from zero to 608 insects. Higher values were recorded in the third month and lower values in the first month. The highest number of *C. cephalonica* was recorded on crushed cocoa beans. *A. fasciculatus* did not breed on either crushed or whole cocoa beans.

Table 8 F1 Progeny produced by *A. fasciculatus* and *C. cephalonica* on cocoa beans

Treatment	Number of F1 progeny*		
	Month 1	Month 2	Month 3
WCA	0.00 ± 0.00 ^a	0.00 ± 0.00 ^a	0.00 ± 0.00 ^a
CCA	0.00 ± 0.00 ^a	0.00 ± 0.00 ^a	0.00 ± 0.00 ^a
WCC	2.70 ± 0.90 ^b	7.90 ± 1.70 ^b	23.50 ± 0.80 ^c
CCC	38.70 ± 15.80 ^c	389.80 ± 13.60 ^d	608 ± 0.20 ^e

*Values means are of six replicates.

Means followed by the same letter in both column and rows are not significantly different from each other at 0.05 level Fisher's test.

WCA = *A. fasciculatus* on whole cocoa beans.

CCA = *A. fasciculatus* on crushed cocoa beans.

WCC = *C. cephalonica* on whole cocoa beans.

CCC = *C. cephalonica* on crushed cocoa beans

4.8 RELATIONSHIP AMONG PERCENTAGE DAMAGE, PERCENTAGE WEIGHT LOSS AND PERCENTAGE FREE FATTY ACID LEVEL

To ascertain the relationship that existed among the %damage, %weight loss and FFA, a correlation test was conducted using percentage damage as an dependent factor. It was observed that, positive correlation existed for all the parameters for all the months. However, the correlation coefficient for the first month was not significant ($P = 0.05$) for both weight loss and free fatty acid level. The strongest correlation existed for free fatty acid level in the second month, while weight loss had the strongest correlation in the fourth month (Table 9) (Appendix 5).

Table 9 Correlation among percentage damage, percentage weight loss and percentage free fatty acid level

Correlation coefficient, (R).		
% damage	% FFA	% wt. loss
D ₁	0.274	0.416
D ₂	0.871	0.755
D ₃	0.814	0.629
D ₄	0.615	0.877

D₁– D₄ = %damage recorded at 1st - 4th month.

R > 0.444 has ($P > 0.05$) and significant.

20 samples were used for each parameter.

4.9 THE BIOLOGY OF *C. CEPHALONICA* ON COCOA BEANS.

The oviposition period of *C. cephalonica* was longer when reared on crushed cocoa beans than on whole beans. Oviposition lasted for 2.85 and 3.1 days when reared on whole and crushed cocoa beans, respectively (Table 10). These values are significantly different from each other ($P = 0.00$). On crushed cocoa beans 174.9 eggs were recorded while 141.7 eggs were recorded on whole cocoa beans, and these means are significantly different from each other. The larval period on crushed cocoa bean was significantly ($P = 0.00$) shorter than that on whole cocoa beans. The total developmental period was also shorter on crushed cocoa beans 33 days than on whole cocoa beans (37.9days).

The pupal developmental period was similar on both forms of cocoa beans.

Adult longevity of *C. cephalonica* on crushed cocoa beans and whole cocoa beans was similar (Table 10).

Table 10 The biology of *C. cephalonica* on cocoa beans.

Trt	OP/days	Fec	LP/days	PP/days	TP/days	Al/days
CC	3.1 ± 0.1 ^a	174.9 ± 5.3 ^b	19.7 ± 0.4 ^a	13.3 ± 0.3 ^a	33.0 ± 0.4 ^a	8.1 ± 0.8 ^a
CW	2.9 ± 0.2 ^a	141.7 ± 7.3 ^a	24.2 ± 0.6 ^b	13.7 ± 0.4 ^a	37.9 ± 0.4 ^b	7.6 ± 0.7 ^a

Values are means of 20 replicates.

Means followed by the same letter(s) are not significantly different ($p > 0.05$) by Fisher's test.

Trt = Treatment.

CC = Crushed cocoa beans.

CW = Whole cocoa beans.

LP = Larval period.

PP = Pupal period.

TP = Total developmental period.

OP = Oviposition period.

Fec. = Fecundity (number of eggs laid per female).

Al = Adult longevity.



Plate 6



Plate 7



Plate 8



Plate 9

Plate 6. Nature of damaged cocoa beans after one month

Plate 7. Nature of damaged cocoa beans after two months

Plate 8 Nature of damaged cocoa beans after three months

Plate 9 Nature of damaged cocoa beans after four months

CHAPTER FIVE

5.0 DISCUSSION

5.1 SURVIVAL AND ESTABLISHMENT OF *A. FASCICULATUS* AND *C. CEPHALONICA* ON COCOA BEANS

The degree of establishment of an insect on its host is not determined only by its ability to survive and grow but also by its ability to breed on its host (Krishna and Mishra, 1985). The increase in the number of an insect on a specific food gives an idea of the suitability of such product as a host for the insect. Insects are known to cause considerable damage to products that are suitable for them as food.

From the results of the insect establishment experiment, it was realised that the number of *C. cephalonica* that was recorded on cocoa beans previously infested with *C. cephalonica* was high throughout the months. This gives an indication that *C. cephalonica* was able to survive and breed well on cocoa beans.

Araecerus fasciculatus on the other hand could not survive beyond the first month. At the end of the first month, all *A. fasciculatus* adults in the 2 kg weight of cocoa beans in each sack were dead. The death of all the *A. fasciculatus* may probably be due to the very low moisture content (7.5%) of cocoa beans used. The most suitable moisture content for storing cocoa beans is 7.5% (Wood and Lass, 1978). Meanwhile *A. fasciculatus* is known to survive on high moisture produce of 8.5% and above (Haines and Hodges, 1991). It was possible for to infest *C. cephalonica* cocoa beans treated with only *A. fasciculatus* because the experimental set up was simulation of what happens at the warehouse. Therefore, the insects had the freedom to move about and infest treatment A, which was supposed to contain only *A. fasciculatus*.

Corcyra cephalonica survived at the expense of *A. fasciculatus* when they were together. However, the increase in the number of *C. cephalonica* was not as high as in the case of *C. cephalonica* alone even although the two treatments had the same number of *C. cephalonica* at the start of the experiment. This suggests some form of competition between the two species. The dead bodies of *A. fasciculatus* might have inhibited the breeding of *C. cephalonica*. This probably might be due to the presence of some chemicals in *A. fasciculatus* that is interfered with the activities of *C. cephalonica*.

The control cocoa beans recorded insects from the second month onwards. This was probably due to cross infestation by *C. cephalonica* because of its freedom to move in the simulated warehouse controlled temperature room. The moth did better with time because they got acclimatized to the conditions in the environment and hence appeared adapted to living there.

5.2 CONTAMINANTS PRODUCED BY *C. CEPHALONICA* AND *A. FASCICULATUS* ON COCOA BEANS

From the results, it was observed that the weight and complexity of contaminants produced by these insect pests increased with time. This may be due to fact that as the insect number increased their biological activities also increased. For instance, in the first month cocoon production was virtually non-existing because the insects were not well adapted to the new environment to reproduce.

The fact that in the first month the control cocoa beans had no contaminants suggests that production of contaminants is a consequent of insect activity. The variation in the weight of the contaminants especially for the first month suggests that insect activity depended on how well adapted the insects were and their population. *Corcyra cephalonica* adapted well on cocoa beans and produced more contaminants than *A. fasciculatus*. The contaminants produced on the treatment with *C. cephalonica* and *A. fasciculatus* was expected to be higher than that produced on the treatment with *C. cephalonica* alone, since 10 of each insect was introduced onto it. as The small quantity of contaminants suggests a kind of competition between the two insects, which led to low activity of each of them.

From the second month, onwards the type of contaminants was almost the same for all the treatments. This is because, the contaminants thereafter was basically produced by *C. cephalonica*. In the second month too, it was observed that the weight of contaminants on the control was rather higher than that on cocoa beans infested with *A. fasciculatus*. Meanwhile, both categories were cross infested by *C. cephalonica*. Why then should the control beans, which had no contaminant in the first month, have more contaminants from the second month onwards? A possible explanation could be that the dead bodies of *A. fasciculatus* inhibited the activities of *C. cephalonica* that cross infested the cocoa beans.

From the second month onwards, the contaminants produced which included silken threads, cocoon, frass, insect fragments, etc made the cocoa beans so bad to be accepted by the International Cocoa Standards (ICS), notwithstanding the number of beans that were damaged. This supports the finding of Christensen (1977) that the Mediterranean flour moth and certain moths spin silken webs over their host/ breeding medium, so that their presence in the product ruins produce more than the amount of product eaten. In the fourth month, over 50% of the beans were clumped together with other contaminants due the production of large quantities of silken thread that formed extensive webbing.

The pungent odour might be due to formation of ammonia products through heavy infestation and insect activities such as defecation, excretion, reproduction and even congestion (Mullins and Cochran, 1972).

5.3 DAMAGE ASSESSMENT

In this study *C. cephalonica* caused considerable damage to cocoa beans. No matter how dry the beans, the presence of *C. cephalonica* possesses a serious threat to the wholesomeness and marketability of cocoa beans.

After one month of storage, *C. cephalonica* can cause up to 2.3% damage to cocoa beans. Meanwhile, insect damage, rodent attack, slatiness, fungal infection etc should not exceed 3% on cocoa beans before it can be accepted as graded I by the ICS (Anon, 1970). This study also showed that when *C. cephalonica* is left uncontrolled on cocoa beans for more than one month, the beans would be considered substandard and unmarketable. This is because the percentage damage will be more than 6% (Anon, 1970).

Another interesting outcome of this work was that, when *C. cephalonica* is found on an arrival cocoa from a given area, no matter how widely apart it is from the other sacks there is strong possibility of cross infestation. This is because of their mobility and high reproduction rate.

The percentage of beans damaged and the percentage weight loss caused by introduction of 10 first instar larvae of *C. cephalonica* and 10 *A. fasciculatus* adult combined in the same sack was almost equal to that caused by 10 *C. cephalonica* larvae alone in the first month. In the subsequent months, the damage caused by *C. cephalonica* alone far exceeded that caused by the two species of insects combined.

It was observed that large number of damaged beans caused only a small amount of weight loss as was also reported by Davies (1960).

5.4 THE RELATIONSHIP BETWEEN PEST DENSITY AND DAMAGE.

It is important to know the level at which control measures should be implemented to prevent an increasing pest population from reaching the economic injury level (Stern *et al* 1959). For this reason it is essential to know the relationship between pest density and the damage caused in order to initiate effective control measures.

Percentage damage and percentage weight loss correlated positively with insect number in each month. This confirmed the fact that there is some correlation between insect numbers found in a produce and the damaged grains or beans and the percentage weight loss (Hall, 1970). This means that the damage suffered by cocoa beans depended on the density of insect pest at a point in time.

5.5 CHANGES IN LEVEL OF FREE FATTY ACID OF COCOA BEANS

The free fatty acid (FFA) level of cocoa beans is a factor that determines the quality of cocoa beans and hence its marketability. The FFA level of the beans is an also important consideration for the manufacturers of chocolate and cocoa powder (Wood and Lass, 1986). In the present study, it was observed that the FFA level, expressed as oleic acid of cocoa beans damaged by *C. cephalonica* and *A. fasciculatus*, was quite high but it was within the acceptable limit of 0.5 – 1% (Wood and Lass, 1986).

The actual increase in FFA level due to these pests was found to be higher for cocoa beans damaged by *C. cephalonica* from the second to the fourth month than all the other treatments. However, in the first month the beans damaged by *A. fasciculatus* recorded the highest FFA level. It can therefore be inferred that *A. fasciculatus* infestation increased the FFA level of the beans more than that of *C. cephalonica*. This is because the first month damage is the actual damage attributable to *A. fasciculatus* alone. The FFA level for the treatment with combined *C. cephalonica* and *A. fasciculatus* was not higher than that for either of them for the first month and for *C. cephalonica* alone for the subsequent months. This indicates some sort of competition between the two insects.

Fats in products are likely to be broken down by lipases into free fatty acids and glycerol during storage, particularly when the temperature and moisture contents are high (Christensen, 1974). This type of change is greatly accelerated by mould because infection of the lipolytic activity of moulds (Christensen, 1974). It is therefore possible that, these insects carried on them some storage moulds and introduced them into the cocoa beans. This supports the finding of Christensen and Kaufman (1969) that, at least

some of the common stored produce insects regularly carry into the products they infest a large load of inoculum of storage fungi. As the insects develop in the products, they provide conditions for the development of the fungi.

5.6 BREEDING OF *C. CEPHALONICA* AND *A. FASCICULATUS* ON COCOA BEANS

For an insect to successfully become a serious pest of a host, it must be able to establish itself successfully, breed and multiply on the host. In this study *C. cephalonica* was able to successfully breed on both whole and crushed forms of cocoa beans. More progeny were produced on crushed cocoa than on whole cocoa beans. This might be due to the fact that *C. cephalonica* is a secondary pest and so prefers damaged beans (crushed beans) to whole beans. *A. fasciculatus* could not breed on either form of cocoa because the moisture content of 7.5% of the cocoa beans was too low to support their breeding.

According to Rose and Behl (1985), the developmental period of *C. cephalonica* depends on the type of food, the variety of food, and the form of food on which it was reared. This finding is confirmed by *C. cephalonica* laying more eggs, changing from larva to pupa faster, developing faster, and living longer as adult on crushed cocoa than on whole cocoa beans. Probably because the crushed cocoa beans provides easy access to the larvae than the whole form.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

The following conclusions and recommendations can be made from the study:

- (1) Insect survival and establishment showed significant differences for the two species of insects. *Cocryra cephalonica* survived and established itself and bred better on the beans more easily than *A. fasciculatus*.
- (2) *Araecerus fasciculatus* could not survive and breed on cocoa beans with moisture content of 7.5%. There was also a strong correlation among %damage, %weight loss and free fatty acid level of cocoa beans.
- (3) *Cocryra cephalonica* produced more contaminants from cocoa beans when alone than when in combination with *A. fasciculatus*.
- (4) More damage was caused by *C. cephalonica* than *A. fasciculatus*.
- (5) There was positive correlation between insect numbers and damage caused.
- (6) The damage caused by *C. cephalonica* alone led to more increase in free fatty acid level of the cocoa beans than that of *A. fasciculatus* alone, and *A. fasciculatus* in combination with *C. cephalonica*.
- (7) *Araecerus fasciculatus* does not pose a serious infestation problem to stored cocoa beans if the beans are well dried to a moisture content of around 7.5%.
- (8) Infestation of one sack of cocoa beans in the warehouse can lead to the entire stack been infested no matter the distance.
- (9) *Araecerus fasciculatus* does not breed on cocoa beans with moisture content approved by ICS

From these results, it will be advisable for COCOBOD to ensure that Purchasing clerks buy cocoa beans with moisture content around 7.5%. This will eliminate the problem of *A. fasciculatus* infestation. Furthermore, any small sign of infestation by *C. cephalonica* should be controlled thoroughly to avoid its spread. Control measures like cleaning the warehouses effectively and fogging them after every cocoa season should be seriously considered. If possible, warm air should be blown through the sacks of cocoa in the warehouse regularly to dry cocoa beans which might not be well dried before bagging. Fumigation with phosphine gas should also be encouraged at all levels of storage.



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Appendix 1

Analysis of Variance on insect survival and establishment

Source	DF	SS	MS	F	p
TRT	15	3808.25	253.88	119.70	0.000
Error	64	135.74	2.12		
Total	79	3944.00			

Analysis of Variance for insect survival and establishment (interaction)

Source	DF	Seq SS	Adj SS	Adj MS	F	Pt
month	3	3080.50	3080.50	1026.83	484.14	0.000
trt	3	465.27	465.27	155.09	73.12	0.000
month*trt	9	262.48	262.48	29.16	13.75	0.000
Error	64	135.74	135.74	2.12		
Total	79	3944.00				

Appendix 2

Analysis of Variance on contaminants

Source	DF	SS	MS	F	p
FRT	15	47073.6	3138.2	66.84	0.000
Error	64	3004.9	47.0		
Total	79	50078.5			

Analysis of Variance for contaminants (interaction)

Source	DF	Seq SS	Adj SS	Adj MS	F	P0
Month	3	38572.4	38572.4	12857.5	273.84	0.000b
trt	3	3795.2	3795.2	1265.1	26.94	0.000
Month*trt	9	4706.1	4706.1	522.9	11.14	0.000
Error	64	3004.9	3004.9	47.0		
Total	79	50078.5				

Appendix 3

Analysis of Variance on wt. loss

Source	DF	SS	MS	F	P
TRT	15	1586.02	105.73	41.29	0.000
Error	64	163.90	2.56		
Total	79	1749.92			

Analysis of Variance for wt. loss (interaction)

Source	DF	Seq SS	Adj SS	Adj MS	F	Pd
Month	3	1260.88	1260.88	420.29	164.11	0.000t
trt	3	232.12	232.12	77.37	30.21	0.000
Month*trt	9	93.02	93.02	10.34	4.04	0.000
Error	64	163.90	163.90	2.56		
Total	79	1749.92				

Appendix 4

Analysis of Variance on Damage

Source	DF	SS	MS	F	P
TRT	15	10819.22	721.28	90.46	0.000
Error	64	510.30	7.97		
Total	79	11329.52			

Analysis of Variance for Damage (interaction)

Source	DF	Seq SS	Adj SS	Adj MS	F	P1
Month	3	8696.65	8696.65	2898.88	363.57	0.000
trt	3	1762.18	1762.18	587.39	73.67	0.000
Month*trt	9	360.38	360.38	40.04	5.02	0.000
Error	64	510.30	510.30	7.97		
Total	79	11329.52				

Appendix 6

Analysis of Variance on %ffa

Source	DF	SS	MS	F	P
RT	27	0.622625	0.023060	59.84	0.000
Error	112	0.043160	0.000385		
Total	139	0.665785			

Analysis of Variance for %ffa (interaction)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
month	3	0.058471	0.058471	0.019490	50.58	0.000%
trt	6	0.482000	0.482000	0.080333	208.46	0.0006
month*trt	18	0.082154	0.082154	0.004564	11.84	0.000
Error	112	0.043160	0.043160	0.000385		
Total	139	0.665785				

Appendix 7

Analysis of Variance for breeding

Source	DF	SS	MS
month	2	361.713	180.856
trt	3	3159.546	1053.182
Interaction	6	758.446	126.408
Error	60	12.693	0.212
Total	71	4292.397	

Analysis of Variance for breeding (interaction)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
trt	3	3159.55	3159.55	1053.18	4978.58	0.000
month	2	361.71	361.71	180.86	854.94	0.000
trt*month	6	758.45	758.45	126.41	597.55	0.000
Error	60	12.69	12.69	0.21		
Total	71	4292.40				

Appendix 8

Analysis of Variance on Larval Period

Source	DF	SS	MS	F	p
TRT	1	2.2347	2.2347	35.10	0.000/
Error	38	2.4193	0.0637a		
Total	39	4.65403			

s

Analysis of Variance on Pupal Period

Source	DF	SS	MS	F	p
TRT	1	0.0265	0.0265	0.47	0.495
Error	38	2.1164	0.0557		
Total	39	2.1429			

Analysis of Variance on Total developmental period

Source	DF	SS	MS	F	p
TRT	1	1.6682	1.6682	62.44	0.000
Error	38	1.0152	0.0267		
Total	39	2.6834			

Analysis of Variance on Fecundity

Source	DF	SS	MS	F	p
TRT	1	16.80	16.80	11.83	0.001r
Error	38	53.98	1.42		
Total	39	70.78			

12.60 13.30