EFFECTS OF VARIETY AND PROCESSED FORMS OF CASSAVA CHIPS ON THE DEVELOPMENT *OF PROSTEPHANUS TRUNCATUS* (HORN) (COLEOPTERA: BOSTRCHIDAE) AND *ARAECERUS FASCICULATUS* (DEGEER) (COLEOPTERA: ANTHRIBIDAE)

BY

EDITH, N CHIJINDU

B Sc (Hons), NNAMDI AZIKIWE UNIVERSITY, AWKA, NIGERIA

A THESIS PRESENTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF PHILOSOPHY IN ENTOMOLOGY, UNIVERSITY OF GHANA, LEGON

*INSECT SCIENCE PROGRAMME
UNIVERSITY OF GHANA,
LEGON

*JOINT INTERFACULTY INTERNATIONAL PROGRAMME FOR THE TRAINING OF ENTOMOLOGIST IN WEST AFRICA COLLABORATING DEPARTMENTS ZOOLOGY (FACULTY OF SCIENCE) & CROP SCIENCE (FACULTY OF AGRICULTURE)

NOVEMBER, 2002

ABSTRACT

Studies were carried out on the effects of variety and processed form of cassava chips on the development of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) and *Araecerus fasciculatus* (Degeer) (Coleoptera: Anthribidae). Additionally, changes in the nutrient composition of the chips due to infestation, and the influence of major nutrients on the population parameters of these insects were also studied. Statistical analysis of insect preference to the processed chips in a choice test revealed that adults of *A. fasciculatus* significantly ($P<0.05$) preferred sun-dried and fermented chips to parboiled and plain chips. On the other hand, no significant difference ($P> 0.05$) was observed in the preference of these chips by *P. truncatus* adults, suggesting that *P. truncatus* selection of chips occurred mostly by chance.

A susceptibility test and adult development at 25-34°C and 61-92%r.h were conducted to further understand the factors responsible for the differences in the processed chips. *P. truncatus* density increased on fermented chips but this was not significantly different ($P>0.05$) from the densities recorded on plain and sun-dried chips. However, on parboiled chips low adult densities were recorded and this was significantly different ($P< 0.05$) from other processed forms. Similar studies with *A. fasciculatus* also revealed the same trend. This suggested that in parboiled chips, conditions are less favourable for higher oviposition, larval development and survival of adults and thus constitute a less susceptible form of cassava chips for storage. Percentage weight loss due to the two pests in separate studies suggested that *P. truncatus* caused more damage to the chips compared to *A. fasciculatus*. Weight loss and frass produced by both insects followed almost the same

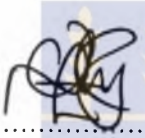
was similar on all the processed form, although *A. fasciculatus* development was slightly prolonged in sun-dried chips.

Insect infestation caused noticeable changes in the nutrient composition of the cassava chips. Starch content decreased in both *P. truncatus* and A. *fasciculatus* infested samples. There was an increase in the sugar content of parboiled chips infested by the two insects whereas sugars in plain, sun-dried and fermented chips were reduced. Correlation analysis revealed relationships between the nutrient composition of the chips and the population parameters of the insects. Significant positive association ($r=0.71$, $P<0.05$) was found between starch content and *P. truncatus* density. Alternatively, *A. fasciculatus* density showed a significantly positive association ($r=0.77$, $P<0.05$) with non-reducing sugar and negative association with reducing sugar ($r= -0.70$, $P<0.05$).

The study has shown the importance of parboiling of cassava as opposed to other processing forms and its effectiveness in conferring protection to chips as a management strategy against losses due to *P truncatus* and *A. fasciculatus*. Changes in the nutrient contents of cassava due to infestation and the relevance of the significant association of the nutrients and population parameters of the insects are also discussed.

DECLARATION

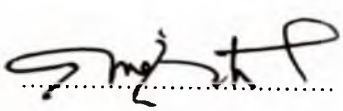
I do hereby declare that this thesis is my original research work conducted at the Plant Protection and Regulatory Services, Pokuase (PPRSD) and Departments of Biochemistry and Nutrition and Food Science, University of Ghana, and that no part of this thesis, either in whole or part has been presented for another degree else where. References to the work of other researchers have been duly cited.



.....

Chijindu, Edith, N.

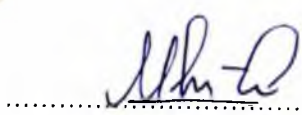
(Student)



.....

Professor J.N. Ayertey

(Principal Supervisor)



.....

Dr. A. R. Cudjoe

(Co- Supervisor)

.....

Dr. W.S.K. Gbewonyo

(Co- Supervisor)

DEDICATION

This work is dedicated to the memory of my father, the late Mr. Marcel O. Chijindu who passed away during the course of this study. May his soul rest in perfect peace! Amen. It is also dedicated to my sweet and caring mother, Mrs. Abigail Chijindu.

ACKNOWLEDGEMENT

See what the Lord has done for me; for this far He has brought me, to him be the glory

With sincere appreciation and heart-felt gratitude, I wish to acknowledge the following personalities: Prof. J.N Ayertey, my Principal supervisor for his patience, the independence he offered me, fatherly advice and constructive criticism. Dr. A. R. Cudjoe and Dr. W.S.K. Gbowonyo, my co-supervisors, for their concern, useful suggestions and encouragement throughout the study. Mr. Bernard Boateng, Lecturer, Department of Crop Science, who, always with a ready smile and patience, assisted me both in the statistical analyses and in providing useful suggestions.

I wish to acknowledge assistance offered by the following departments: Department of Plant Protection and Regulatory Services Pokuase and all the staff particularly Mr Eric Quaye, Mr. Jamina, Mr. Narh, for their untiring help in getting the materials for the experiment, productive comments and assistance. Many thanks to the Department of Crop Science and their staff especially the chief technician, Mr. Tonyigah and other technicians, Mr Vincent Eziah, Mr. Ampah, Mr. Asante, Haruna for the priceless assistance they offered, especially during the processing of the materials. My appreciations also go to the Departments of Biochemistry and Nutrition and Food Science and their technicians, Mr. Bosompim, Aunty Rose, Aunty Doris, Emma, Success, Ben and Flora. Also to Ecological Laboratory, and their technicians, Mr. Sarquah, Mr. Elegba and Prince for their immense help and encouragement during the proximate analysis.

My deepest appreciation is also extended to my fiancé, Engr. James Nwankwo for his continuous moral support, love and encouragement throughout the study. Special thanks to my mum, Mrs. Abigail Chijindu, my brothers, Mr. Emma Chijindu and the family,

Engr. Vin Chijindu and family, sisters Stella, Uju, Ify and Ogo, your love, interest, encouragement, support and never-ending faith and prayers have always been there for me to lean on. I love you all.

- My classmates, Raphael Abanja, Isaiah, Michael, Danjuma, Aboagye, Annobil and Tolu, I say bravo! It has been nice knowing you all. To my roommate, Naiki, room neighbours, Nkem and Helena, my friends, Evelyn, Dr. Gyang, Ibrahim, Duna and Gazama, I appreciate you all for making my stay enjoyable.

I wish to extend my appreciation to Prof. E.I Egwuatu and Dr. N.J. Okonkwo of Nnamdi Azikiwe University Awka for their encouragement. I also express gratitude to the two collaborating departments, Zoology and Crop Science for providing some of the equipment and facilities for the work. Finally, I thank DAAD for sponsoring my study.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

PLATE

CHAPTER ONE

1.0 INTRODUCTION

Cassava, *Manihot esculenta* (Crantz) and other root and tuber crops such as yams and sweet potatoes are important staple food crops in the tropics. Cassava plays a major role in efforts to alleviate the African food crisis because of its efficient production of food energy, its year-round availability, tolerance to extreme stress conditions, and suitability to the peasant farming system in Africa (Hahn and Keyser, 1985). Over half of the world's cassava is produced in the humid and sub-humid tropics of sub-Saharan Africa, where it is the fourth most important source of calories for human consumption (IITA, 1999).

The major limitations of cassava as a food crop include its potentially toxic cyanoglucoside content, its low protein content and its short shelf- life. Traditionally, the challenges posed by most of these constraints have been met through the development of a range of processing techniques (Walston, 1991; UNIDO, 1997)

Cassava processing techniques vary from region to region. The common processing techniques practiced by most people include grating, soaking, boiling and fermentation, stacking, chipping and drying. Fermentation of cassava is by far the most important and widely used means of processing cassava in Nigeria (Oyewole, 1992). In many other African countries including Ghana, cassava is commonly eaten after boiling the peeled, fresh tuberous roots. The boiling and subsequent eating qualities of fresh cassava can vary substantially among different cassava varieties.

In spite of the various processing techniques which fresh cassava roots undergo, its products are still prone to deterioration. Efforts have therefore been intensified in the

processing of cassava products that have long storage life, such as cassava chips Traditionally, cassava is sliced into small pieces and sun-dried over a period of time However, in some countries the chipped cassava is given certain treatments before drying. In Tanzania and Nigeria, for instance, the chips are fermented prior to drying (Hodges *et al.*, 1985; Oyewole, 1992). In Ghana, the chips are usually sun-dried during which some form of fermentation takes place (Nicol, 1991). In India, they are parboiled before drying. Parboiling of chips is thought to improve the shelf–life as compared to plain chips. This is due to the harder texture of the former resulting from partial gelatinisation of starch and subsequent binding of the gelled starch (Balagopalan *et al.*, 1988; Rajamma *et al.*, 1994).

The relatively low standards of traditional processing and poor post-harvest handling prevailing in the cassava-producing countries have exacerbated the problem of storage of this commodity. As a result, a greater proportion of chips are lost mainly to insects, moulds, rodents, etc. Cassava chips tend to be hygroscopic in nature. According to Halliday *et al.* (1967) the form and texture of the chips facilitate moisture uptake and also increase the surface area exposed to attack by insects and moulds. The growth of mould due to moisture uptake may also lead to infestation of mould-feeding insects, ultimately resulting in increased total infestation. Therefore, the shapes of plain dried chips are mostly lost quickly due to insect infestation and are reduced to powdery mass. On the other hand, the parboiled chips are riddled by adults and larvae and lose their shape and rigidity only after prolonged infestation (Prem kumar *et al.*, 1996).

Over two-dozen insect species are reported to infest dry cassava (McFarlane, 1982) The two most important storage pests, according to Nyakunga (1982) are the Bostrichids,

Dinoderus spp. and *Prostephanus truncatus* (Horn). Parker *et al.* (1981) noted the importance of *Araecerus fasciculatus* (Degeer) as a pest of dried cassava.

The wide range of insects that feed directly on dried cassava is the major cause of weight loss in this produce. In Ghana, various weight loss estimates have been attributed to storage insects. Killick (1966) estimated losses of up to 19% after 3 months and 63% after four to five months due to insect pests. Stumpf (1998) recorded weight loss of 39-50% in chips stored for 8 weeks by *P. truncatus*. In a recent survey carried in the northern Ghana, Entsie and Ofosu (2001) reported loss of about 20% of stored maize and about 25% of stored "Kokonte" due to *P. truncatus* during the storage period in the year 2000. On the other hand, little information is available on the extent of weight loss caused by *A. fasciculatus* in stored cassava in Ghana. In India, however, Rajamma *et al.* (1994) reported 7-17.8% loss in plain chips and 1.1 to 2.5% in parboiled chips due to attack by *A. fasciculatus*. The importance of this loss potential is due to the extent of production and storage of dried cassava roots. In Togo, 120,000 to 150,000t of cassava chips are produced annually (Adam, 1988) and a large part of the production is stored.

The activities of insects during storage have also been reported to cause quality loss in chips. In India, Kumar *et al.* (1996) studied biochemical changes in dried chips due to *A. fasciculatus*, *Rhyzopertha dominica* and *Sitophilus oryzae* and found reductions in the starch content of fully infested plain chips. McFarlane (1982) also suggested that mould and insect development might cause some quality changes during prolonged storage under conditions likely to favour rehydration of chips.

Hodges *et al.* (1985) assessed the damage of *P. truncatus* on fermented and plain cassava chip in Tanzania. Rajamma *et al.* (1994) also evaluated the effect of *A. fasciculatus*

damage on plain and parboiled chips in India. Therefore, it was imperative to investigate how *P. truncatus* and *A. fasciculatus* would perform on chips of similarly treated Ghanaian cassava varieties and to evaluate these, since this would help provide information for better long-term storage.

1.1 OBJECTIVES

The main objective of this work was to investigate the influence of differently processed chips of two varieties of cassava on the development of *P. truncatus* (Horn) and *A. fasciculatus* (Degeer) at three storage periods.

Specific Objectives were:

(i) To evaluate the effect of differently treated cassava chips on the population density of *P. truncatus* and *A. fasciculatus* at three storage periods.

(ii) To assess the extent of deterioration of the processed cassava chips of two cultivars by *P. truncatus* and *A. fasciculatus* at three storage periods.

(iii) To evaluate the effect of infestation by the two insects on the nutrient composition of the differently processed cassava chips.

(iv) To determine the developmental period of *P. truncatus* and *A. fasciculatus* on the different treatments of cassava chips.

(v) To establish the interaction between the nutrient composition of the cassava treatments, the population density and weight of the adult insects.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 ORIGIN, DESCRIPTION AND PRODUCTION OF CASSAVA *MANIHOT ESCULENTA* (CRANTZ)

Cassava is a perennial woody shrub with an edible root, which grows in tropical and subtropical areas of the world. It is a plant of the New World, which originated from northeast Brazil. Central America is assumed to be another source (Onwueme, 1978). Having begun with these two regions, cassava is now cultivated in all the tropical regions of the world. It was introduced to Africa in the 16th century and became established at various locations on the continent (Lynam, 1991). It has the ability to grow on marginal lands where cereal and other crops do not grow well. Cassava root has high resistance to plant disease and high tolerance to extreme stress conditions, such as periods of drought and poor soils (Lorraine, 2000). It has a potential tuber yield of 70 tonns per hectare and has the highest output per unit area among all staple foods providing starch (Cock, 1985).

Individual cassava varieties are recognized by the leaf and root form, the duration of vegetation, the yield and the content of hydrogen cyanide (Onwueme, 1978). The latter constitutes the difference between the sweet and the bitter cassava. Diop (1998) reported that linamarin is present in much larger quantities usually up to 90% of the total content The normal range of cyanogenic glycosides content calculated as HCN content of cassava falls between 15mg to 400 mg HCN per 1kg fresh weight.

The overall production of cassava root in Africa was estimated at 85 2million tonnes in 1997 and 93 million in 2000. Out of this Ghana produced about 8 2% in 1997 and 8 6% in

2000 (FAO, 1998; MOFA, unpublished). In 1999, Nigeria produced 33million tonnes making it the world's largest producer (IITA, 2000). In terms of area harvested, a total of 16.8 million hectares was planted with cassava throughout the world in 2000, about 64% of which was in Sub-Saharan Africa (IITA, 2000).

2.1.1 IMPORTANCE OF CASSAVA

Cassava constitutes the major source of dietary energy for over 500 million people in the world (Cock, 1985). It is the basis of many products, including food. In Africa, it is mostly used for human consumption and commercially for the production of animal feed and starch-based products (IITA, 2000). It is estimated to provide approximately 37% of the food calories consumed in Africa (Lancaster *et al.*, 1982). Cassava roots are processed into a wide variety of granules, pastes, flour etc., or consumed freshly boiled or raw. In most of the cassava growing countries in Africa, the leaves are consumed as a green vegetable, which provides protein and vitamin A and B. Cassava starch is used as a binding agent in the production of paper and textiles. It is also used as a monosodium glutamate, an important flavouring agent in Asian cooking. Although grains are the primary source of flour in food application such as bread making, pastas, and breakfast foods, there is evidence that cassava flour has been used for bread making in the Caribbean for several generations (Sokolov, 1992). In Africa, cassava is beginning to be used as a partial substitute for wheat flour. In the Northern Region of Ghana, dried cassava chips are normally pounded or milled by commercial plate mills to prepare "kokonte" (a product prepared from low cyanide cassava varieties) (FAO, 1998). Other popular cassava products in Ghana are "gari", "fufu", "agbelima", "agbelikaklo", and "yakeyake".

In recognition of the potential of cassava, the International Fund for Agricultural Development and the Office of Foreign Disaster Assistance of the US Agency for International Development, are supporting collaborative efforts to promote cassava production and use to avert famine and provide a source of cash income for farmers (IITA, 1999).

2.1.2 NUTRITIONAL COMPOSITION OF CASSAVA

Like most root crops such as sweet potatoes, yams and Irish potatoes, cassava is primarily a source of carbohydrates, and contains very little fat or protein. In fact, its protein content is said to be the lowest among the root crops. On the other hand, it is relatively rich in calcium and ascorbic acid (vitamin C) and contains significant amounts of thiamine (Vitamin B), riboflavin (vitamin B_2) and Niacin (Doku, 1969). In Ghana, fresh cassava roots contain 62% water, 149kcal energy, 1.2% protein, 0.2% fats, 35.7% carbohydrate and 1.1% fibre (Tayie and Lartey, 2000). It is also reported that cassava root contains about 60-70.2% moisture, 0.7-1.2% protein, 51.3% starch (32-35% total carbohydrate), 0.8% fibre, 0.3 –0.5% ash and trace amounts of fat (Grace, 1977; Lancaster *et al.*, 1982; Diop, 1998). Similarly, Onwueme (1977) recorded 62% water, 35% carbohydrate, 1-2% proteins, 0.3% fats, 1-2% fibres and 1-% minerals. FAO (1953) cited in Doku (1969) reported 1.2% protein, 0.3 fat, 33% calcium, 0.7% iron and other minerals. Mealy and waxy cassava tuberous roots have amylose contents of about 17% (IITA, 1977). Cassava also contains some soluble carbohydrate that is sugars, which convey a pleasant sweet taste to the tubers of the non–poisonous strains. The amount in peeled root is only 1–3% of the total dry matter, but it rises notably at the age of 16–18 months when the starch content is beginning to decline.

However, it is usual to give the nutritional values of foodstuffs on the raw product rather than on the foods prepared from them. For a crop like cassava whose roots are subjected to such handling and processing forms as soaking in water, grating, grinding, fermenting, roasting, boiling, pounding, etc during processing, it would be misleading since varying amounts of the elements and vitamins in the raw tubers are lost under these various forms. One thing that appears certain is that the various methods of processing the roots free the products from HCN and thereby render the food innocuous and reduces the level of deterioration of the food.

Knowledge of the actual nutrient composition of foods prepared from cassava at present is lacking not only in Ghana but also in most parts of the tropics. However, Oyenuga (1955) reported that bitter dried cassava contain 28% dry matter, 2.58% crude protein, 0.43% crude fibre and 2.4% total ash while the sweet dried cassava contains 28.5% dry matter, 1.66% crude protein, 1.6% crude fibre and 5.22 % total ash. The nutrient composition of "Gaplek", a dried cassava product from Indonesia contains 1.5% protein, 1.0% fat, 85% carbohydrate, 0.3% ash and 0.5% fibre (Grace, 1977). Padmaja *et al.* (1994) reported that glutamic acid and aspartic acid dominated the amino acid profile of parboiled chips while glutamic acid and arginine dominated in the plain dried chips in India. In Nigeria, the proximate composition of "gari" and "fufu" include 81.8–87% and 73% carbohydrate, 0.1 and 0.4% oil, 0.9–1.5% and 1.26% protein, 1.4–2.3% crude fibre, 0.9–1.4% and 0.15% ash respectively (FAO, 1984 cited in Walston, 1991). In Ghana, boiled, roasted and cassava "fufu" contain 36%, 56% and 33.5% carbohydrate, 0.6%, 0.95% and 0.6% protein respectively (Tayie and Lartey, 2000).

2.1.3 PROCESSING OF CASSAVA

Traditionally, cassava roots are processed by various methods into numerous products and utilized in various ways according to local customs and preferences. Processing methods include peeling, soaking, chipping, grating, pressing, milling, drying, stacking and fermentation, most of these being adaptations of yam- processing techniques (Hahn, 1989). These methods are generally geared towards products that have the preferred taste, flavour and texture and are safe for consumption. Cassava processing procedures vary, depending on products, from simple processing to complicated procedures for processing into gari, flour etc. The most important traditional culinary preparations of cassava in Africa are "boiled or roasted roots", "fufu"(pounded boiled cassava or cassava flour stirred with boiled water over a low – heat fire to give a stiff dough), "eba"(gari soaked in hot water to produce a thick paste) and "Chickwangue"(steamed fermented pulp wrapped in leaves). Processing technologies for cassava in Ghana have been classified into three broad categories namely; (1) dry cassava products, which can be fermented or unfermented, (2) fermented-grated cassava, (3) starch and tapioca (FAO, 1998).

2.1.4 PROCESSING OF CASSAVA CHIPS

The extreme perishability of cassava roots stimulated the development of a range of processing techniques, even by the earliest Amerindian cultivators of the crop more than 4,000 years ago (Mcfarlane, 1982). Processing is therefore indispensable to facilitate preservation, improve palatability and product quality as well as reduce cyanogenic glycoside toxicity. The production of cassava chips therefore, is the simplest way of obtaining a product which will keep and which can be stored. FAO (1998) reported that the purpose of processing cassava roots into a wide range of products is to control the deterioration of the products and losses. Equally, the processing or cooking which the

cassava roots undergo prior to being consumed reduces these substances to a point that poisoning is prevented (Lancaster *et al.*, 1982; MOFA- GTZ, 1994). The production process of cassava chips always follows the same pattern and more or less shows a high degree of mechanization, slight deviation from this leads to chips with varying quality, textures, reflecting the regional demand and flavour preferences.

In the processing of chips, the cassava roots are peeled immediately after harvesting with the traditional cutting tools. The peeled roots are usually washed and cut into chips of various sizes and the optimal chip geometry for natural drying is a bar of 5x1x1 centimeters (Cock, 1985; Hodges *et al.* 1985).

The purpose of chipping is to expose the maximum surface of starchy flesh and to encourage rapid drying (Diop, 1998). The size of chips, however, varies from region to region and is influenced by climatic conditions of the area. Thus, the pieces are mostly larger in the dry northern parts of Ghana than those in the South of the Country (GTZ, 1993). Furthermore, processing of chips depend on the cassava type used. Chips obtained from bitter cassava varieties are soaked in water after peeling and this is often done for one to three days, either before or after the chipping operation during which some fermentation takes place that gives the chips the sour flavour favoured by some consumers (Hodges *et al.*, 1985; Diop, 1998). The submerged fermentation was found to have effect on the carbohydrate, protein and mineral content of cassava root (Oyewole and Odunfa, 1989). According to them, fermentation causes a reduction in the starch content. The total soluble and reducing sugar levels increased during the first 3 and 24 hours respectively but decreased afterwards for the remainder of fermentation period. Similarly, Onwueme (1978) reported soaking of freshly peeled root for 1-2 days and brief boiling. The

National Root Crop Research Institute in Nigeria suggested 15 minutes blanching of the cassava chips (Jakubczyk, 1982). In addition, chips are often boiled in water for 10 minutes to improve their storage ability and thus reduce their susceptibility to infestation. This procedure is mostly practiced in India where edible chips are processed into sun-dried white chips and parboiled chips (Balagopalan *et al.*, 1988). In addition, parboiling of cassava chips prior to milling into flour has been suggested to improve the pasting properties of cassava flour (Raja and Ramakrishina, 1990). In Ghana, the chips are usually sun-dried during which period slight fermentation takes place (Nicol, 1991). In spite of these processing technologies practiced in the tropics, the preferred processing method has not yet been sufficiently investigated.

2.2. INSECT INFESTATION OF CASSAVA CHIPS

Processed products are essentially inert, and storage losses result from the activities of external factors, rather than endogenous process, in contrast to the situation with fresh cassava. The principal cause of post harvest losses during chip storage is infestation by insect pests. Different types of cassava products to some extent attract different insect pests. Even whole, peeled cassava roots, especially if they have been soaked to remove free cyanide before drying, can suffer damage by one or more of the various beetles that ubiquitously attack a wide range of dried starchy foodstuffs (Mcfarlane, 1982). When roots have been chipped to facilitate drying, the increased surface area and the incidental fragmentation into smaller particles can be expected to encourage infestation by a wide range of stored product insects. Where drying is only marginally adequate or where the cassava pieces are stored in a humid atmosphere, fungal growth occurs and the infestation is likely to include a variety of mould-feeding insects

Cassava chips are conducive for development of numerous stored product insects and as many as 21 insect species have been reported to be associated with stored cassava chips, mainly Coleopterans (Ingram and Humphries, 1972; Balagopalan *et al.*, 1988, Anon 1991). The important species recorded are *Rhyzopertha dominica* (Fabricius), *Prostephanus truncatus* (Horn), *Araecerus fasciculatus* (Degeer), *Ahasverus advena* (Walt), *Stegobium paniceum* (Linnaeus), *Tribolium castaneum* (Herbst) and *Dinoderus minutus* (Fabricius). In India, the species reported to infest stored cassava chips are *A. fasciculatus, D.* bifoveolatus (Wollaston), *Lasioderma serricorne* (Fabricius) and *Tribolium* spp. (Pillai and Rajamma, 1986). In Indonesia, Mangoendihardjo (1981) found that *A. fasciculatus*, *R. dominica*, *S. oryzae* and *T. castaneum* were the most important pests of dried cassava.

It is common knowledge that tropical conditions generally favour the rapid development of insects that attack stored produce. In Tanzania, Nyakunga (1982) and Hodges *et al.* (1985) reported *Dinoderus* sp. and *P. truncatus* as two most important storage pests of cassava According to Lamboni (undated) cited in Jochenkuoth (1993), *P. truncatus* (Horn), *D. minutus* and *Tribolium* sp. are among the most significant insect pests in the storage of cassava chips among small farm-holders in Togo. Insect pests are also the most severe constraint to cassava chip storage in Ghana. Stumpf (1998) reported a number of different species as pests of cassava chips in the Northern Region of Ghana These insects mostly belong to the families Anthribidae (*A. fasciculatus*), Bostrichidae (*D. minutus* and *P. truncatus)*, Cleridae (*Thaneroclerus buqueti*), Curculionidae (*S. zeamais*), Ostomidae, (*Tenebroides mauritanicus*), Silvanidae, (*Oryzaephilus surinamensis*) among several others. The species in the family Bostrichidae were reported as the main cause of post - harvest losses of chips in Northern Ghana.

2.3 PESTS OF STORED CASSAVA CHIPS

2.3.1 *P. TRUNCATUS* (Larger Grain Borer)

2.3.1.1 DESCRIPTION

P. truncatus (Horn) is a species that belongs to the family Bostrichidae. The adult beetle is black and 3 - 4.5 mm long. The body is typically cylindrical and head ventral to the prothorax (Haines, 1991). The larva is white and has parallel sides that are not tapering like many other larvae.

2.3.1.2 IDENTIFICATION, ORIGIN AND SPREAD OF *P. TRUNCATUS*

Horn (1878) and Kingslover (1971) provided the identification of the adult *P.truncatus* and other Bostrichids. The larval and pupal stages were described by (Spilman, 1984). Adults may be sexed using clypeal tubercles (Shires and Macarthy, 1976) and pupae according to the size and shape of the genital papillae (Bell and Watters, 1984). A new character for identifying larval instars was reported by Helbig and Schulz (1994). Three larval instars of *P.truncatus* were observed at 25°C and 75% RH based on the greatest distance between the ventrally sclerotized lateral structures of the fronto-clypeus.

Its origin and accidental introduction into Africa are available in a review by Markham *et al.*, (1991). The presence of the beetle has been confirmed to date in a total of 13 African countries (Sumani and Ngolwe, 1996). At present, it seems likely to invade all maize and cassava growing areas of tropical Africa, and it is the only recent example of invasion by a serious storage pest on a regional and continental scale. Transport of foodstuff from surplus regions into deficit regions across the continent and the exchange of goods in traditional market places promote the rapid propagation of this pest (Richter and Biliwa, 1991).

2 3 1 3 INCIDENCE OF *P. TRUNCATUS* IN GHANA

As a consequence of an earlier introduction of the Larger Grain Borer into Togo in 1984, a survey was carried out in 1986 in Ghana-Togo border to determine the presence of the beetle in the country (Ofosu, pers. Com. Cited in Boateng, 1996), but the result proved negative. It was until 1989 when a second survey revealed that LGB was present in villages in the Volta Region over a 150km stretch of the border with Togo; from Kpetoe in the south to Ameyoe in the north (Dick et al 1989). In April 1991, another survey revealed considerably higher population build-up at places where the insect had been found in the earlier survey (Ayertey and Brempong-Yeboah, 1991). Two years later, a Ghana LGB project showed that LGB was present in all districts of the Volta region (GLGBP, 1993). A national monitoring programme, with 101 permanent trapping sites, has revealed the incidence of the insect in every region of the country (Robin Boxall pers. Com. Cited in Boateng, 1996). The most serious affected parts of the country, apart from the Volta Region, are Saboba district of the Northern Region, the Dangbe West district of Greater Accra and the areas of Eastern Region bordering the volta Region (Addo, 1994). Recently, a rapid survey was carried out in the northern region of Ghana, which revealed that LGB occurs in almost all the 13 district of the region (Entsie and Ofosu, 2001). High LGB populations were found in the Saboba/Chereponi, Zabzugu/Tatale, Gushiegu/ Karaga, Nanumba, Bole, Salaga and Tamale districts. Previous survey in this region indicated high LGB population levels in only three Districts (Saboba/Chereponi, Zabzugu/ Tatale and Gushiegu/ Karaga).

2 3 1 4 LIFE HISTORY AND BEHAVIOUR

The life cycle and behaviour of *P. truncatus* (Horn) has been investigated by a number of authors under different conditions (Subramanyam *et al.*, 1985) Bell and Watters (1982)

observed that the life cycle of this species was completed in 24 - 25 days under optimum conditions on a whole grain or on flour packed firmly into glass tubes. On the contrary, Shires (1979) reported 35.4 days on rearing the pest on loosely packed maize flour. Hence it is assumed that these wide discrepancies in the development of *P truncatus* are related to the nature of the substrate and the climatic conditions.

2.3.1.5 OVIPOSITION

After mating, the adult females lay most of their eggs within the grain in blind-ending chambers bored at right angles to the main tunnels (Howard, 1983). On maize grain at 27°C and 70% RH over a 10-day period, females laid on average 1.4 eggs per day on 1 g lot of maize while 6g lots gave an average of 3.9 eggs per day. On cassava, oviposition rate was somewhat lower on 1 g or 6g lots of the dry roots. Fecundity was 1.1 and 2.3 eggs respectively (Nyakunga, 1982).

Shires (1980) reported that female adults laid most eggs on or in maize grains at 15-20 days old and some continued to lay eggs for a further 70- 80 days. Mean total egg production was 156 eggs per female on *M. esculenta* and 52 eggs per female on *Poincinia regia* Bojer (Helbig and Schulz, 1994).

2.3.1.6 EGG HATCHING, LARVAL LIFE AND ADULT EMERGENCE

Egg hatchability of *P. truncatus* maintained at 32°C and 70% RH occurred after an average of 4.1 days (Bell and Watters, 1982) and 5.5 days (Hashem, 1989). The larval period lasted 17 days (Hashem, 1989) and 25.4 days on maize grain (Shires, 1980). Pre-pupal and pupal stages of 1 day and 6.5 days respectively were observed (Hashem, 1989). On the contrary, Haines (1991) reported that the mean pupal period of *P. truncatus* was

4.7 days such that an average development from egg to adult at 32°C and 70% RH took 25.4 days. At 30°C and 70% RH, Hashem (1989) reported 30.4 days. The development period was found to be more rapid on maize than on cassava (Haines, 1991). Hence the mean developmental period on maize and blocks of dried cassava at 27°C and 70% RH were 32.5 days and 40 days respectively.

2.3.1.7 PEST STATUS AND LOSSES DUE TO *P. TRUNCATUS*

Insect pests are the major cause of damage and losses in storage with the beetles of the Bostrichid family being the most destructive. *P. truncatus* is a pest with a high damage potential and losses caused can be very high. Consequently, the pest status of this very important pest in the Neotropics has been a subject of considerable debate because of serious discrepancies in loss report (Boeye, 1988). Naturally, the magnitude of loss caused by *P. truncatus* varies greatly within very wide limits according to the various factors affecting the preparation of the product. These factors include correct and adequate drying and protection from re-absorption of water. They are found to influence oviposition, development and rate of increase in this insect. Therefore, the amount of damage likely to be caused in future will depend on how rapidly the population increases. This in turn depends mainly on the temperature and relative humidity of the environment, moisture content of the food and the nutritional value of the product (Howe, 1965).

Hodges *et al.* (1985) reported weight losses of 52.3 % for unfermented and 73.67% for fermented cassava chips after a storage period of four months in Tanzania. In a similar study conducted in Tanzania, weight losses of maize after 3-6.5 months of storage averaged 8.7% (Hodges *et al.*, 1983) and in some samples reached 30-35%. This agrees with the report of Golob and Hodges (1982) that *P. truncatus* caused 34% weight loss

after storage period of 4 - 6 months. In a separate study in Tanzania, Golob (1988) reported 9% loss after 5 months storage. Investigation in Tanzania showed that 20% of stored produce was infested after harvesting. At the end of harvesting period (after 5- 6 months) 80% of the granaries were infested by *P. truncatus* (Hodges, 1984).

Extensive damage in cassava was also recorded in Togo. In glass jar trials, Helbig (1993) found a higher loss potential with *P. truncatus* on cassava than with *D. bifoveolatus*. In Togo, Helbig and Schulz (1996) recorded 75% loss of chips after 8 and 12-week periods. In comparison, only 30-33% of maize grains were transformed to dust (Helbig, 1993). However, the smooth structure of cassava chips and the lack of a protective covering both favour the boring activity of *P. truncatus*.

In Ghana, Stumpf (1998) recorded weight losses between 39% and 57% due to *P. truncatus* attack on cassava chips. Comparing this to damage caused by other pests of cassava chips such as *D. bifoveolatus, R. dominica* and *S. zeamais*. Under similar conditions, *P. truncatus* was found to be the most serious pest.

2 3 1 8 CONTROL OF *P. TRUNCATUS*

In the West African Region, IITA, GTZ, and the Overseas Development Administration (ODA) now Department for International Development (DFID) of the United Kingdom (UK), in Collaboration with various national organizations, have been conducting field research to identify and introduce technically and socio-economically acceptable strategy for the control of *P. truncatus*. However, the effective strategy for the control of *P. truncatus* varies according to locations, and has not yet been fully established (Kossou *et al.*, 1995). Control methods against *P. truncatus* include chemical control, physical

control, resistant varieties, biological control and integrated control methods (Markham, 1992).

There have been few chemicals that are both effective as insecticide and safe to apply directly to stored foods. Two methods for the insecticide protection of harvested cassava against *P. truncatus* were tested in Togo. Firstly, soaking the tubers in insecticide solution, then drying them and cleaning up the residues. The second method consisted of an organophosphate and pyrethroid mixture (Markham, 1992). Other control measures include biological control using predator, *Teretriosoma nigrescens* Lewis (Coleoptera: Histeridae) and a parasitic wasps *Anisopteromalus calandrae* (Howard) (Helbig, 1995; Bonuire, 2002). Application of integrated control strategy involving combination of chemical and biological control with other methods such as storage hygiene, resistant varieties, and appropriate storage structures, has been used in the control of *P. truncatus* (Affognon *et al.*, 1995).

2.3.2 *ARAECERUS FASCICULATUS* (DEGEER) (COLEOPTERA: ANTHRIBIDAE):

The adult of *A. fasciculatus* is moderately large (3.5 mm) and dull brown to grey brown in colour (Wrigley, 1988; Haines, 1991). The larva is about 4.5–6 mm long, whitish in colour with an ochre head, narrow, apodal and hairy (Wrigley, 1988). The prothorax and the elytra of the adult bear many small dark patches, which gives the insect a mottled appearance.

2.3.2.1 LIFE HISTORY AND BEHAVIOUR OF *A. FASCICULATUS*

The adults of *A. fasciculatus* lay eggs in the field and in the warehouse when the produce is in storage (Appert, 1992). The females become sexually matured 6 days after adult

emergence (Conclaves *et al.*, 1976). Before egg deposition, mating takes place in females 4-7 days and in males 3 days after emergence (Kumar and Karnavar, 1986). Egg laying starts immediately after copulation and are laid singly on each seed of cocoa (Appert, 1992). Each female may lay 5-6 eggs on cocoa beans (Cotterell, 1934).

2.3.2.2 EGG HATCHING, LARVAL AND ADULT EMERGENCE

The eggs take about a week to hatch. The larvae live within the seeds and feed on the cotyledon. The larva within the seed digs tunnels and fills the seed with its dejecta and thus causing hidden infestation. The larval period is about one and half months (Wrigley, 1988). The larvae pupate within the bean (Vitelli, 1976) and pupation lasts 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% RH (Cabal Concha, 1956). On coffee beans, Vitelli *et al.* (1976) reported 56 days at 72°F and 26 days at 80°F on artificial diet. Rajamma *et al.* (1994) reported 38 days and 59 days on two different cassava varieties. Adults live for more than 17 weeks but longevity is severely reduced at low humidities (Haines, 1991).

2.3.2.3 CONTROL OF *A. FASCICULATUS*

A. fasciculatus causes serious damage to coffee, cocoa and dried cassava chips especially when the moisture content is very high. The control of this insect has been achieved mostly through chemical means. In Indonesia, the traditional method employed by farmers by spraying cassava chips with chilli juice did not affect pest infestation (Mangoedihardjo, 1981). Although control of *A. fasciculatus* has mostly been achieved through chemical control, biological control of this pest has been tried on a few occasions. The larvae are parasitized by the Pteromalid, *Anisopteromalus calandrae* (Howard) and the Bethylids,

Cephalonomia gallicola (Ashmed) and *Plastanoxus* sp. (Goncalves *et al.*, 1976). Haines (1991) reported that mites, *Cheyletus* sp. and *Monieziella* sp. are predators of the eggs.

2.4 NUTRITIONAL CHANGES IN CASSAVA CHIPS INFESTED BY INSECTS

Quality factors such as dry matter, cyanogenic content of cassava are important in determining the acceptability and end use of different varieties (Wheatley and Gomez, 1985). Nutritional loss represents reduction in food value, as a result of reduction of protein, carbohydrate and vitamin contents in the produce. The effect of insect-infestation on the nutritional value of produce varies with the composition of product affected and the species of insect (Hall, 1970). This is because different insects prefer different parts of products with various compositions. For instance, weevils that feed mainly on the carbohydrate portion of produce remove considerable amounts of the caloric potential with a little portion of vitamins and proteins removed. In India, insect infestation drastically reduced all the amino acid fractions in both parboiled and plain chips studied (Padmaja *et al.*, 1994). The essential amino acid concentration and their chemical components also indicated that there was a substantial decrease in the protein nutritional quality with insect infestation. Similarly, Pingale *et al.* (1954) reported that loss of thiamine in rice stored for eight months were 10-15% greater in infested than the uninfested portion.

Insect infestation not only decreases the protein content of food produce but also starch contents. In India, PremKumar *et al.* (1996) reported a decrease in the starch content from 83.5 % to 77. 9 % in fully infested plain cassava chips but minimal decrease in partially infested chips. In parboiled chips, there was substantial reduction in starch content (78% to 57%) and increase in sugar content in fully infested chips. This increase

was observed to be due to increased hydrolysis of the gelatinized starch present in parboiled chips by the salivary enzymes of the three insects, *Sitophilus oryzae* and *R. dominica* and *A. fasciculatus*. It is also known that gelatinized starch is more readily digested (both in vitro" and " in vivo") than native raw starch (Moorthy and Padmajo, 1991). In a similar study Padmaja *et al.* (1994) observed that there was a predominance of sugars such as sucrose, maltose and glucose in infested parboiled cassava chips compared with the quantity present in uninfested chips.

In Ghana, during trials under controlled conditions, Stumpf (1998) observed that the starch level of the cassava variety "SORAD" was reduced by about 7.0% after 12 weeks of storage. This result confirms the findings of Wright *et al.* (1993) that *P. truncatus* infestation reduced starch levels by about 4% in the station trial in Togo. However, there were reports of reduction in other nutrient components of cassava due to insect infestation. PremKumar *et al.* (1996) reported a reduction in crude fiber content in plain dried and parboil cassava chips. There was also slight reduction in bulk density and loss of viscosity. Similarly, in maize, Torrenblanca *et al.* (1983) reported reduction in the ether extract and ash component by 20.68 and 28.38%, respectively due to *P. truncatus* attack. There is also significant difference in seed moisture content and fat acidity values of maize seed infested by *P. truncatus* and *R. dominica* compared to control samples (Demianyk and Sinha, 1987).

Biochemical changes in stored produce have also been attributed to duration of storage. 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). However, Allotey

(1988) was of the opinion that the length of storage is important in determining the effect of any factor on a produce. Kumar *et al.* (1991) found that about 7% reduction of the starch level was measured on plain dried cassava chips during storage. In contrast are losses measured during field studies in Ghana with only a slight decrease of 0.3% of the starch level of local varieties (Stumpf, 1998). Glass *et al.* (1959) reported changes in both reducing and non-reducing sugars in wheat. The decrease in non-reducing sugars was almost exactly compensated for by the increase in reducing sugars. However, Pixton and Hill (1967) were of the opinion that storage of sound wheat for six years reduced the total sugar content, especially the non-reducing sugars. It has also been established that the longer the storage of a produce, the greater the decrease in the hydrophilic characteristics and aggregation of the protein molecules (Kozlova and Nekrasov 1957). The protein content in wheat was also found to be slightly but consistently higher in mould-damaged samples than in corresponding sound samples (Daftary *et al.*, 1970). In contrast, there was no change in the crude protein of wheat stored for eight years (Pixton and Hill, 1967).

2.5 INFLUENCE OF VARIETIES AND METHOD OF PROCESSING ON INSECT INFESTATION IN DRY CASSAVA CHIPS

Susceptibility and resistance to attack vary with the varietal characters of produce and with the post-harvest processing, which modifies the hardness, gelatinisation and rheological characteristics (Majumder, 1975). The hydroscopic nature of most cassava products (which permits moisture uptake) increases their susceptibility to damage by insects (Halliday *et al.*, 1967). It was also found that the method of processing influenced the amount of weight loss and the index of susceptibility in most produce For instance,

blanching or cooking of yam before drying reduces the intensity of damage by insect (Nwana and Azodeh, 1984).

In a related manner, it was found that the harder texture of parboiled cassava chips resulting in partially gelatinised starch make them less susceptible to insect damage during storage (Pillai and Rajamma, 1986; Rajamma and Premkumar, 1993). Correspondingly (Beevi *et al.*, 1991) reported that *A. fasciculatus*, *S. oryzae* and *T. castaneum* caused less damage in parboiled chips than in raw chips. In addition, Rajamma *et al.* (1996) found that parboiled cassava chips of all the varieties studied were resistant to both *A. fasciculatus* and *S. oryzae* while an improved cassava variety (76-9) was moderately resistant. In a similar study, susceptibility to damage of Yam varieties by *A. fasciculatus* was assessed by weight loss in the chips and by an index of susceptibility (Nwana and Azodeh, 1984). These parameters however, were significantly influenced by variety, but the least susceptible variety did not suffer the least weight loss. According to Dobie (1974), a susceptible variety has a higher calculated population than a resistant variety therefore; the growth rate provides the selection index.

A comparative study on insect infestation of fermented and non-fermented cassava chips showed that non-fermented cassava reduced infestation by *A. fasciculatus* while *S. oryzae*, *D. minutus* and *L. serricorne* caused equal or more damage to fermented cassava (Rajamma *et al.*, 1986). In a similar study conducted in Tanzania, Hodges *et al.* (1985) reported that adult *P. truncatus* preferred fermented to unfermented cassava, thus fermented cassava roots suffered greater weight losses in store than the unfermented roots.

The varietal characteristics of cassava have also been established to have influence on the development of insects. Pillai (1977) reported that two cassava varieties studied were found to be less susceptible to *A. fasciculatus*. There are also indications that insect pests attack bitter (high cyanide) cassava varieties less than the non-cyanide ones (Rajamma and Premkumar, 1993; Rajamma *et al.*, 1994). Studies on the effects of cyanogens in cassava chips and flour on *R. dominica* and *T. castaneum* show that large concentrations of cyanogens (900 ppm) caused mortalities of 99 and 88% respectively in these insects after 6 weeks (Rajamma *et al.*, 1994).

CHAPTER THREE

3 0 GENERAL METHODOLOGY

3.1 STUDY AREA

The experiments were conducted under room temperature and humidity at the Plant Protection and Regulatory Services Directorate (PPRSD), Pokuase and at the Departments of Biochemistry, and Nutrition and Food Science, University of Ghana, Legon from August 2001 to July 2002.

3.2 REARING OF INSECTS

Two species of insects, *P. truncatus* and *A. fasciculatus* were reared. *P. truncatus* adults were collected from the Kpeve Agricultural Station in the Volta region while adults of *A. fasciculatus* were sieved from infested cassava chips from a market in Mardina respectively.

3.2.1 REARING OF *P. TRUNCATUS* AND *A.FASCICULATUS*

P. truncatus was cultured on maize, which is the preferred substrate, and cassava as a substitute (Haines, 1991). The maize and cassava substrates were cold sterilized in a freezer for two weeks to kill any insect or organism that might be in them. After two weeks, the substrates were transferred into an oven set at 70°C for heat sterilization for three hours When cooled, 500g of each substrate were measured into one-litre Kilner jars sterilized at 60°C for three hours. Fifty to hundred adult insects were introduced into each jar. The whole set up was placed in trays containing machine oil to prevent the crawling of other insects into the culture. The culture was allowed to stand under ambient conditions for 6 months. On the other hand, *A. fasciculatus* was reared on cassava chips (Haines, 1991) The chips and culture jars were sterilized at 70°C for three hours Fifty adults of *A.*

fasciculatus were introduced into each culture jar (Plates 1a and 1b). The culture was left to stand for 6 months under ambient conditions. One week to four week old adults of these two insects were used for the experiment. (See Plates 2a and 2b)

Plate 1a

Culture of *Prostephanus truncatus*

Plate 1b

Culture of *Araecerus fasciculatus*

Plate 2a

Adult and larva of P. truncatus

Plate 2b

Adult and larva of A. fasciculatus

3.3 PROCESSING OF CASSAVA CHIPS

Two cassava cultivars Afisiafi (an improved variety) and Yebesi (a local variety) were collected from cassava farms at Nsawam and Amasaman near Accra. Light green petiole and pale reddish brown tubers identify Afisiafi morphologically while Yebesi has scarlet red petioles and brown tubers. The tubers were peeled and cut into chips and were subjected to four types of treatments namely, sun drying, fermentation by soaking in water, parboiling and plain oven drying.

3.3.1 FERMENTATION (SOAKING IN WATER)

Fresh cassava tubers of each cultivar were peeled immediately after harvest. They were chopped up manually into round chips of approximately 3x3x1cm. Four-kilogram weight of the chips was weighed into a plastic chamber and four litres of water added. The set up was allowed to stand for 24 hours under ambient conditions. After 24 hours, water was drained off from the chips. The chips were then put in a tray for oven drying at 60°C (Rajamma *et al.*, 1994) and a loading rate of 3-5 kg per tray (Onwueme, 1978 modified).

3.3 2 SUN DRYING

The cut chips as in the above description were spread on wire gauze of 3 mm width at a loading rate of 5 kgm^{-2}. The chips were allowed to stand for 24 hours after which slight fermentation had taken place. The chips were then pre-heated in an oven at 60°C for 24 hours to kill any insect that might have infested the chips during sun drying.

3.3.3 PARBOILING

Three litres of water were measured into a metallic chamber (22x12cm high), which was placed on a heater and allowed to boil. One-kilogram weight of the chips was carefully put

into the boiling water. The mixture was stirred continuously for two minutes (Modification of method by (Rajamma *et al.*, 1994). After that, the water was drained from the chips and spread on a metallic rack for 30 minutes to reach room temperature. The ratio of weight of chips (kilograms) to volume of water (litres) used was 1:3 w/v (Rajamma *et al.*, 1994) After reaching room temperature, the chips were placed on metallic trays at a loading rate of 3-5kg and oven dried at 60°C for 24 hours.

3.3.4 PLAIN CHIPS

Freshly cut chips were dried immediately after chipping in an oven at 60°C for 48 hours without any treatment. After drying, the chips were allowed to cool, packed in airtight bags and then frozen for two weeks. Later, the samples were conditioned for another two weeks in a room with ambient mean temperature of 30±3°C and humidity of 82.7 ± 0.6% before they were used. Before artificially infesting the chips, they were fumigated with Phostoxin (Phosphine gas) for 7 days to ensure that any infestation during the conditioning was controlled.

3 4 DETERMINATION OF MOISTURE CONTENT

The moisture content (mc) of the initial uninfested, infested and control samples was determined by oven method as described by (Rajamma *et al.*, 1994, Stumpf, 1998). Ten grammes weight of cassava chip each of the processed chips were weighed into crucibles and the weight of the samples taken (W1). The weight of the samples and the crucibles was also taken (W2). They were exposed in the oven for two hours at 130°C and allowed to cool in desiccators before the final weights of the sample and the crucibles (W3) were taken. The percentage moisture content of the samples were obtained using the formula

$$\% \text{ Moisture content} = \frac{(W2 - W3)}{W1} X\ 100$$

3.5 PROXIMATE ANALYSIS

Samples of the differently processed chips were taken and milled for determination of the following nutrient composition of cassava flour: protein, sugars, starch, ash, fat, crude fiber and moisture content using methods of Bainbridge *et al.* (1996) for Assessing Quality Characteristics of Non-Grain Starch Staples (NGSS). Infested samples were analysed for their nutrient composition at the end of storage.

3.6 EXPERIMENTAL DESIGN OF THE SUSCEPTIBILITY TEST

Two insect species and two cassava varieties, each processed into four forms (plain, parboiled, sun-dried and fermented chips) were used for the experiment. Thirty insects were introduced onto the processed chips in wide-mouth glass jars. Each processed form was replicated four times for each insect species, each cassava variety and for each of the three storage periods. Four replicates of control treatment of each processed form were similarly set up for 49, 59 and 69 days for *P. truncatus* and 59, 69 and 79 for *A. fasciculatus*

3.7 DATA ANALYSIS

Data collected for insect numbers were transformed using Log_{10} (x+1) and percentage weight loss using arcsine and then analysed statistically using simple factorial ANOVA model in SPSS release 10.0 for windows statistical package (SPSS Inc, 1999). Means were separated after accessing level of significance using F-test (α 0.05) with LSD. Correlation analysis was performed on the relationship between the nutritional composition of cassava processed forms and insect population parameters and weight loss. Paired t-test was also performed on the changes in the nutrient composition of the chips after infestation. Graphs were drawn using Microsoft excel (Microsoft Corp., 2000).

CHAPTER FOUR

4.0 DESCRIPTION OF EXPERIMENTS

4.1.PREFERENCE FOR PROCESSED CHIPS BY *P. TRUNCATUS* AND *A. FASCICULATUS*

4.1.1 INTRODUCTION

Preference for a particular produce by an insect could be attributed to factors such as the quality, texture and other physical or chemical characteristics of the produce. This is also related to the suitability of the produce for oviposition and total development. Laboratory studies conducted by Rajamma *et al.* (1994) with *A. fasciculatus*, and Hodges *et al.* (1985) with *P. truncatus* in choice tests on a limited number of processed chips showed that adults of these insects preferred different chips. Whereas *A. fasciculatus* selected plain chips, *P. truncatus* preferred fermented chips. While the range of processed chips used in these studies was limited, the chips were not compared in the same experiment. In the present experiment, a choice test was conducted to evaluate the preferences of *P. truncatus* and *A. fasciculatus* adults given a wider range of processed chips.

4.1.2 MATERIALS AND METHODS

Ten grammes of each type of chips were placed on petri dishes for *A. fasciculatus* and on filter papers for *P. truncatus*. They were arranged in a circular form, 8 cm from each other in a transparent trough (Plate 3). Ten adults of *A. fasciculatus* and *P. truncatus* were released in a petri dish placed at the centre of the trough 4.2cm from the other petri dishes. The set up was monitored for 12 hours at two-hourly intervals. The adult numbers found on each processed chip were recorded. At the end of the monitoring period, the adults were removed and the chips transferred into glass vials for F1 emergence.

Plate 3.

Preference bioassay

Preference was assessed based on the number of adults recorded in each treatment and the subsequent F1 adults that emerged from them.

4.1.3 DATA COLLECTION

The number of adults recorded on each processed chips at each hourly interval were not significantly different; as a result, the number collected at the 12^{th} hour was used for the analysis. This was added to the number of F1 adults.

4.1.4 DATA ANALYSIS

Data was analysed using Analysis of variance and the means separated using LSD (Section 3.7).

4.1.4 RESULTS AND DISCUSSION

The mean number of *A. fasciculatus* and *P. truncatus* adult recorded on the various processed chips is shown in Table 1. A cursory look at the table revealed that more adults were recorded on fermented chips and least numbers on parboiled chips. Statistically, however, numbers recorded on fermented and sun-dried chips were significantly higher ($P< 0.05$) (Appendix 1) than on plain and parboiled chips. Analysis of variance revealed that insect preference for processed form was not influenced by cassava variety used, as interaction was not significant ($P> 0.05$).

Physical factors of the chips (such as texture, hardness, etc) may be responsible for the preference shown by the insects. Hodges *et al.* (1985) were of the opinion that fermentation leads to softening of the texture of the chips which permits easy boring by the insect and that may have accounted for the insect preference. Sun-dried chips are also known to undergo some little fermentation (Nicol, 1991). Rajamma *et al.* (1994) noted that insects

which caused reduced boring by the insect. For *P. truncatus* adults, no significant difference (P>0.05) was found in their preference for a particular processed chip (Table 1). This contrasts with work by Hodges *et al* (1985) where adults of *P. truncatus* appeared to prefer fermented chips compared to unfermented chips.

Table 1: Preference of *A. fasciculatus* and *P. truncatus* for differently processed cassava chips of two varieties.

	*Mean (± s. e) number of insects	
	A. fasciculatus	*P. truncatus*
Processed form		
Plain	1.2 (±0.2) [a]**	2.5 (± 0.4) [a]
Parboiled	0.8 (± 0.3) [a]	1.0 (± 0.3) [a]
Sundried	2.7 (± 0.6) [b]	2.0 (± 0.5) [a]
Fermented	3.0 (± 0.7) [b]	2.3 (± 0.5) [a]
Variety		
Afisiafi	1.8 (± 0.4) [a]	1.7 (± 0.1) [a]
Yebesi	2.1 (± 0.5) [a]	1.7 (± 0.1) [a]

* Mean of four replicates ± standard error (±s.e)

** Means followed by same letter vertically are not significantly different from each other (P>0.05) by LSD.

4.2 SUSCEPTIBILITY OF PROCESSED FORMS OF CASSAVA TO DAMAGE BY *P. TRUNCAUS* AND *A. FASCICULATUS*

4.2.1 INTRODUCTION

Methods of processing several crops have been found to influence the amount of losses they experience in storage and other indices of susceptibility. For instance, blanching or cooking of yam before drying reduces the intensity of damage by insects (Nwana and Azodeh, 1984). Susceptibility to attack varies not only with the post-harvest processing but also with the varietal characteristics of the produce.

A number of parameters have been used to study and evaluate susceptibility to insect infestation, especially in grains. These include percentage of damaged produce, weight loss of the produce, total progeny count, percentage of parent mortality and weight of the progeny of the infesting insect. Widstrom *et al.* (1972) evaluated these parameters for their efficiency and adaptability. It was reported that total progeny rated comparable to or better than any of the other parameters and produce weight loss as the best economic indicator for susceptibility. Storage period is also known to influence the extent of susceptibility of a produce to insect infestation, as longer storage durations tend to exacerbate susceptibility indices.

In the studies carried out in Tanzania to evaluate these parameters on cassava chips, Hodges *et al.* (1985) observed that fermented cassava chips suffered greater weight losses than the unfermented chips due to *P. truncatus* attack. In a similar study conducted in India, Rajamma *et al.* (1996) found that unfermented cassava chips reduced infestation by *A. fasciculatus*. Furthermore, it was observed that parboiled cassava chips were attacked less by *A. fasciculatus* than the plain chips (Rajamma and PremKumar, 1993, 1994). The

previous authors in separate experiments investigated susceptibility of cassava chips to infestation by *P. truncatus* and *A. fasciculatus*.

In the present study, a non-choice test was carried out to assess the susceptibility of four processed forms of cassava chips of the two cultivars to infestation by *P. truncatus* and *A. fasciculatus* at three storage periods.

4.2.2 MATERIALS AND METHODS

Susceptibility test was conducted at Plant Protection and Regulatory Services, Pokuase at room temperature range of 25-34°C and humidity of 61-92%.

One hundred and fifty gramms, 200 g and 300 g of each of the differently processed chips of the two cultivars were weighed into glass jars. Thirty 1-4 weeks old adults of *P. truncatus* were introduced into each jar, which was then covered with heavy-duty wire gauze. Each treatment was replicated four times and then allowed to stand for 49, 59 and 69 days. A similar experiment was set-up for *A. fasciculatus* (thirty 1-4 week old adults were also used), but 75 g, 100 g and 150 g of each treatment was used and these were kept for 59, 69 and 79 days respectively (modification of methods used by Helbig and Schulz, 1995, Rajamma *et al*., 1994) The different storage periods used for the two insect was based on their developmental periods. The numbers of adult insects at the end of each trial were recorded. Control treatments were provided for each processed form to monitor weight changes due to fluctuations in the environmental conditions over storage duration A thermo-hygrometer was mounted throughout the experiment to record temperature and relative humidity. Susceptibility was assessed based on the adult population density of the start population and F1 adults, weight of adult, percent weight loss weight of frass and the development of the two insects.

4.2.3 DATA COLLECTION

At the end of each storage period, the contents of the jars were sieved with sieves of 1mm and 1.3mm mesh width. The number of both live and dead adult insects was taken. The pieces, which remained on the sieve, were weighed and the weight difference from the initial input was classified as loss. The weight of the frass was also taken. 10 live adults were randomly selected and their weights taken using a sensitive balance.

4.2.4 DATA ANALYSIS

Data collected on insect numbers were transformed using Log_{10} (x+1). The percentage weight loss was first converted to dry weight loss using the formula:

((100-mc)* wtloss) / 100, where mc is the moisture content of the chips determined in section 3.4. The percentage dry weight loss was then transformed using arcsine. The entire data were analysed statistically using simple factorial ANOVA model in SPSS.

4.2.5 RESULTS AND DISCUSSION

4.2.5.1 *P. TRUNCATUS* ADULT POPULATION DENSITY

During the 49 days of storage, significant differences were observed in the mean numbers of adults of *P. truncatus* recorded on the processed chips (see Table 2). Across varieties, fermented chips recorded the highest number of adults (407) followed by 395.9 and 351.0 adults found on plain and sun-dried chips respectively. However, parboiled chips supported the lowest number of adults (89.0) Statistical analysis revealed that parboiled chip was significantly different from other processed chips ($P<0.05$) (Appendix 2)

The number of adult *P. truncatus* recorded gradually increased with storage duration on all processed forms, At 69 days, fermented chips recorded the highest number of adults (619.9). This suggests that prolonged storage under conditions likely to favour moisture uptake may result in increased infestation.

Table 2: Mean* number of *P. truncatus* adults recorded on processed chips of two cassava varieties at three storage periods

Processed form	Length of storage (days)		
	49	59	69
Plain	395.9 (± 34.5) [b]**	463.0 (± 46.4) [b]	499.6 (± 48.1) [b]
Parboil	89.0 (± 16.4) [a]	166.0(± 36.0) [a]	220.6 (± 48.6) [a]
Sundried	351.0(± 42.1) [b]	415.4 (± 48.69) [b]	533.3 (± 43.43) [b]
Fermented	407.0(± 53.9) [b]	435.8 (± 65.77) [b]	619.9 (± 74.45) [c]

* Means of four replicates (± s.e)

**Means followed by same letter vertically are not significantly different from each other (P>0.05) by LSD.

* Values are pulled across varieties.

The chemical and physical factors combined may explain why parboiled chips experienced the lowest *P. truncatus* numbers. The reduced starch content, which ranged from (76.3 to 79.8 %) (Appendix 8) as compared to other samples and the hard texture in parboiled may have played a significant role. Although the starch content in fermented chips also reduced due to fermentation (ranged from 76.8 to 78.8), the texture was soft enough to permit easy boring. In maize for instance, Howard (1983) and Li (1988) recorded reduced oviposition rate when *P. truncatus* was maintained on flinty and popcorn maize varieties. Li (1988) further explained that this was due to the higher energy cost of tunneling the harder maize since the female had to lay eggs in blind-ending tunnels thereby leading to reduced fecundity and consequently the population size is reduced on the harder maize variety. This suggests that in parboiled chips, conditions are less favourable for higher oviposition, egg and larval development and survival of the adults. The low numbers of adults recorded on parboiled chips confirmed the protective role of the gelatinized chips (Pillai and Rajamma, 1986).

From the analysis, a significant interaction of variety and processed forms was observed ($P<0.05$) (Appendix 2). This indicates that varietal characteristics of cassava had influence on the performance of the processed chips. Significantly more adults were recorded on processed forms of Yebesi, a local variety than on Afisiafi, an improved variety (see Fig 1). This might be due to the presence of more starch in the local variety, which ranged from (76.8 to 83.1 %) than the improved variety, which ranged from (78.8 to 84.7 %). The correlation between starch and density was also positive and significantly high ($r= 0.71$, $P=0.044$) supporting the assertion by Detmers *et al.* (1993), Wright *et al.* (1993) and Scholz *et al.* (1997) that *P. truncatus* breeds well in products with high starch content.

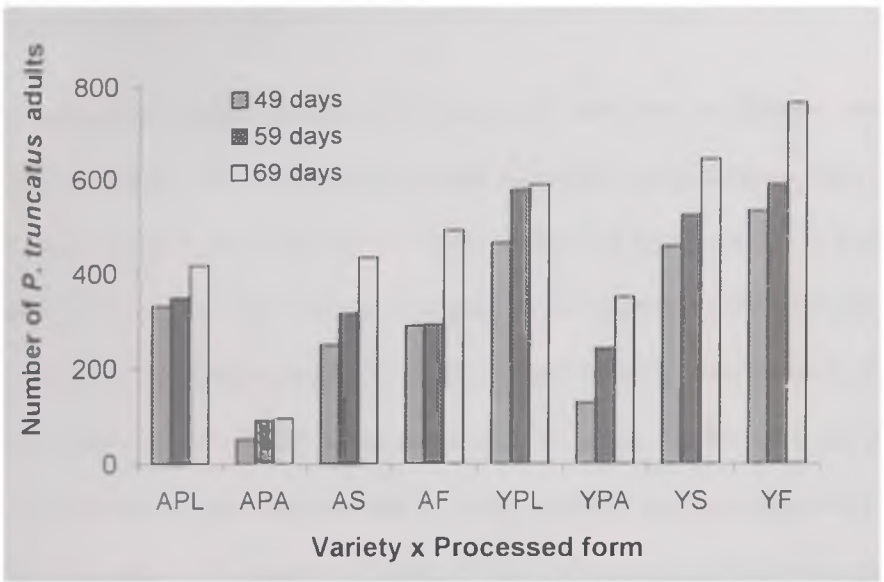


Fig. 1: Number of adult *P. truncatus* recorded on processed chips of two cassava varieties at three storage periods.

KEY:

APL= plain Afisiafi
APA= parboiled Afisiafi
AS= sun-dried Afisiafi
AF= fermented Afisiafi

YPL= plain Yebesi
YPA= parboiled Yebesi
YS= sun-dried Yebesi
YF= fermented Yebesi

4.2.5.2 WEIGHT LOSS DUE TO ADULTS OF *P. TRUNCATUS* ON DIFFERENT PROCESSED CHIPS

The percentage dry weight loss caused by adults of *P. truncatus* on different processed chips is presented in Table 3. The results indicate that weight loss in cassava chips due to damage by adults of *P. truncatus* was very high. Weight loss in chips due to *P. truncatus* also increased over time. This increase was gradual, as significant differences were not observed among the storage periods. Such losses were equated to the amount of chips reduced to dust by both the start population and the F1 adults. In this work, the overall average percentage weight loss recorded on plain, sun-dried and fermented chips were 71.5%, 71.2% and 71.7%, respectively after 69 days of storage by which time many of these chips had disintegrated. The lowest amount of loss (20.9%) was recorded for parboiled chips where the adult numbers recorded were comparatively lower than in other chips. Analysis of variance revealed significant differences among the processed chips ($P<0.05$) (Appendix 3) in the manner in which they incurred losses due to insect.

The varietal characteristics of the two cultivars seemed to have played a significant role in the amount of loss caused to processed chips. The interaction between variety and processed form was significant ($P<0.05$) (Appendix 3) at the initial periods of storage. Therefore weight loss as high as 93.4% was recorded on fermented Yebesi as compared to fermented Afisiafi, which recorded 49.9% loss (Fig 2). Relatively low weight losses were recorded on parboiled chips of the two cultivars with parboiled Afisiafi incurring the lowest amount of loss. The high percentage weight loss caused by *P. truncatus* in this study confirmed the several reports that *P. truncatus* adults generate high losses in stored cassava chips (Hodges *et al.*, 1985, Helbig and Schulz, 1995, Stumpf, 1998). Interestingly, Helbig and Schulz (1995) reported a reduction of 27% due to *T. nigrescens*

in plain cassava chips stored for 56 days. However, in this study just parboiling chips resulted in a lower loss reduction of 49% when the chips were stored for 59 days

Table 3: Mean* percentage dry weight loss of processed cassava chips of two varieties due to *P. truncatus* at three storage periods.

Processed form	Length of storage (days)		
	49	59	69
Plain	63.4 (± 10.3) b**	68.2(±8.8) b	71.5 (±7.7) b
Parboiled	13.0 (± 3.2) a	19.3 (±9.5) a	20.9 (±5.0) a
Sundried	56.0 (±7.7) b	59.9 (±7.4) b	71.2 (±6.7) b
Fermented	59.4 (±9.2) b	64.5 (±10.2) b	71.7 (±8.8) b

* Means of four replicates (± s.e)

**Means followed by same letter vertically are not significantly different from each other (P>0.05) by LSD.

* Values are pulled across varieties.

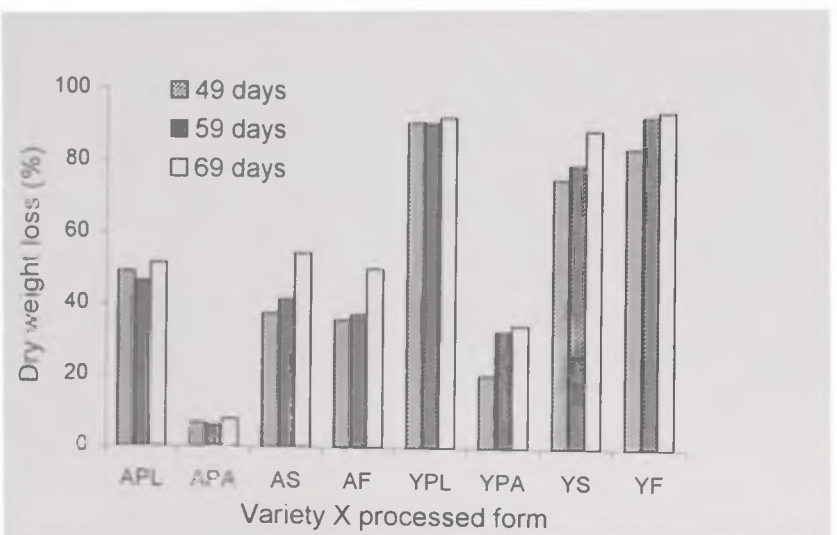


Fig 2 Percentage dry weight losses of processed chips of two cassava varieties resulting from *P. truncatus* infestation at three storage periods

KEY

APL= plain Afisiafi
APA= parboiled Afisiafi
AS= sun-dried Afisiafi
AF= fermented Afisiafi
YPL= plain Yebesi
YPA= parboiled Yebesi
YS= sun-dried Yebesi
YF= fermented Yebesi

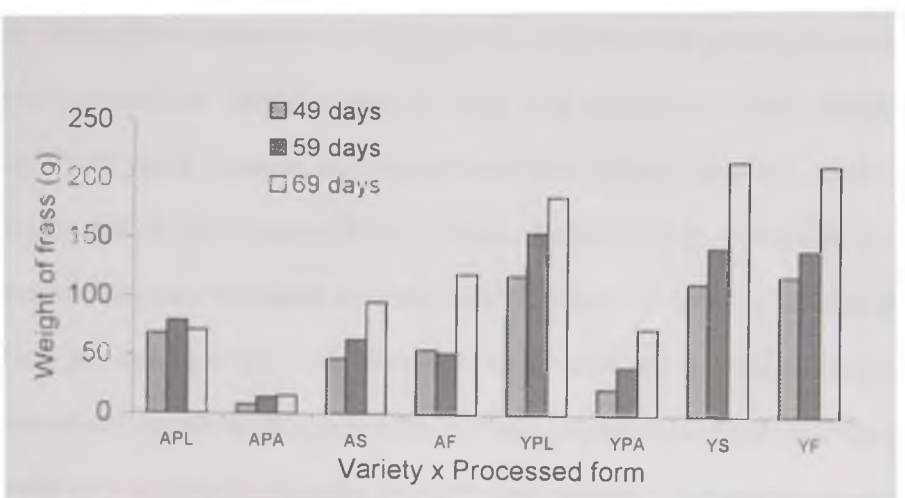
4.2.5.3 FRASS PRODUCTION

P. truncatus produced a lot of dust by boring into the cassava chips. The amount of frass produced on plain, parboiled sun-dried and fermented chips is shown in Table 4 Significantly large amount of frass was produced on plain, sun-dried and fermented chips compared to the amount produced on parboiled chips after 69 days of storage. The trend of frass production was consistent with that of weight loss discussed earlier. Analysis also revealed significant interaction ($P< 0.05$) (Appendix 4) between processed form and variety at the initial periods of storage. Significantly large amount of frass was produced on fermented and sun-dried Yebesi compared to the amount recorded on sun-dried and fermented Afisiafi, yet parboiled chips of the two varieties recorded the lowest amount of frass with parboiled Afisiafi recording the lowest weight (Fig 3). The smooth structure of the chips and lack of a protective covering both favoured the boring activity of *P. truncatus* and consequently high frass production.

Table 4: Mean* weight (in gramme) of frass produced by *P. truncatus* adults from processed chips of two cassava varieties at three storage periods.

Processed form	Length of storage (days)		
	49	59	69
Plain	93.0 (± 9.9) [b]**	116.8 (± 15.0) [b]	128.0 (± 24.7) [b]
Parboil	15.2 (± 3.4) [a]	27.5 (± 6.0) [a]	44.3 (± 11.0) [a]
Sundried	79.3 (± 12.9) [b]	102.6 (± 15.9) [b]	155.2 (± 23.4) [b]
Fermented	86.5(± 13.6) [b]	96.1 (± 18.4) [b]	165.6 (± 22.2) [b]

* Means of four replicates (±s.e).
** Means followed by same letter vertically are not significantly different from each other (P>0.05) by LSD.
* Values are pulled across varieties.



* Fig. 3: Weight of frass produced by *P. truncatus* infestation of processed chips of two varieties at three storage periods.
* Weight measured in grams (g)

KEY

APL= plain Afisiafi
APA= parboiled Afisiafi
AS= sun-dried Afisiafi
AF= fermented Afisiafi
YPL= plain Yebesi
YPA= parboiled Yebesi
YS= sun-dried Yebesi
YF= fermented Yebesi

4.2.5.4 POPULATION DENSITY OF *A. FASCICULATUS* ON PROCESSED CHIPS

The analysis of variance performed on the number of *A. fasciculatus* adults recorded on different processed chips revealed significant differences among the forms ($P<0.05$) (Appendix 5). Plain cassava chips supported the highest number of adults (59.9) compared to that recorded on sun-dried (48.5), fermented (42.4) and parboiled (30.0) at the initial storage period (Table 5). As the storage duration was prolonged, plain cassava chips showed equal performance with sun-dried and fermented chips with fermented chips recording the highest number of adults (108.5). This observation suggested that over time, the samples could degenerate both in quantity and quality, thereby exhibiting similar performance in their ability to support insect. However, parboiled chips consistently recorded the lowest number of adults (36.8) at the end of storage.

Analysis of variance showed that significant differences exist between similarly processed forms of the different varieties ($P<0.05$) (Appendix 5) at the initial periods of storage. Plain Yebesi supported the highest number of adults (70) compared to plain Afisiafi, which recorded (55) adults. However, parboiling reduced the population numbers in both varieties with parboiled Afisiafi having the lowest number of adults (Fig 4). At the end of storage, fermented Yebesi had the highest number of adults compared to fermented Afisiafi although this was not significant ($P > 0.05$). Therefore, the physical and/ or chemical factors of the varieties could account for the performance of the processed chips. The correlation analysis revealed some significant interaction ($P< 0.05$) (see Appendix 13) between the population densities of *A. fasciculatus* and the sugars, fibers and moisture content of the chips (Table 13).

Table 5: Mean* number of *A. fasciculatus* adults recorded on processed chips of two cassava varities at three storage periods

Processed form	Length of storage (days)		
	59	69	79
Plain	59.9 (± 2.7) c**	76.3(± 6.9) b	99.1 (± 2.5) b
Parboiled	30.0 (± 0.0) a	31.8 (± 1.1) a	36.8 (± 2.3) a
Sundried	48.5 (± 2.5) b	84.3 (± 14.4) b	97.0 (± 9.8) b
Fermented	42.4 (± 2.4) b	76.3 (± 3.2) b	108.5 (± 8.6) b

* Means of four replicates (±s.e)

** Means followed by same letter vertically are not significantly different from each other (P>0.05) by LSD.

* Values are pulled across varieties

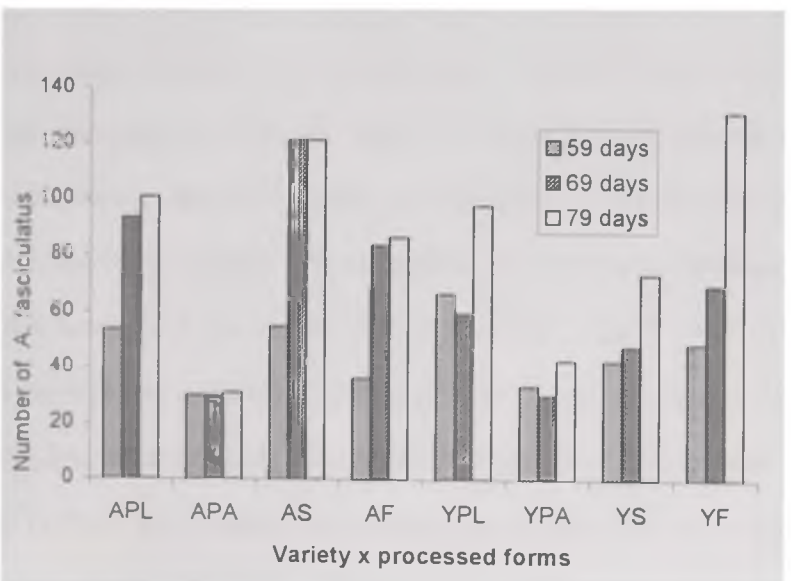


Fig 4 Adult number of *A. fasciculatus* recorded on processed chips of two cassava varieties at three storage periods

KEY

APL= plain Afisiafi
APA= parboiled Afisiafi
AS= sun-dried Afisiafi
AF= fermented Afisiafi
YPL= plain Yebesi
YPA= parboiled Yebesi
YS= sun-dried Yebesi
YF= fermented Yebesi

4.2.5.5 WEIGHT LOSS OF DRIED PROCESSED CHIPS DUE TO *A. FASCICULATUS*

Table 6 shows the mean weight loss caused by adults of *A. fasciculatus*. The apparent weight loss caused by adults of *A. fasciculatus* was significantly higher in plain chips (15.9%) compared to parboiled chips (1.3%) at the initial storage period. There was consistent significant increase ($P<0.05$) (Appendix 6) in the weight loss through the storage period and plain chips suffered the highest amount of loss (20.6%) at the end of storage. Parboiled chips experienced the least losses, which ranged from 1.3-2.6%. Analysis of variance showed that cassava variety played a significant role in the performance of processed form as the interaction was found to be significant ($P<0.05$). Plain Afisiafi recorded the highest loss of about 34% (Fig 5). The smooth structure and lack of protective covering of the fermented, plain and sun-dried chips compared to the hard texture of parboiled chip, could have favoured the boring activities of the insect and the subsequent losses. Analysis also showed that *P. truncatus* density had positive and significant association ($r= 0.95$, $P< 0.05$). The result gives an indication of the very considerable losses, which could result from infestation by this pest if the chips are not protected. Correlation analysis revealed positive and significant interaction between the population density of *A. fasciculatus* and weight loss ($r= 0.88$, $P< 0.05$). This suggested that the insect density could explain the weight losses recorded during the storage periods. Earlier work by Rajamma *et al.* (1994) established that *A. fasciculatus* adults caused losses of about (7.0%-17.8%) on plain chips compared to parboiled chips where the insect caused 1.1- 2.5% weight loss. In addition, Rajamma *et al.* (1996) reported weight loss of (8.9-19.4) on plain chips and (0.6-2.6) on parboiled chips. In the present study, the mean weight loss on plain chips ranged from (15.9-20.6) while on parboiled chips the loss ranged from

(1.3-2.6). This suggested that the weight loss values observed in this study was comparable to that reported by these authors.

Table 6: Mean* percentage weight loss caused by *A. fasciculatus* adults to processed chips of two cassava varieties at three storage periods.

Processed form	Length of storage (days)		
	59	69	79
Plain	15.9 (± 0.9) c**	20.23 (± 2.36) c	20.56 (± 1.59) c
Parboiled	1.3 (± 0.3) a	1.9 (± 0.2) a	2.6 (± 0.2) a
Sundried	4.5 (± 0.8) a	9.3 (± 1.5) b	16.3 (± 3.7) b
Fermented	9.8 (± 0.9) b	12.3 (± 1.5) b	16.9 (± 1.5) b

* Means of four replicates (± s.e)

**Means followed by same letter vertically are not significantly different from each other (P>0.05) by LSD.

* Values are pulled across varieties.

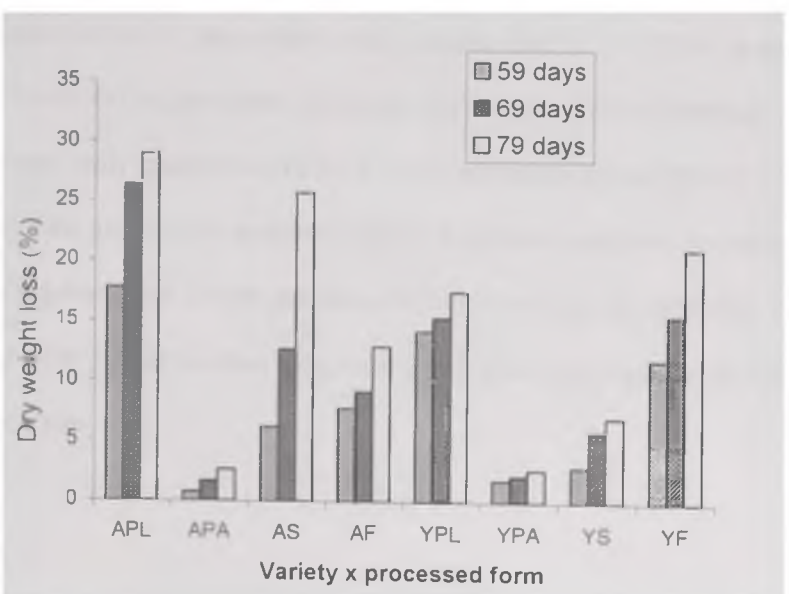


Fig.5 Percentage (%) dry weight loss of processed chips of two cassava varieties resulting from *A. fasciculatus* infestation at three storage periods

KEY

APL= plain Afisiafi
APA= parboiled Afisiafi
AS= sun-dried Afisiafi
AF= fermented Afisiafi
YPL= plain Yebesi
YPA= parboiled Yebesi
YS= sun-dried Yebesi
YF= fermented Yebesi

4.2.5.6 FRASS PRODUCTION

The frass production of the adults of *A. fasciculatus* is shown in Table 7. From the table the highest amount of frass was produced in plain and fermented chips where significantly more adults were recorded than on parboiled chip. In this study, the frass produced in plain chips ranged from (8.9-21.7). This value however, was significantly ($P<0.05$) (see Appendix 7) higher than that produced in parboiled chips where frass production ranged from 0.36-0.62. The interaction between variety and processed form was significant ($P<0.05$) (Appendix 7). *A. fasciculatus*, unlike *P. truncatus* caused more damage to Afisiafi which seemed to have more sugars than Yebesi (Fig 5).

The potential of *A. fasciculatus* to cause damage was found in studies by Pillai and Rajamma (1986) and Rajamma *et al.* (1994, 1996). Rajamma *et al.* (1994) found that frass production by *A. fasciculatus* adults ranged from (0.1-0.26 %) in parboiled chips and (10.9–47.49) in plain chips. However, the amount of frass produced by this pest in the present study ranged from (0.3-0.6 %) on parboiled chips to (8.9-21.7 %) on plain chips. The frass produced on parboiled chips in the present study was not similar to that reported by Rajamma *et al.* (1994) the values fall below 1% and are negligible. On the other hand, the upper limit of the frass value recorded on plain chips was almost twice that observed in the present study.

Table 7: Mean* weight of frass (in gramme) produced by *A. fasciculatus* adults from processed cassava chips stored for three periods.

Processed form	Length of storage (days)		
	59	69	79
Plain	8.9 (± 0.8) c**	18.0 (± 3.4) c	21.7 (± 4.6) c
Parboiled	0.36 (± 0.1) a	0.41 (± 0.2) a	0.62 (± 0.2) a
Sundried	4.5 (± 1.3) b	11.1 (± 3.1) b	14.4 (± 1.9) b
Fermented	4.7(± 0.3) b	8.4 (± 1.2) b	15.3 (± 3.0) b

* Means of four replicates ± standard error

**Means followed by same letter vertically are not significantly different from each other (P>0.05) by LSD.

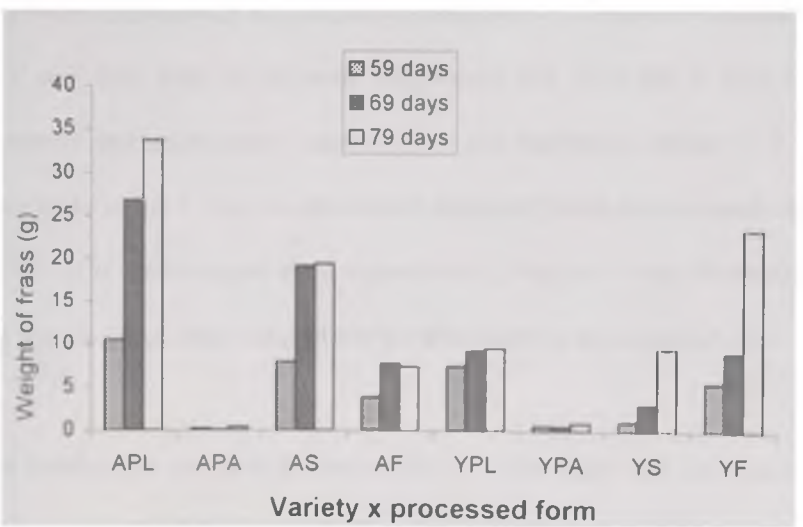


Fig 6 Weight of frass produced by *A. fasciculatus* infestation of processed chips of two cassava varieties at three storage periods
* Weight measured in grams (g)

KEY

APL= plain Afisiafi
APA= parboiled Afisiafi
AS= sun-dried Afisiafi
AF= fermented Afisiafi
YPL= plain Yebesi
YPA= parboiled Yebesi
YS= sun-dried Yebesi
YF= fermented Yebesi

4 3 DEVELOPMENT OF INSECTS ON CASSAVA CHIPS

4 3 1 INTRODUCTION

Development of any insect from larva to adult is dependent on a number of factors, which may be related. Factors such as temperature, humidity, the nature of substrate, etc is known to affect to a large extent, the development of insects. Although there is an optimum value for each insect species, varying conditions affect the development of each insect species.

The development of *P. truncatus* is more rapid on maize at 27°C and 70% RH than on cassava (Shires, 1979, 1980) hence, the mean developmental period on maize and a block of cassava took 32.5 days and 40 days, respectively (Haines, 1991). In Tanzania, Hodges *et al.* (1985) reported 40.3 days on unfermented and 41.7 days on fermented cassava chips at 27°C and 70% RH. At the same temperature and 50% RH, it was 42 days on both fermented and unfermented cassava chips. On emergence, males of *P. truncatus* were reported to weigh 3.3mg on unfermented chips and 3.4mg on fermented chips at 70% R.H. At 50% R.H, their weights were, respectively 2.7mg and 3.4mg. However, the females on the same forms of chips weighed heavier than males by an average of 13%.

The development period of *A. fasciculatus* on coffee beans took between 46 and 66 days at 28°C and 76-80% RH (Cobal-Concha, 1956). Vitelli *et al.* (1976) reported 56 days at 72°F and 26 days at 80°F on artificial diet. In contrast, Rajamma *et al.* (1994) reported 38 days and 59 days on two different cassava varieties. In the light of the above, the developmental periods of *P. truncatus* and *A. fasciculatus* were studied using two differently processed Ghanaian cassava varieties.

4.3.2 MATERIALS AND METHOD

The developmental period of the insects was conducted at Plant Protection and Regulatory Services, Pokuase at room temperature range of 25-34°C and humidity of 61-92%. Twenty adults of *P. truncatus* and *A. fasciculatus* were put into petri dishes containing 30g each of plain, parboiled, sundried and fermented chips of a local variety, Yebesi and improved variety, Afisiafi. The petri dishes were covered with petri dishes of equal sizes. Before infestation, the moisture content of the chips was determined using the method described in section 3.4. The insects were allowed to lay eggs for one week after which the adults were removed and the samples kept for emergence of new adults. The newly emerged adults were counted daily and removed. The minimal time needed for insect development was calculated from the third day after insect release until the first day of emergence. The mean weight of three F1 adults that emerged was also taken using a sensitive Mettler balance model KERN 870.

4.3.3 RESULTS AND DISCUSSION

4.3.3.1 DEVELOPMENTAL PERIOD

The mean developmental period of *P. truncatus* and *A. fasciculatus* are shown in Table 8. The mean developmental period of *P. truncatus* on plain, parboiled sun-dried and fermented cassava chips were 36.3, 37.0, 36.4, and 36.1 days respectively. Analysis of variance showed no significant difference ($P > 0.05$) (Appendix 8) between the developmental periods. The developmental period observed in the present study is shorter than those observed by Nyakunga (1982) and Hodges *et al.* (1985). The reason is not clear, although it is possible that it was due to the fact that they worked under controlled environmental conditions. At 50% and 70% RH, Nyakunga (1982) studying a Tanzanian strain of unsexed *P. truncatus* adults developing on small blocks of unfermented cassava recorded

mean developmental periods of 46.7 and 43.1 days respectively. Hodges *et al.* (1985) also recorded 40.3-40.7 days on unfermented and 41.7-42.0 days on fermented cassava at 70% RH. At 50%RH, they recorded 42-44 days on unfermented and 42-43 days on fermented chips. This small difference in developmental period at this range of humidity was also found when the beetles developed on maize.

On the other hand, in the present study, the mean developmental period of *A. fasciculatus* on plain, parboiled, sun-dried, and fermented cassava chips were 58.4, 55.5, 61.7 and 57.4 days respectively. Significant difference ($P<0.05$) (Appendix 9) was found between the developmental periods on sun-dried chips and other processed forms. It was found from the nutritional composition of the processed chips that the protein content of sun-dried chips was higher than those contained in other chips (Appendix 10). The nutritional components of the two varieties also showed that sun-dried Afisiafi had significantly higher protein content ($t=2.86$, $P< 0.05$) than that of sun-dried Yebesi. Correlation analysis of the nutrient showed that protein content correlates positively with developmental period (Table 13). Vowotor (1992) was also of the view that high protein levels in grain were positively related to the developmental period of *S. zeamais*. This suggested that increasing the protein level increases the developmental period. Therefore, it might explain why in the present study the developmental period of *A. fasciculatus* on sun-dried chips was longest (61.7 days).

Also, the long developmental period recorded in this study could also be attributed to the moisture content of the chips, as low moisture content would result in longer development. Eduku (1994) reported that the mean developmental period of *A. fasciculatus* on cassava chips at moisture contents of 8.8% and 13.5% were respectively 63.7 and 37.4 days. In the

present study, the moisture content within the range of 11.4- 14.5% resulted in developmental period that ranges from 55.5- 61.7 days. However, the range of developmental period recorded in this study falls within the range of 46-66 days reported by Cobal-Concha (1952) on coffee at 28°C and 76- 80% RH. Conversely, Vitelli *et al.* (1976) reported 56 days at 22.2°C and 26 days at 26.7°C on artificial diet.

Table 8: Developmental period (in days) of *A. fasciculatus* and *P. truncatus* to variously processed cassava chips.

Processed form	Mean (± s. e) developmental period	
	A. fasciculatus	*P. truncatus*
Plain	58.2 (± 2.0) [ab]**	36.3 (± 0.5) [a]
Parboiled	55.5 (± 1.5) [a]	37.0 (± 1.0) [a]
Sundried	61.7 (± 1.3) [b]	36.4 (± 0.9) [a]
Fermented	57.4 (± 0.9) [ab]	36.0 (± 0.2) [a]

* Means of four replicates ± standard error.

** Means followed by same letter vertically are not significantly different from each other (P>0.05) by LSD.

* Values are pulled across varieties.

4.3.3.2 ADULT WEIGHT

The mean weight of *P. truncatus* and *A. fasciculatus* adults taken at the end of each storage period are shown in Tables 9 and 10. Analysis of variance revealed that no significance differences ($P>0.05$) existed in the weight of adults recorded on the differently processed forms of cassava chips. The result of this work was comparable to that observed by Hodges *et al.* (1985).

The interaction between variety and processed form was not significant, suggesting that varietal characteristics of the chips did not play any significant role in the weight of adults at the end of storage period. Correlation analysis showed that the weight of adult *P. truncatus* and *A. fasciculatus* at the end of storage had no significant association with any of the nutrients.

Table 9: Mean weight (mg)* of *P. truncatus* adults reared on processed cassava chips stored for three periods.

Processed form	Length of storage		
	49 days	59 days	69 days
Plain	3.55 (± 0.1) [b]**	3.44 (± 0.03) [a]	3.58 (± 0.06) [b]
Parboil	3.08 (± 0.12) [a]	3.30 (± 0.06) [a]	3.43 (± 0.05) [ab]
Sundried	3.31 (± 0.10) [ab]	3.30 (± 0.10) [a]	3.31 (± 0.06) [a]
Fermented	3.30(± 0.09) [ab]	3.28 (± 0.09) [a]	3.44 (± 0.07) [ab]

* Means of four replicated (± s.e)

** Means followed by same letter vertically are not significantly different from each other (P>0.05) by LSD.

* Values are pulled across varieties.

Table 10: Mean weight (mg)* of *A. fasciculatus* adults reared on processed cassava chips stored for three periods.

Processed form	Length of storage		
	59 days	69 days	79 days
Plain	5.75 (± 0.20) [a]**	5.43 (± 0.23) [a]	5.31 (± 0.24) [a]
Parboil	5.83 (± 0.20) [a]	4.98 (± 0.12) [a]	4.97 (± 0.07) [a]
Sundried	5.11 (± 0.09) [b]	5.03 (± 0.05) [a]	5.19 (± 0.23) [a]
Fermented	5.14 (± 0.20) [b]	4.95 (± 0.21) [a]	4.91 (± 0.20) [a]

* Means of four replicates (± s.e)

** Means followed by same letter vertically are not significantly different from. each other (P>0.05) by LSD

* Values are pulled across varieties.

The mean weight of adults within 0–24 hours of emergence was also taken as they emerged during the developmental period study. The mean weights of *P truncatus* F1 adults on plain, parboiled, sun-dried and fermented chips were respectively 2.7, 3.5, 2.6 and 2.6 (Table 11). Insects emerging from parboiled chips were significantly heavier ($P < 0.05$) than those from other processed forms. Correlation analyses of nutrient composition of the cassava varieties with some insect population parameters showed that F1 adult weight of *P. truncatus* correlated positively with the content of reducing sugars and negatively with non-reducing sugars (Table 13). It was observed also that parboiling caused an increase in the sugar content of the chips. This increase, according to PemKumar *et al.* (1996), could be due to increased hydrolysis of the gelatinized starch. Therefore, the weight of F1 adults depended on the sugar content of the chips.

Similarly, when the weight of *A. fasciculatus* F1 adult was also taken the mean weight on plain, parboiled, sun-dried and fermented chips were 3.98, 4.05, 4.08 and 4.33, respectively (Table 11). However, no differences were observed in the mean weight of the adults. The interaction between variety and processed form was also not significant.

Table 11 Mean weights (mg)* of F1 adults of *A. fasciculatus* and *P. truncatus* on differently processed chips.

Processed form	Mean weight of insects	
	A. fasciculatus	*P. truncatus*
Plain	3.98 (± 0.12) a**	2.69 (±0.11) a
Parboiled	4.05 (± 0.08) a	3.45 (± 0.04) b
Sundried	4.09 (± 0.09) a	2.59 (± 0.19) a
Fermented	4.33 (± 0.11) a	2.58 (± 0.18) a

* Means of four replicates (± s.e)

** Means followed by same letter vertically are not significantly different from each other (P>0.05) by LSD.

* Values are pulled across varieties.

CHAPTER FIVE

5.0 NUTRITIONAL CHANGES IN CASSAVA CHIPS INFESTED BY INSECTS

5.1 INTRODUCTION

The first visible indication of food deterioration in dried cassava is often the detection of growth of bacteria and fungi. Among losses caused by fungi growing in stored food are biochemical changes and production of toxins (Christensen and Kaufmann, 1969). Macfarlane (1982) reported conversion of sugars and starch into carbon dioxide and water as a result of metabolic activities of the microorganism. In the course of storage, other organisms, such as species of mould-feeding insects attack cassava chips thereby causing more deterioration. Padmaja *et al.* (1994) and PremKumar *et al.* (1996) reported that insect infestation caused substantial changes in quality characteristics of cassava chips. Some authors suggested that the duration of storage also contributes in food deterioration (Allotey, 1988; Kumar *et al.*, 1991). Therefore, this work was undertaken to evaluate how insect infestation and duration of storage could contribute to quality deterioration in cassava chips.

5.2 MATERIALS AND METHODS

Immediately after processing and conditioning, samples of cassava chips as described in section 3.3, they were taken and milled for initial biochemical analysis. At the end of the storage period, fully infested powder from both *P. truncatus* and *A. fasciculatus* were sieved to remove the dead beetles. Samples were also collected from the controlled treatments for the different durations of storage. They were analysed to determine the moisture content, protein, crude fiber, ash, fat, total carbohydrate, reducing and non-reducing sugars and starch, using the methods for Assessing Quality Characteristics of Non- Grain Starch Staples (NGSS) described by Bainbridge *et al.* (1996)

5.2.1 DETERMINATION OF MOISTURE CONTENT

The moisture content (mc) of cassava flour was determined using the oven method described by Osborne and Voogt (1978). Five grammes samples each of the processed chips were weighed into crucibles and the weight of the samples taken (W1). The weight of the samples and the crucibles was also taken (W2). They were placed in the oven for two hours at 130°C and allowed to cool in desiccators before the final weights of the sample and the crucibles (W3) were taken. The percentage moisture content of the samples were obtained using the formula:

$$\% \text{ Moisture content} = \frac{(W2 - W3)}{W1} X\ 100$$

5.2.2 DETERMINATION OF CRUDE PROTEIN

Protein was determined by the micro-Kjeldal method multiplied by the factor 6.25 to determine the nitrogen content was measured. One gramme weight of cassava flour was weighed into a dry 100 ml Kjeldahl flask. One tablet of copper catalyst was added into the samples in the flask and 8 ml of concentrated sulphuric acid (H_2SO_4) added. A blank containing only a tablet of copper catalyst and sulphuric acid was prepared. The mixture was stirred and placed in a heater to digest, when the mixture became greenish- blue (this took about thirty minutes to 1hour, time depending on the sample). This was cooled and about 30 ml of water added. After digestion, 10 ml of 0.1NHCL was measured in a volumetric flask and a drop of Tashiro indicator (0 1g methyl red + 0 5g methylene blue dissolved in 200 ml, 70% ethanol) added. This was then connected to a distillation chamber and 10 ml of 40% NaOH.. The distillate was then titrated with 0.1N NaOH to faint pink colour. The percentage nitrogen was converted to percentage protein by a conversion factor of 6.25.

5 2 3 DETERMINATION OF CRUDE FIBRE

The crude fibre content of the cassava flour was determined by Van Soest's method (1963) Two grammes of each of the samples (W1) were weighed into conical flasks and 200 ml of boiling 1.25% H_2SO_4 added to digest the samples. A spatula full of celite was added and the samples boiled gently for 30 minutes and then filtered through a glass fibre filter paper. The residue was then transferred into the conical flask and 200 ml of 1.25% NaOH added and heated for another 30 minutes (antifoaming agent added to avoid foaming). The mixture was filtered and flushed with 100 ml of Hydrochloric acid (HCl) and a small quantity of hot water into a sintered glass Buchner funnel. The residues were dried in an oven at 105°C overnight. The dried residues were cooled in desiccators and their weight taken (W2). These were then transferred into muffle furnace at dull red heat (550-660°C) for six hours. The samples were cooled and their final weights taken (W3).

The percentage fiber was determined as follows:

$$\% \, Fiber = \frac{(W2 - W3)}{W1} X \, 100$$

5.2.4 DETERMINATION OF ASH CONTENT

The percentage ash content of the cassava was determined by Van Soest's method (1963). The dry selected crucibles were heated in the muffle furnace at 600°C for 30 minutes and cooled in desiccators. The weights of dried crucibles were taken. Two grammes of the samples (W1) were weighed into the crucibles and their weight taken (W2). These were transferred into the muffle furnace at 600°C for six hours to ash. The samples were cooled in desiccators and the final weight of the sample plus the crucible taken (W3)

$$Percentage \, ash \, content = \frac{(W2 - W3)}{W1} X \, 100$$

5.2.5 DETERMINATION OF FATS

The fat content was determined by method of Rodney (1992). Five grammes of finely ground cassava flour from samples (W1) (described in section 5.2) were weighed into 125ml Erlenmeyer flask and fifty milliliters of hexane x isopropanol (3: 2) in 300ml containing 180ml of hexane and 120ml of isopropanol added. This was warmed on a hot plate in a hood for 15 minutes. The extraction mixture was filtered rapidly through fluted qualitative grade filter paper into a refluxed flask and twenty milliliters of warm hexane-isopropanol poured through the solid residue in the filter. The solvent was removed from the extract under rotary evaporator and yellow oil obtained. The weight of the oil plus the flask (W3) and the weight of the flask (W2) were taken. The percentage fat content of the sample was obtained as follow:

$$\% Fat = \frac{(W3 - W2)}{W1} X\ 100$$

5.2.6 DETERMINATION OF TOTAL CARBOHYDRATE

One gramme weight of the sample (described in section 5.2) was weighed into a refluxing flask and 20 ml of 1M HCl were added. The mixture was clamped in a refluxing set up and allowed to boil for two hours on a hot plate. After heating, 20 ml of 1M NaOH was added and then filtered using glass fiber filter paper. The total carbohydrate was determined using *Anthrone's* method, which is the combination of methods by Egan *et al.* (1981) and Osborne and Voogt (1978). The absorbance of the samples was read using spectrophotometer at wavelength of 620 nm.

5.2.7 DETERMINATION OF REDUCING SUGARS

One gramme sample of cassava flour was weighed into a wide-necked 200 ml volumetric flask and 150 ml of hot water added. This was kept warm by shaking to extract the water-

soluble matter. The solution was clarified by addition of 5 ml Carrez I solution (21.9 g zinc acetate dihydrate in water conataing 3 g acetic acid, make up to 100 ml with water), followed by 5 ml of Carrez II solution (10.6 g potassium ferrocyanide trihydrate in water make up to 100 ml with water). The mixture was filtered through a glass fiber filter paper. One milliliter of the filtrate was taken for reducing sugar determination using Anthrone's method. The samples absorbance was read using spectrophotometer at wavelength of 620 nm.

5.2.8 DETERMINATION OF NON- REDUCING SUGARS

Non- reducing sugars were determined by complete hydrolysis of the reducing sugars through refluxing in dilute HCl. Five millilitres of the clarified samples was measured into a 250ml quick-fit Erlenmyer flask and 2ml of 1M HCL was added. This was made up to 20ml using distilled water. The mixture was refluxed on a hot plate for 10 minutes. This was cooled and 2ml of 1M NaOH and 3ml of water was added. Non- reducing sugar was determined using Anthrone's method.

5.2.9 DETERMINATION OF STARCH CONTENT

The starch content was determined by subtracting the reducing and non-reducing sugar contents from the total carbohydrate.

5.3 DATA ANALYSIS

Data were analysed by paired t-test to detect significant changes. Direct comparison of the composition of the initial uninfested samples, control and fully infested samples was also made

5 4 RESULTS AND DISCUSSION

The nutritional changes observed in dried cassava chips due to infestation by *P. truncatus* and *A. fasciculatus* are presented in Table 12. Insect infestation caused some major changes in the nutrient composition of the processed chips of the two cultivars. The moisture content of the chips during storage increased due to infestation. The moisture content in the flour infested by *P. truncatus* increased from 8 to 9.3% at the beginning of the storage to between 11.5 and 13.3% at the end of storage (see Appendix 8). In *A. fasciculatus* infested samples, moisture content increased from between 8-9.3% to 10.9% Statistical analyses showed significant increase in the moisture content in most of the infested samples (Table 12).

It is likely that insect activities may have created a moist micro-climate within the infested chips, which led to increasing moisture content levels. Stumpf (1998) observed that moisture content of cassava chips increased from 8-9% at the beginning of storage, to 14 - 16% at the end of storage due to infestation. Significant differences were not found in the moisture levels of plain and sun-dried Yebesi infested by both *P. truncatus* and A. *fasciculatus*

The protein content of the cassava chips increased significantly due to infestation but this was more pronounced in chips infested by *P. truncatus*, which increased from (0.2- 1.5) (Table 12).

Table 12: Changes in nutrient levels of two cassava varieties processed similarly after infestation by insects [a]

P. truncatus

Afisiafi	Me	Protein	Ash	Fiber	Fat	Starch	R-sugar	N- sugar
Plain	-3.10*	-0.25 *	-0.39 ns	0.26 ns	0.00 ns	3.62 *	0.71 ns	0.73 ns
Parboiled	-3.75*	-0.63 **	-0.17 *	0.065 ns	0.05 ns	4.34 *	-2.33 **	-1.46 ns
Sun dried	-3.9 *	-0.91 *	-0.04 ns	0.47 *	0.08 ns	6.03 *	0.45 *	-0 63 ns
Fermented	-4.5 *	-0.70 *	-0.35 ns	0.57 *	0.00 ns	7.70 *	0.56 *	-0 38 ns
Yebesi								
Plain	-2.55 ns	-0.45 **	-0.39 **	0.53 *	0.25 ns	7.47 **	0.83 **	0.71 ns
Parboiled	-4.55 **	-0.27 ns	-0.56 ns	0.5 *	0.30 ns	5.70 **	-0.94 *	-1.76 **
Sun dried	-3.15 ns	-1.50 *	-0.22 *	0.68 *	0.25 ns	4.73 ns	0.49 *	0.41 ns
Fermented	-3.30 *	-0.44 *	-0.44 *	0.65 *	0.05 ns	6.82 **	1.20 **	0.42 ns

A. *fasciculatus*

Afisiafi								
Plain	-1.34 ns	-0.13 *	-0.025 ns	0.1 *	0.03 ns	2.07 **	2.00 **	0.33 ns
Parboiled	-2.05 *	-0.18 ns	0.39 **	0.09 ns	0.03 ns	1.87 ns	-3.00 **	-1.68 *
Sun dried	-1.95 *	-0.30 *	-0.045 ns	0.78 *	0.00 ns	1.46 **	1.05 **	0.3 ns
Fermented	-1.87 ns	-0.46 *	-0.22 ns	0.53 *	0.25 ns	4.70 *	0.79 *	-0.43 ns
Yebesi								
Plain	-1.25 *	0.00 ns	-0.30 *	0.27 *	0.08 ns	6.08 *	1.39 *	0.14 ns
Parboiled	-2.3 *	-0.07 *	-0.005 ns	0.40 *	0.25 *	3.53 **	-1.01 *	-1.51 *
Sun dried	-1.70 ns	-0.17 *	0.2 ns	0.41 *	0.2 ns	9.11 **	0.41 **	0.79 **
Fermented	-0.05 ns	-1.16 **	-0.43 *	0.25 ns	0.03 ns	6.02 ns	0.41 **	1.03 *

[a]Paired T- test: values.quoted are either not significant (ns), significantly different at 5% (*) or at 1% (**).

[b]Negative sign indicates that there was an increased change.

[c]Means of four replicates

Generally, the increase in the protein content was least in the parboiled chips infested by *A. fasciculatus*. Wright *et al.* (1993) observed that the nutritional quality of chips is less likely to decrease due to pest infestation; instead, some nutritional variables might be enhanced. This, it is suggested, was probably caused by the addition of protein to the damaged chips by cast skins, nitrogenous compounds and insect bodies, which remain in the chips during the chemical analysis. This may explain the increase in the protein content of the infested samples in this study. Conversely, Padjama *et al.* (1994) reported that insect infestation drastically reduced all the amino acid fractions in both plain and parboiled chips. However, the extent of reduction was greater in parboiled chips. There was increase in the ash content of chips infested by both *P. truncatus* and *A. fasciculatus*, although most were not significantly different. However, the reason for this has not yet been fully ascertained. It is possible that processing may have contributed to this. For instance, Oyewole (1992) noted that fermentation of cassava causes some changes in the nutritional composition of cassava, which included both addition and reduction in the mineral content of the chip. Also, the suggestion by Wright *et al.* (1993) could equally explain the significant increase in the ash content of some of the samples. Insect infestation did not cause any significant change in the fat content of the chips.

The starch content decreased in the samples due to infestation by the two insects. In the present study, reduction in the level of starch due to *P. truncatus* ranged from (3.0-10.0%) while in *A. fasciculatus* infested samples, it ranged from (1.8-7.6%). Therefore the observed reduction in the starch content of cassava chips might have resulted from the utilization of starch by the insect feeding on the chips. Kumar *et al.* (1991) found that in a trial under controlled conditions, about 7% reduction of the starch level was measured on plain dried chips due to *P. truncatus*. Also, Wright *et al.* (1993) noted that *P. truncatus*

infestation reduced starch levels of cassava by about 4% in the station trials in Togo. The starch level of "SORAD" was reduced by about 7% after 12 weeks of storage under controlled condition while in the field, 0.3% reduction was recorded (Stumpf, 1998). The results of this study also agreed with that reported by PremKumar *et al.* (1996).

The sugar content of the infested samples also changed due to infestation. The reducing and non- reducing sugars decreased in infested samples. Although reduction in sugar content was observed in infested plain and sun-dried and fermented chips, there was increase in the sugar content in parboiled chips. The large increase in reducing sugars observed in infested parboiled chips might have resulted from the increased hydrolysis of the gelatinized starch present in parboiled chips by the salivary enzymes of the two insects. Compared with native raw starch (present in plain dried chips), the gelatinized starch is acted upon easily by hydrolytic enzymes (PremKumar *et al.*, 1996). It is also known that gelatinized starch is more readily digested (both *in vitro* and *in vivo*) than native raw starch (Moorthy and Padmaja, 1991). Although large quantities of free sugars are released in parboiled chips, the insects consumed only a small proportion; as a result, the residual sugar content increased in the remaining powder. A high performance liquid chromatographic analysis of the sugar profiles in insect infested cassava chips reinforces this finding and it was observed that there was a predominance of sugars such as sucrose, maltose and glucose in infested parboiled chips compared with the quantity present in uninfested chips (Padmaja *et al.*, 1994).

The crude fiber content in all the samples underwent reduction with insect infestation. The reduction was more obvious in *P. truncatus* infested samples. The results indicated the possible utilization of crude fiber during insect feeding. PremKumar *et al.* (1996) reported

that insect infestation caused reduction in crude fiber from (1 26-0 24) in fully infested plain chips.

Direct comparisons of the nutrient composition of the initial uninfested samples and the control samples at the end of storage period showed no changes in the nutrients as a result of storage period. Statistical analysis also revealed no significant difference (P>0 05) between the nutrient contents of the initial uninfested samples and the control. The observed changes, found mostly in grains due to storage, occurred after a long period. Pixton and Hill (1967) reported reduction in the total sugar content, especially the non-reducing sugars in wheat stored for six years. It has also been established that the longer the storage of a produce, the greater the decrease in the hydrophilic characteristics and aggregation of the protein molecules (Kozlova and Nekrasov, 1957). It is therefore concluded that the changes observed in dried cassava chips in this study are due to insect pest infestation.

CHAPTER SIX

6.0 EFFECT OF NUTRITIONAL COMPONENTS IN DIFFERENTLY PROCESSED CASSAVA CHIPS OF TWO CULTIVARS ON THE DEVELOPMENT OF *P. TRUNCATUS* AND *A. FASCICULATUS*

6.1 INTRODUCTION

To further understand the factors that may affect the development of *P. truncatus* and *A. fasciculatus* on cassava forms under investigation, a study was conducted on the major nutritional factors in cassava that have been reported to affect the development of these two insects particularly *P. truncatus*. Unlike in fresh cassava roots, where successful relationships have been established between the development of insects that attack cassava notably, *Phenacoccus manihoti* (Calatayud and Ru, 1994) and biochemical basis for susceptibility and resistance, little or no information is available on dry cassava chips. The objective of this study therefore was to determine how the weight of developing insects and developmental period, population density, and weight loss might be influenced by the major nutrients present in the different cassava forms.

6.2 MATERIALS AND METHODS

Ten live adults were randomly selected from the four replicates of the four cassava processed forms and their mean weights taken (Section 4.2.3). Also the mean weights of three newly emerged insects were taken during the study of developmental period (Section 4.3.2). The mean adult densities of *P. truncatus* and *A. fasciculatus* were taken at the end of the storage period. Percentage weight loss caused by the two insects was also determined at the end of every storage period (Section 4.2.3). The nutritional contents of the cassava chips were determined as described in chapter 5

6.3 DATA ANALYSIS

Relationships between nutritional contents of the cassava and the mean weight of insect, developmental period, the population density and weight loss were evaluated by simple correlation analysis.

6.4 RESULTS AND DISCUSSION

Correlation between the nutritional contents of processed forms of cassava chips with population density of insects, F1 weights, developmental period and weight loss is shown in (Table 13). Moisture content within the range of (8-9.3%) (Appendix 8) in the chip correlated positively and significantly influenced the population density of *P. truncatus* adults (r=0.83, P=0.01). This indicated that the amount of moisture in the chips associated linearly with the population density of *P. truncatus* adults. It is, however; obvious that *P. truncatus* is a species that can thrive at both low and high moisture levels. Haines (1991) found that maize grain at moisture content of 10.6% and 90% RH were heavily infested by *P. truncatus*. In addition, Hodges *et al.* (1983) observed *P truncatus* thrives on maize at lower moisture content in a field study. It is therefore, possible that the levels of moisture content observed in this study were obviously beneficial to the insects and could have affected the susceptibility to damage by insects of dried chips

Similarly, *A. fasciculatus* adults showed the same trend with the moisture content, which had a positive association with *A. fasciculatus* density (r =0.71, P=0.04). This is expected of a species that breeds mostly at high moisture level and whose development can be severely affected by low humidity (Allotey, 1991; Haines, 1991; Rajamma and PremKumar, 1994).

Table 13: Correlation between insect population parameters and the nutritional contents of cassava chips [a]

	Mc	Protein	Starch	R-sugar	N-sugar	Ash	Fat	Fiber
P. truncatus								
Density	0.83*	-0.16ns	0.71*	-0.69ns	0.53ns	-0.53ns	-0.12ns	0.77*
Dev. period	0.67ns	-0.18ns	-0.23ns	0.31ns	-0.19ns	0.20ns	0.16ns	-0.56ns
Adult weight	0.15ns	-0.43ns	0.243ns	0.016ns	0.04ns	-0.28ns	0.09ns	-0.42ns
F1 weight	-0.70ns	-0.31ns	-0.43ns	0.81*	0.89*	-0.06ns	0.53ns	-0.62ns
Weight loss	0.800*	-0.17ns	0.82*	-0.78*	0.59ns	-0.38ns	0.03ns	0.63ns
A. fasciculatus								
Density	0.71*	0.23ns	0.37ns	-0.76*	0.72*	-0.13ns	-0.49ns	0.82*
Dev. period	0.32ns	0.72*	0.44ns	-0.45ns	0.52ns	0.30ns	-0.09ns	0.50ns
Adult weight	0.64ns	0.10ns	0.48ns	-0.33ns	0.39ns	0.07ns	0.15ns	0.01ns
F1 weight	-0.62ns	-0.78*	-0.10ns	-0.10ns	-0.11ns	-0.66ns	-0.06ns	0.39ns
Weight loss	0.36ns	0.42ns	0.39ns	-0.66ns	0.76*	0.17ns	-0.52ns	0.54ns

[a]Correlation coefficients (r): ns not significant or * significant at 5%.

[b]Means of four replicates

Moisture content in chips also showed positive significant (r=0.79, P<0.05) association with percentage weight loss.

The weights of F1 adults of both *P. truncatus* and *A. fasciculatus* were negatively correlated with the moisture content, although this was not significant. Vowotor (1992) observed that the mean weight of the fourth instar larva of *Sitophilus zeamais* was significantly high when moisture content was low. Also, a significant (r=0.77, P<0.05) and negative association was found between the protein content and F1 weight of *A. fasciculatus*. No association was, however, found between the F1 adults of *P. truncatus* and protein. This observation was similar to the findings by Singh and McCain (1963) who reported no relationships between protein and progeny weight of *S. zeamais*.

No significant association was observed between the protein content and the developmental period of *P. truncatus*. On the other hand, *A. fasciculatus* developmental period correlated positively and significantly (r=0.72, P<0.05) with the protein content in cassava chips. This confirmed the findings that high protein levels in maize correlated positively with the total developmental period of *S. zeamais*. On the contrary, Dobie (1977) reported a negative relationship between protein and susceptibility in terms of F1 progeny and days to their emergence.

The general relationship of the total carbohydrate contents of the chips and some parameters of insect developmental biology is also shown in Table 13. The starch and crude fiber contents showed positive and significant correlation (r=0.71, P<0.05 and r=0.77, P<0.05, respectively) with *P. truncatus* density. Weight losses due to the insect activity also showed significant association with starch content (r=0.82, P=0.01). This result suggested

that the amount of starch in the chips might influence the survival of, and damage by adults of *P. truncatus*. The observation by Scholz *et al* (1997) that *P. truncatus* responded in general to odours from starchy commodities verifies this finding. Detmers *et al.* (1993) also reported that the possibility of breeding by adults of *P. truncatus* was dependent on the high starch content in the wood of *M. esculenta*. In their study, F1 adult weights were observed to be positively associated with the reducing sugars and negatively to non-reducing sugars. This inverse relationship between the reducing and non-reducing sugars was observed in the studies by Glass (1959) in wheat.

On the contrary, no association was found between starch and *A. fasciculatus* density. Rather, significant positive associations were observed between the non-reducing sugars ($r=0.72$, $P<0.05$) and negative associations with reducing sugars ($r=0.76$, $P<0.05$) and *A. fasciculatus* density. These suggested that unlike in *P. truncatus* where starch is needed for its population build-up, *A. fasciculatus* adults might prefer sugars.

No associations were found between the ash and fat contents in the chips and any of the parameters of insect developmental biology during the study.

CHAPTER SEVEN

7.0 SUMMARY AND CONCLUSIONS

The effect of variety and processed forms of cassava chips on the development and damage-caused by two common pests of cassava chips, *P. truncatus* and *A. fasciculatus* was studied in the laboratory. The studies are important to understand how these varietal resistance and the processed forms can be used as an independent control methods or as an adjunct to other control measures. The escalating costs of insecticides, the spreading of insecticide-resistant insects, the growing concern about indiscriminate use of insecticides and their undesirable side effects increase interest in such studies.

In the study, the general performance of parboiled chips in conferring protection to chips against both *P. truncatus* and *A. fasciculatus* was observed in the relatively low numbers of adults recorded, low weight loss and frass produced. The effectiveness of parboiling in suppressing the population of the *P. truncatus* This explains why traditional small-scale farmers in India have continued to store the crop in this form over the years with relatively low losses even without the use of chemical protectants (Rajamma *et al.*, 1994). The less dense texture of plain, sun-dried and fermented chips which enhanced feeding and subsequent population increase and weight loss, suggests that none of these processed forms is useful for long term storage.

In the present study, *P. truncatus* was more destructive pest than *A. fasciculatus* on processed cassava chips. Weight losses on various processed chips due to *P. truncatus* ranged from (13.0–20.9%) in parboiled chips to (59.4–71.7%) in fermented chips On the other hand, losses in processed chips due to *A. fasciculatus* ranged from (1.3–2.6%) in

parboiled chips to (9.8–16.9%) in fermented chips. This destructive potential of *P. truncatus* is confirmed by experimental work in Togo Wright *et al.* (1993) and Compton *et al.* (1993), and in Tanzania by Hodges *et al.* (1985). Moreover, the enormous destructive potential of *P. truncatus* could be attributed to its enormous amount of frass produced and high reproductive rate in comparison to *A. fasciculatus*. However, the effectiveness of parboiling in suppressing the population of the insects when breeding on dried cassava chips was similar to that observed in the studies by Rajamma *et al.* (1994) and Helbig and Schulz (1995). In 56 days trial, Helbig and Schulz (1995) found that number of *P. truncatus* resulting from populations developing on cassava was reduced from 1117 adults to 39 adults on addition of *T. nigrescens*. In the present study, after 59 days, the pest population was reduced from 463 to 166 adults. It is clear that weight losses in cassava due to *P. truncates* can be very high with an overall average, recorded in the present study, of 63.4% on plain chips after 49 days, rising to 71.5% after 69 days, by which time many of the roots had disintegrated. However, on parboiled chips, the weight loss value was reduced significantly from 13% after 49 days and 20.9% after 69 days.

Since the production of cassava chips is assuming a new importance and being a crop produced all- year- round, care must be taken, else cassava chips will serve as the breeding ground for these insects to infest other crops. Therefore control efforts should be geared towards environmentally- friendly and cost- effective solutions to reducing infestation e.g. by parboiling. Improvement in the processing of cassava chips and other storage techniques are crucial for long-term storage. Therefore, the various treatments given to cassava chips during processing to enhance their physical characteristics should further be explored in the effort to control these pests. Such methods include blanching or parboiling, addition of magnesium or calcium, addition of calcium to boiling water, which increase the

compressive strength (Eggleton and Asiedu, 1994), or addition of salt (Agona *et al*., 1998). In areas where fermentation of cassava is indispensable due to high cyanide content, few minutes parboiling before drying is recommended. In addition, the chemical factors of cassava that have been observed to enhance breeding of these pests, such as the starch and the sugar contents, should be considered during breeding for resistance.

Since the nutritional losses in infested chips are quite minimal there is still the possibility of using the infested chips in animal feed formulations and for the manufacture of starch-based chemicals. Although these losses are quite minimal, other waste products such as uric acid, faecal matter and exuviae which create foul odour that consequently decrease the possibility of using cassava for human consumption should be considered. The potentially harmful effects of fungi and bacterial metabolites inoculated by insects on consumers are worth considering and need to be incorporated in pest management strategies.

From the study, the following conclusions can be drawn:

- The infestation of cassava chips by *A. fasciculatus* was generally low. However, the interaction between variety and processed form was significant, with fermented Yebesi consistently recording the highest pest densities throughout the storage period. *A. fasciculatus* density also increased over time but remained comparatively low on parboiled chips.
- The population densities of *P. truncatus* were high on all varieties. Their population increased rapidly and reached maximum levels at the 69-storage period. However, the densities on parboiled chips of the two cultivars remained relatively low compared to other processed forms.

- Cassava variety influenced weight losses in *P. truncatus* infested samples although this was not significant in *A. fasciculatus* infested samples.
- Parboiled chips recorded the least weight loss at almost all the storage periods investigated.
- The texture of chips (parboiled: chips gelatinized and fermented: - less dense texture) may explain the density levels of both *P. truncatus* and *A. fasciculatus*.
- Both *P. truncatus* and *A. fasciculatus* densities strongly correlated positively with weight loss.
- *P. truncatus* density and weight loss had strong association with the starch content of cassava while *A. fasciculatus* density and weight loss related more to sugars.
- Insect infestations caused some significant changes in the nutrient composition of the infested chips. These reductions were more pronounced in *P. truncatus* infested samples than was observed in *A. fasciculatus* infested samples. The starch, sugars and crude fiber contents, underwent significant reduction due to insect infestation.
- The sugar content of uninfested parboiled chips increased due to processing but the increase was more pronounced in pest-infested parboiled samples.

7.1 RECOMMENDATIONS

From this study, it is recommended that further work be carried out in which:

1. The influence of parboiling on the developmental biology of the insects is evaluated
2. The various time and temperature for parboiling be assessed for improved processing
3. The effect of the various moisture levels of the processed chips on the developmental biology of the insect

REFERENCES

Adam, F. (1988). Presentaion du Togo. In proceedings of the Regional African Workshop on the containment and control of larger grain borer, Report iii, pp. 73-88.

Addo, S. (1994). Tolerance of different maize varieties and wood species used in maize storage structures in the Volta Region, Ghana, to the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). M. Phil. Thesis, University of Ghana, Legon

Affognon, H., Bell, A., Schneider, H. and Borgemeister, C. (1995). Summary of the recommendations of the West African Regional Workshop on the larger grain borer, *Prostephanus truncatus*, Cotonou, Republic of Benin, 8pp.

Agona, J. A., Silim, M.N., Giga, D. P. and Rees, D (1998). The effect of salting sweet poatato chips prior to drying on infestation by *Araecerus fasciculatus* Degeer (Coleoptera: Anthribidae). *Trop. Agric.,* (Trinidad), **75**: 84-88.

Allotey, J. (1988). Insect pest spectrum of palm kernel and damage caused by them. *Insect Sci. Applic.*, **9 (5)**: 619- 623.

Allotey, J. (1991). Development and fecundity of the rice moth, *Corcyra cephalonica* (Pyralidae). *Discovery and Innovation*, **3**: 123- 126.

Anon., (1991). Annual Report, Central Tuber Crops Research Institute, Sreekariyam, Trivandrum, India, pp. 34-36.

Appert, J. (1992). The storage of grains and seeds. Tropical Agriculturist. Rene Coste (ed), Macmillan Press London, 146pp.

Ayertey, J. N. and Brempong-Yebogh, C. Y. (1991). A survey of the larger grain borer, *Prostephanus truncatus* (Horn) in some areas in Ghana. In: Ndoye, M. (ed). Exotic Pests in Africa, Prevention and Control. Proc. Symposium 9th Scientific Conference, African Assoc. Insect. Scientists, Accra, Ghana, Sept., 1991. pp. 59-66.

Bainbridge, Z., Tomlins, K., Wellings, K. and Westby, A. (1996). Methods for Assessing Quality characteristics of Non- Grain Starch Staples (part 3 laboratory methods). pp. 21- 40.

Balagopalan, C., Padmaja, G., Nanda, S. K. and Moorthy, S. N. (1988). Cassava in Food, Feed and Industry. CRC Press Inc., Florida, pp. 37-50.

Beevi, S. R., Visalakshi, A., Mammen, K. V., Ramla, B. S., Nair, N. G., Palaniswami, M. S., Rajendran, P. G., Abraham, K. and Potty, V. P. (1991). Nature and extent of damage caused by insect pests to stored cassava chips. Recent Advances in the production and utilization of tropical tuber crops. *J. Root Crops*, **17**: 197-200.

Bell, R. J. and Waters, F. L. (1982). Environmental factors influencing the development of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) on stored maize. *J. Stored Prod. Res.* **18**, 131-142.

Boateng, B. A. (1996). Effects of maize variety and season on population dynamics of the Larger Grain Borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) and *Sitophilus zeamais* Motsch (Coleoptera: Curculionidae) and grain loss in the traditional Ewe storage barn in Ghana. M.phil Thesis, University of Ghana, Legon. 113pp.

Bonu-Ire, M. S. T. (2000). Evaluation of some biological control agents against the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). M.Phil Thesis, University of Ghana, Legon.90pp.

Boeye, J. (1988). Autokologische Untersuchungen zum Verhaiten des Groben Kornbohrers, *Prostephanus truncatus*(Horn) (Coleoptera: Bostrichidae). Ph.D Thesis, University of Kiel, 195pp. (Abstract only seen).

Cabal concha, A. (1956). The biology and control of the coffee weevil, *Araecerus fasciculatus* (Degeer) (Coleoptera: Anthribidae) at Baranuilla, clombia. *Rev. Fac. Nac. Agon.* (Medelin). **18 (49)**: 30- 31, 49- 72.

Calatayud, P. A. and Ru, B. L. (1994). Potential biochemical mechanisms used by Congolese cassava to resist mealybug. Orstom, Montpellier, France. Pp.485. In: Cassava biotechnology Network. Proceedings of the second International Scientific Meeting, Boijon, Indonesia. Vol. II.

Christensen, C. M. (1974). Storage of cereal grains and their products. American Association of Cereal Chemists Incoporated. St. Paul, Minnesota. 549 pp.

Christensen, C. M. and Kaufmann, H.H. (1969). Maintenance of quality in stored grain storage. The role of fungi in quality loss. University of Minnestota Press, Minneapolis, vii + 153 pp.

Cock, J. H. (1985). Cassava New Potential for a Neglected Crop. West View Press /Bauder and London, 192 pp.

Compton, J. A. F. (1991). Survey of farm storage of maize and dried cassava, Central Region Togo, Feb.-March 1991, NRI report R1773, xiii + 90 pp.

Compton, J. A. F., Wright, M. A. P., Gay, C. and Stabrawa, A. (1993). A rapid method for loss- assessment in stored maize and dried cassava. NRI report R5103, Chatham, UK.

Cotterell, G. S. (1934). Infestation of cocoa by the weevil (*Araecerus fasciculatus*) and moth (*Ephestia cautella*). Bull. Dept. Agric. Gold Coast (Accra), 28, 14pp. *Ann. Rev. Appl. Entomol.*, p. 22- 618.

Daftary, R. D., Pomeranz, Y. and Saucer, D. B. (1970). Changes in wheat flour damage by moulding during storage; effect on lipids, lipoproteins and proteins. *Agri. Food Chem.*, **18**: 613-618.

Demianyk, C. J. and Sinha, R. N. (1987). Effect of infestation by larger grain borer, *Prostephanus truncatus* (Horn) and lesser grain borer, *Rhyzopertha dominica* (F) (Coleoptera: Bostrchidae) on stored corn. *Environ. Entomo.*, **16 (3)**: 618- 624.

Detmers, H. B., Laborius, G. A., Rudolph, D. and Schulz, F. A. (1993). Infestation of wood with the larger grain borer *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). *Mitteilungen der Deutschen Gesellschaft fur Allgemeine und Angewandte Entomologie*, **8 (4- 6)**: 803- 808 (Abstract only seen).

Dick, K. M. Rees, D. P. Lay, K. K. and Ofosu, A. (1989). Occurrence of larger grain borer, *Prostephanus truncatus* (Horn) in Ghana. *FAO Plant Protection Bulletin*, **37 (3)**: 32.

Diop, P. H. (1998). Storage and Processing of Roots and Tubers in the Tropics. D.J.B. Calverley, Consultant. 8 pp.

Dobie, P. (1974). The laboratory assessment of the inherent susceptibility of maize varieties to post-harvest infestation by *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae). *J. Stored Prod. Res.*, **10**: 183- 197

Dobie, P. (1977). The contribution of the Tropical Stored Products Center to the study of insect resistance in stored maize. *Trop. Stored Prod. Inf.*, **34**: 7- 22.

Doku, E. V. (1969). Cassava in Ghana. Arakan Press Ltd., Kotobabi, Accra. Ghana. pp. 35-37

Eduku, A. (1994). Acomparison of the development of the coffee bean weevil, *Areacerus fasciculatus* (Degeer) (Coleoptera: Anthribidae) on cassava chips and cocoa beans. Bsc. Dissertation, University of Ghana, Legon. 44pp.

Egan, H., Kirk, R. and Sawyer, R. (1981). The Luff Schoorl method. Sugars and preservatives. pp. 152-153. In: Person's Chemical Analysis of Foods. 8th edition. Harlow, UK. Longman Scientific and Technical.

Eggleston, G. and Asiedu, R. (1994). Effects of boiling on the texture of cassava clones: a comparison of compressive strength, intercellular adhesion and physicochemical composition of the tuberous roots. *Trop. Sci.*, **34**: 259- 273.

Entsie, E and Ofosu, A. (2001). Rapid survery of the current distribution of *Prostephanus truncatus* (Horn) and *Teretrius nigrescens* in Ghana. Report presented to the Plant Protection and Regulatory Services Directorate, Ministry of Good and Agriculture, Ghana, 12 pp.

FAO, (1953). Food composition tables for international use. In: Doku, E. V. (1969) cassava in Ghana, Arakan Press Ltd. Kotobabi, Accra, Ghana. pp. 35-37

FAO, (1984). Proximate composition of gari and fufu. Vol. II. In: Walston, J.P (1991). Post- harvest and processing technologies of Africa staple foods: a technical compendium. *FAO Agric. Serv. Bull.*, **89**: 174- 207

FAO, (1998). Food Outlook. Food and Agricultural Organization, Rome. http//: www.fao.org.

Glass, R. L., Ponte, J. G., Christensen, C. M. and Gaddes, W. F. (1959). Grain storage studies xxviii. The influence of temperature and moisture levels on the behaviour of wheat stored in air or nitrogen. *Cereal Chem.*, **36**: 341- 356.

GLGBP (1993). Field studies in the Volta Region. MOFA/ ODA (UK), Ghana LGB project, Quartely report 2, April-June, 1993.

Golob, P. (1988). Current status of the larger grain borer, *Prostephanus truncatus* (Horn) in Africa. *Ins. Sci. Appl.*, **9 (6)**: 737- 745.

Golob, P. and Hodges, R. (1982). Study of an outbreak of *P. truncatus* (Horn) in Tanzania. Report of the Tropical Product Institute, G164. 23 pp

Goncalves, L. I., Bitran, H. V. and Bitran, E. A. (1976). Contribution to the study of the biology of the coffee borer, *Araecerus fasciculatus* (Degeer, 1775) (Coleoptera: Anthribidae). *J. Agri. Res.* China, **25 (1)**: 44- 52.

Grace, M. R. (1977). Cassava Processing, FAO Plant Production and Protection Series No. 3, Rome.

Hahn, K. (1989). An Overview of African Traditional Cassava Processing and Utilization. Outlook on Agriculture, **18: 2**

Hahn, S. K. and Keyser, J. (1985). Cassava: A basic food in Africa. *Outlook on Agriculture*, **4**: 95-100.

Haines, C. P. (1991). Insect and Arachnids of Tropical Stored Products: their Biology and Identification (A Training Manual). Natural Resouces Institute. pp, 22-27.

Hall, W. D. (1970). Handling and storage of food grains in tropical and subtropical areas. Commission for Technical Cooperation in Africa, South of the Sahara. *FAO. Agri. Dev.*, **90**: 16- 35.

Halliday, D., Qureshi, A. H. and Broadbent, J. A. (1967). Technical report No. 16: Investigations on the storage of gari, in: Ann Rep. Nigerian stored product Research Institute, 1967, Lagos, Nigeria: Federal Ministry of Trade, 150 pp.

Hashem, M. Y. (1989). Untersuchungen zur Biologie des Groben Kornbohrers, Prostephanus truncatus (Horn) und des Getreideka puziners, *Rhyzopertha dominica* (Fab.) (Coleoptera: Bostrichidae). *Mitt. Dtsch. Ges. Aua. Angew. Ent.*, **7**:205- 209. (Abstract only seen).

Helbig, J. (1993). Untersuchungen Zu Okologie und Biologie Von, *Prostephanus truncatus*(Horn) (Coleoptera: Bostrichidae) in Togo unter besonderer Berucksichtigung der Wechselbezie-hung mit dem predator Teretriosoma nigrescens Lewis (Coleoptera: Histeridae). Ph.D thesis, Technical University of Berlin. (Abstract only seen).

Helbig, J. (1995). The ecology of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) in Togo with particular emphasis on interaction with the predator, *Teretriosoma nigrescens*. Deutsche Gesellschaft fur Technische Zusammenabeit (GTZ) GmbH, Eschborn, 111 pp. (Abstract only seen).

Helbig, J and Schulz, F. A (1994). Studies on the biology of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrchidae) on wood. *Journal of Applied Entomology*, **117 (4)**: 380- 387.

Helbig, J. and Schulz, F. A. (1996). The potential of the predator, *Teretriosoma nigrescens* Lewis (Coleoptera: Histeridae) for the control of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) on dried cassava chips and cassava wood. *J. Stored Prod. Res.*, **32 (1):** 91- 96.

Hodges, R. J. (1984). Field ecology and monitoring of *Prostephanus truncatus*. Proceedings GASGA workshop on the larger grain borer, *Prostephanus.truncatus*; 24-25 February, 1983 TPI, Slough publ. GTZ, Eschborn, pp. 32-38.

Hodges, R. J., Dunstan, W. R., Magazini, I. and Golob, P. (1983). An outbreak of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) in East Africa. *Protection Ecology*, **5 (2)**: 183- 194.

Hodges, R. J., Meik, J. and Denton, H. (1985). Infestation of dried cassava (*Manihot esculenta* Crantz) by *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) *J. Stored Prod. Res.* **21**: 73 – 77.

Horn, G. H. (1878). Revision of the Bostrichids of the United States. *Proceedings of the American Philosophical Society*, **17**:540-555.

Howard, D. C. (1983). The population biology of the greater grain borer, *Prostephanus truncatus* (Horn), Ph.D Thesis. University of Reading.

Howe, R. W. (1965). A summary of estimates of optimal and minimal conditions for population increase of some stored products insects. *J. Stored Prod. Res.*, **1**: 177- 184.

IITA, (1977) Textural profile and amylase content of cassava. 1977 Annual Report of the International Institute of Tropical Agriculture, Nigeria.

ITA, (1999). Cassava Catches on. International Institute of Tropical Agriculture Annual Report, pp. 27.

IITA, (2000). Improving IPM approaches for LGB control in Africa. International Institute of Tropical Agriculture Annual Report, 4 pp.

Ingram, J. S. and Humphries, J. R. O. (1972). Cassava storage: a review. *Trop. Sci.*, **14**, 131-148.

Jakubczyk, T.E. (1982). Roots and tubers processing in some African countries, In: African Regional Center for Technology (ARCT). Roots and tubers production, storage, processing and marketing in Africa, Dakar. pp. 112- 126.

Jochenkuoth (1993). Traditional storage of yams and cassava and its improvement. GTZ Post- harvest project. Pickhuben 4, D-20457, Hamburg, Germany.

Killick, A. (1966). A study of Contemporary Ghana. The Economy of Ghana, In: Agriculture and Forestry. Allen and Unwin Publications, 1227 pp.

Kingslover, J.M. (1971). Key to the genera and species of Bostrichidae commonly intercepted in USDA quarantine inspections. U. S. Department. of Agriculture, Agricultural Quarantine Inspection, Memorandum No. 697 (unpublished). 11pp.

Kossou, D.K. and Bosque- Perez, N.A. (1995). Insect pest of maize in storage: biology and control. IITA Research Guide 32. Training Programme, International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, 18 pp.

Kozlova, L.T. and Nekrasov, B.P. (1957). Changes in wheat quality during prolonged storage. Trudy Tsentr. Nauch Issledovate. Lab. Glavnoe. Upravlenie Gosudarst. *Material*, 4: 60- 80.

Kumar, G.A. and Karnavar, G.K. (1986). Reproductive biology of the stored product pest, *Araecerus fasciculatus* (Degeer) (Coleoptera: Anthribidae). *Entomol.*, **11 (4)**: 309- 310.

Kumar, P. T., Moorthy, S.N., Balagopalan, C., Jayaprakas, C.A., Raja, K.C.M. and Ramakrishina, S.V. (1991). Compositional and pasting characteristics of plain-dried and parboiled cassava (*Manihot esculenta* crantz). *Food Chem.*: **38**: 79 – 88.

Lancaster, P.A., Ingram, J.S., Lim, M.Y. and Coursey, D.G. (1982). Traditional cassava-based food: Survey of processing techniques. *Eco.Bot.*, **36 (1)**: 12 -45.

Li, L. (1988). Behavioural ecology and life history evolution in the larger grain borer, *Prostephanus truncatus* (Horn). Ph.D Thesis. University of Reading, U.K. vii + 229 pp.

Lorraine, L.N. and Fahmah L.C.J. (2000). Tapioca root and tapioca flour: Consumption and potential. Department of Nutrition and Food Science, University of Maryland College Park. Maryland pp. 2074.

Lynam, J. K. (1991). The development potential of root crops in Africa. In: Entwicklung und Landilcher Raum, vol. 25, pp. 8-12.

Majumder, S. K. (1975). The importance of taxonomy and of laboratory studies on the biology, nutrition and physiology of insects infesting stored products. Proceedings of the first International Working Conference on Stored Products Protection, Savannah, Georgia, USA. pp. 18-29.

Mangoedihardjo, S. (1981). Studies on major pests of dried cassava and their control. Proceedings of BIOTROP symposium on pests of stored products, Bogor, Indonesia. pp. 115- 126.

Markharm, R. H. (1992). Biological control of the Larger Grain Borer in Biological Control Manual: Case studies of biological control in Africa. *UNDP/FAO*, *2*: 129-142.

Markharm, R. H., Wright V. F. and Rios Ibarra, R. M. (1991). A selective review of research on *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) with an annoted and updated bibliography. *CEIBA*, **32 (1):** 90 pp.

McFarlane, J. A. (1982). Cassava storage: storage of dried cassava products. *Trop. Sci.*, **24 (4)**: 205 – 233.

Microsoft Corp. (2000). Microsoft Excel 6.0. Microsoft Corporation, California, USA.

MOFA, (unpublished). Production of cassava crop in Ghana. Compilation of cassava production in different regions of Ghana from 1996-2000 by Ministry of Food and Agriculture, Ghana.

MOFA-GTZ, (1994). Survey on post-harvest system of yams and cassava. Post Harvest Project, Tamale, Ghana.

Moorthy, S. N. and Padmaja, G. (1991). Comparative study on digestibility of raw and cooked starch of different tuber crops. *Journal of Root Crops*, **17**: 255- 258.

Nicol, K. (1991). Post-harvest protection of root and tuber crops for small farm holders. In: Prospektion zur priifung neuer Arbeitsbereiche Fiir das GTZ-projekt Fiir Nachernterfragen in Benin, Ghana und Togo. *Bericht der lokalen Gutachter*, GFA (edi), **2**, 1-26. (Abstract only seen).

Nwana, I. E. and Azodeh, I. C. (1984). The effect of variety and processing method on the damage to dried yams by *Araecerus fasciculatus* (Degeer) (Coleoptera: Anthribidae). *Trop. Stored Prod. Inf.*, **49**: 3- 7

Nyakunga, Y. B. (1982). The biology of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) on cassava. University of Reading, M Sc. in Technology of Crop Protection.

Onwueme, I. C. (1978). The tropical tuber crops, yam, cassava, sweet potato and cocoyam. John Wiley and Sons. Chichester.

Osborne, D. R. and Voogt, P. (1978). The analysis of nutrients in foods. Food Science and Technology, a series of monographs. Academic Press, London, New York. 250 pp.

Oyenuga, V. A. (1955). The composition and nutritional value of certain feeding stuffs in Nigeria. *Emp. J. Exp. Agric.* **23**: 81-95.

Oyewole, O. B. (1992). Cassava processing in Africa. In: Application of biotechnology to traditional fermented foods. Report of an Ad- Hoc Panel of the Board on Science and Technology for International Development, National Research Council, USA. pp. 89- 92.

Oyewole, O. B. and Odunfa, S. A. (1989). Effect of fermentation on the carbohydrate, mineral and protein contents of cassava during *fu-fu* production. *J. Fd. Comp. and Analy.*, **2**: 170- 176.

Padmaja, G., Premkumar, T., Plumbs V., Bainbridge, Z. and Wood, J. F. (1994). Amino acid and sugar profiles of insect infested and uninfested plain dried versus parboiled cassava chips. *Tropical Science,* **34**: 409- 415.

Parker, B. L., Booth, R. H. and Haines, C. P. (1981). Arthropods infesting stored cassava (*Manihot esculenta* Crantz) in Peninsular Malaysia. *Prot. Ecol.*, **3**. 141 – 156.

Pillai, K. S. (1977). Susceptibility of cassava to *Aracerus fasciculatus*. In: Cock, J, MacIntyre, R. and Graham, M. Proceedings of the 4th Symposium of the International Center for Tropical Agriculture (CIAT), California, pp. 202- 203.

Pillai, K. S. and Rajamma, P. (1986). Storage pest of tuber crops. Annual Progress report. Central Tuber Crop Research Institute, Trivandrum, Kerala, India. Pp.89- 90.

Pingale, S. V., Rao, M. N. and Swaminathan, M. (1954). Effect of insect infestation on stored grain (ii) Studies on husk hand pounded, milled, raw rice and parboiled milled rice. *J. Sci. Fd. Agric.*, **8**: 512- 516.

Pixton, S. W. and Hill, S. T. (1967). Long-term storage of wheat. *J. Sci. Fd Agric.*, **18**: 94- 98.

PremKumar, T, Moorthy, S. N., Balagopalan, C., Jayaprakas, C. A. and Rajamma, P. (1996). Quality changes in market cassava chips infested by insects. *J. Stored Prod. Res.*, **32 (2)**: 183-186.

Raja, K. C. M and Ramakrishna, S. V (1990). Compositional and pasting characteristics of plain-dried and parboiled cassava (*Manihot esculenta* Crantz). *Fd. Chem.*, **38**: 79-88.

Rajamma, P. and Premkumar, T. (1993). Influence of varieties and method of processing on insect infestation in dry cassava chips. Paper presented at the International Symposium on Tropical Tuber Crops: Problems, prospects and future strategies, Trivandrum, India, ISRC, Central Tuber Crop Research Institute (CTCRI).

Rajamma, D., Padmaja, G and Lakshmi, K. R. (1994). Residual cyanide in processed cassava chips related to storage insects. Central Tuber crops Research Institute (CTCRI), Trivandrum, India, pp. 451-452.

Rajamma, P., Premkumar, T., Kurup, G. T, Palaniswami, M. S., Potty, V. P., Padmaja, G., Kabeerathumma, S. and Pillai, S. V. (1996). Influence of varieties and method of processing on insect infestation in dry cassava chips. Tropical Tuber Crops: Problems, Prospects and Future Strategies. Pp.321- 328.

Richter, J. and Biliwa, A. (1991). Landesweite Erhebung mittels pheromonefallen zur Verbreitung Von *Prostephanus truncatus* (Horn) (Col.: Bostrichidae) in Togo. *Anzeiger fur Schadlingskunde, Pflanzenschutz und Umweltschutz*, **64**: 89- 92. (Abstract only seen).

Rodney, F. B. (1992). Modern Experimental Biochemistry (2nd ed.). The Benjamin/ Cummings Publishing Company, Inc, Bridge Parkway, Redwood city, California. pp. 330.

Scholz, D., Tchabi, A., Borgemester, C, Markham, R. H., Poehling, H. M. and Lawson, A. (1997). Host- finding behaviour of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae): Primary attraction or random attack? *J. Appl. Entomol.*, **121 (5)**: 261- 269.

Shires, S. W. (1979). Influence of temperature and humidity on survival, development period and adult sex ratios in *Prostephanus truncatus* (Coleoptera: Bostrichidae). *J. Stored Prod. Res.*, **15**: 5- 10.

Shires, S. W. (1980). Life history of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) at optimium conditions of temperature and humidity. *J. Stored Prod. Res.*, **15**: 5- 10.

Shires, S. W. and McCarthy, S. (1976). A character for sexing line adults of *P. truncatus* (Horn) (Coleoptera: Bostrichidae). *J. Stored Prod. Res.*, **12:** 273-274.

Singh, D. N. and McCain, F. S. (1963). Relationship of some nutritional properties of the corn kernels to weevil infestation. *Crop Sci.*, **3**: 259- 261.

Sokolov, R. (1992). America's First Food Writer – Columbus described the preparation of the Cassava bread that is still baked in the Caribbean. *Nat. Hist.* **101 (10)** 68 – 71.

Spilman, T. J. (1984). Identification of larvae and pupae of the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) and the larger black flour beetle, *Cynaeus angushtus* (Coleoptera: Tenebrionidae). pp 44-53 In

Proceedings of the third International Working Conference on Stored-Product Protection. Kansas State University Manhattan, Kansas, USA. October 23-28. 1982. 72B x 7pp.

SPSS, (1999). SPSS for Windows Release 10.0. SPSS Incorporated, California, USA.

Stump, F. E. (1998). Post-harvest loss due to pests in dried cassava chips and comparative methods for its assessment. A case study on small-scale farm households in Ghana. Ph.D. Thesis, Humboldt University, Berlin. 172 pp.

Subramanyam, B. H., Cutkomp, L. K. and Darveaux, B. A. (1985) A new character for identifying larval instars of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). *J. stored Prod. Res.* **21**, 101-104.

Sumani, A. J. and Ngolwe, A. R. K. (1996). Zambia-the status of the larger grain borer. In: Management of farm storage pests in East and Central Africa. Proceedings of the East and Cental Africa Storage Pest Management Workshop, 14- 19, April, 1996. International Institute of Biological Control, pp. 77- 182.

Tayie, F. A. K. and Lartey, A. (2000). Nutrient contents of some typical Ghanaian foods. Nutrition and Food Science Department, University of Ghana, Legon.: In Human Nutrition in Tropical Africa by Latham, 8pp

Torreblanca, R. A., Adem, C. H. and Bourges, R. H. (1983). Perdidas Producidas por *Prostephanus truncatus* (Horn) en maize almacenado bajo condiciones controladas. In memorias dei coloquio International Sobre Conservation de Semilla y granos Almacenados, Oaxtepec, 20- 25 October, 1980. (Abstract only seen).

UNIDO, (1997). Food Processing Technologies for Africa. Hamid, A.D.(ed). United Nations Industrial Development Organization (UNIDO), Vienna. pp. 122- 143.

Van Soest, P. J. (1963). Use of detergents in the analysis of fibrous feeds. Rapid method for the determination of fiber and lignin, *J. Official Agric. Chem.*, **46 (5)**: 829.

Vitelli, M. A., Nigg, H. N. and Brook, R. F. (1976). Laboratory rearing of the coffee bean weevil. *Florida Entomologist*, **59 (3)**: 301- 303.

Vowotor, K. A. (1992). Effect of maize variety and storage form on oviposition and development of maize weevil, *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae). M.phil Thesis, University of Ghana, Legon. 157 pp.

Walston, J. P. (1991). Post- harvest and processing technologies of Africa staple foods: a technical compendium. *FAO Agric. Ser. Bull.*, **89**: 174- 207.

Wheatley, C. and Gomez, G. (1985). Evaluation of some quality characteristics of cassava storage roots. *Quality Plants Food for Human Nutrition*, **35**: 121-129

Widstrom, N. W., Redlinger, L. M. and Wiser, W. J. (1972) Appraisal of methods for measuring corn kernel resistance to *Sitophilus zeamais*. *Ann. Ent. Soc. Amer.*, **65 (3):** 790- 792.

Wright, M.; Akou-Edi, D. and Stabrawa, A. (1993) Infestation of dried cassava and maize by *Prostephanus truncatus*: entomological and socio-economic assessments for the development of loss reduction strategies. Larger Grain Borer Project, Togo. NRI – Report, R1941, Chatham, UK, 141 pp.

Wrigley, G. (1988) Coffee. AICTA. Longman, Singapore. 221 pp.

APPENDICES

Appendix I: Analysis of variance of preference test.

Appendix 1a: Preference of *A. fasciculatus* to chips.

Tests of Between-Subjects Effects

Dependent Variable: AFPREF

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.866[a]	7	.267	2.172	.094
Intercept	66.171	1	66.171	539.281	.000
VAR	5.199E-02	1	5.199E-02	.424	.524
STFORM	1.728	3	.576	4.694	.016
VAR * STFORM	8.591E-02	3	2.864E-02	.233	.872
Error	1.963	16	.123		
Total	70.000	24			
Corrected Total	3.829	23			

[a] R Squared = .487 (Adjusted R Squared = .263)

Appendix 1b: Preference of *P. truncatus* to chips.

Tests of Between-Subjects Effects

Dependent Variable: PREFS

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.942[a]	7[a]	.135	1.427	.262
Intercept	68.548	1	68.548	726.524	.000
VAR	3.513E-02	1	3.513E-02	.372	.550
STFORM	.744	3	.248	2.627	.086
VAR * STFORM	.164	3	5.456E-02	.578	.638
Error	1.510	16	9.435E-02		
Total	71.000	24			
Corrected Total	2.452	23			

[a] R Squared = .384 (Adjusted R Squared = .115)

Appendix 2: Analysis of variance of population density of *P. truncatus* adults at 49, 59 and 69 days of storage

Tests of Between-Subjects Effects
Dependent Variable: DENSTY49

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3.425[a]	7	.489	50.750	.000
Intercept	185.195	1	185.195	19207.229	.000
VAR	.501	1	.501	52.002	.000
STFORM	2.816	3	.939	97.347	.000
VAR * STFORM	.108	3	3.603E-02	3.737	.025
Error	.231	24	9.642E-03		
Total	188.852	32			
Corrected Total	3.657	31			

[a] R Squared = .937 (Adjusted R Squared = .918)

Tests of Between-Subjects Effects
Dependent Variable: DENSTY59

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.002[a]	7	.286	14.766	.000
Intercept	199.232	1	199.232	10286.936	.000
VAR	.706	1	.706	36.449	.000
STFORM	1.264	3	.421	21.763	.000
VAR * STFORM	3.151E-02	3	1.050E-02	.542	.658
Error	.465	24	1.937E-02		
Total	201.699	32			
Corrected Total	2.467	31			

[a] R Squared = .812 (Adjusted R Squared = .757)

Tests of Between-Subjects Effects
Dependent Variable: DENSTY69

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.229[a]	7	.318	33.292	.000
Intercept	217.618	1	217.618	22756.514	.000
VAR	.578	1	.578	60.400	000
STFORM	1.387	3	.462	48.332	000
VAR * STFORM	.264	3	8.814E-02	9.217	000
Error	.230	24	9.563E-03		
Total	220.076	32			
Corrected Total	2.458	31			

[a] R Squared = .907 (Adjusted R Squared = .879)

Appendix 3: Analysis of variance of dry weight loss due to *P. truncatus* adults at 49, 59 and 69 days of storage

Tests of Between-Subjects Effects
Dependent Variable: *P.truncatus* drwtlss49

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	26865.798[a]	7	3837.971	104.100	.000
Intercept	73524.564	1	73524.564	1994.250	.000
VAR	11788.572	1	11788.572	319.748	.000
STFORM	13247.735	3	4415.912	119.775	.000
VAR * STFORM	1829.491	3	609.830	16.541	.000
Error	884.839	24	36.868		
Total	101275.200	32			
Corrected Total	27750.637	31			

[a] R Squared = .968 (Adjusted R Squared = .959)

Tests of Between-Subjects Effects
Dependent Variable: *P.truncatus* drwtlss59

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	26498.141[a]	7	3785.449	81.240	.000
Intercept	89794.636	1	89794.636	1927.089	.000
VAR	13237.483	1	13237.483	284.091	.000
STFORM	12382.118	3	4127.373	88.578	.000
VAR * STFORM	878.540	3	292.847	6.285	.003
Error	1118.304	24	46.596		
Total	117411.080	32			
Corrected Total	27616.445	31			

[a] R Squared = .960 (Adjusted R Squared = .948)

Tests of Between-Subjects Effects
Dependent Variable: *P.truncatus* drwtlss69

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	25871.072[a]	7	3695.867	106.996	.000
Intercept	112890.380	1	112890.380	3268.191	.000
VAR	9717.437	1	9717.437	281.321	.000
STFORM	15852.749	3	5284.250	152.980	.000
VAR * STFORM	300.886	3	100.295	2.904	.056
Error	829.012	24	34.542		
Total	139590.465	32			
Corrected Total	26700.084	31			

[a] R Squared = .969 (Adjusted R Squared = .960)

Appendix 4: Analysis of variance of frass produced by *P. truncatus* adults at 49, 59 and 69 days of storage

Tests of Between-Subjects Effects
Dependent Variable: *P.truncatus* frass49

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	52869.085[a]	7	7552.726	44.954	.000
Intercept	150152.000	1	150152.000	893.710	.000
VAR	18403.211	1	18403.211	109.537	.000
STFORM	31118.107	3	10372.702	61.739	.000
VAR * STFORM	3347.766	3	1115.922	6.642	.002
Error	4032.235	24	168.010		
Total	207053.320	32			
Corrected Total	56901.320	31			

[a] R Squared = .929 (Adjusted R Squared = .908)

Tests of Between-Subjects Effects
Dependent Variable: *P.truncatus* frass59

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	78650.197[a]	7	11235.742	38.491	.000
Intercept	235265.416	1	235265.416	805.971	.000
VAR	36152.933	1	36152.933	123.853	.000
STFORM	37936.642	3	12645.547	43.321	.000
VAR * STFORM	4560.623	3	1520.208	5.208	.007
Error	7005.674	24	291.903		
Total	320921.287	32			
Corrected Total	85655.871	31			

[a] R Squared = .918 (Adjusted R Squared = .894)

Tests of Between-Subjects Effects
Dependent Variable: *P.truncatus* frass69

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	150731.974[a]	7	21533.139	24.664	.000
Intercept	486406.174	1	486406.174	557.133	.000
VAR	73416.330	1	73416.330	84.092	.000
STFORM	72582.621	3	24194.207	27.712	.000
VAR * STFORM	4733.023	3	1577.674	1.807	.173
Error	20953.242	24	873.052		
Total	658091.390	32			
Corrected Total	171685.216	31			

[a] R Squared = .878 (Adjusted R Squared = .842)

Appendix 5: Analysis of variance of population density of *A. fasciculatus* adults at 59, 69 and 79 days of storage

Tests of Between-Subjects Effects
Dependent Variable: DENSTLG59

Source	Type III Sum of Squares	df	Mean Square	F	Sig
Corrected Model	.395[a]	7	5.643E-02	78.646	.000
Intercept	86.540	1	86.540	120613.367	.000
VAR	1.167E-02	1	1.167E-02	16.264	.000
STFORM	.316	3	.105	146.998	.000
VAR * STFORM	6.692E-02	3	2.231E-02	31.088	.000
Error	1.722E-02	24	7.175E-04		
Total	86.952	32			
Corrected Total	.412	31			

[a] R Squared = .958 (Adjusted R Squared = .946)

Tests of Between-Subjects Effects
Dependent Variable: DENSTLG69

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.373[a]	7	.196	132.990	.000
Intercept	100.910	1	100.910	68428.758	.000
VAR	.238	1	.238	161.055	.000
STFORM	.952	3	.317	215.203	.000
VAR * STFORM	.183	3	6.108E-02	41.421	.000
Error	3.539E-02	24	1.475E-03		
Total	102.318	32			
Corrected Total	1.408	31			

[a] R Squared = .975 (Adjusted R Squared = .968)

Tests of Between-Subjects Effects
Dependent Variable: DENSTLG79

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.361[a]	7	.194	185.630	.000
Intercept	114.051	1	114.051	108862.056	.000
VAR	3.658E-03	1	3.658E-03	3.492	.074
STFORM	1.164	3	.388	370.305	.000
VAR * STFORM	.194	3	6.461E-02	61.668	.000
Error	2.514E-02	24	1.048E-03		
Total	115.437	32			
Corrected Total	1.386	31			

[a] R Squared = .982 (Adjusted R Squared = .977)

Appendix 6 Analysis of variance of dry weight loss due to *A. fasciculatus* adults at 59, 69 and 79 days of storage

Tests of Between-Subjects Effects
Dependent Variable: *A. fasciculatus* WEIGHT LOSS%59

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	964.624[a]	7	137.803	42.983	.000
Intercept	2264.693	1	2264.693	706.401	.000
VAR	.658	1	.658	.205	.655
STFORM	898.138	3	299.379	93.382	.000
VAR * STFORM	65.827	3	21.942	6.844	.002
Error	76.943	24	3.206		
Total	3306.260	32			
Corrected Total	1041.567	31			

[a] R Squared = .926 (Adjusted R Squared = .905)

Tests of Between-Subjects Effects
Dependent Variable: *A. fasciculatus* WTLSS%69

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2735.190[a]	7	390.741	93.732	.000
Intercept	5228.820	1	5228.820	1254.296	.000
VAR	430.128	1	430.128	103.180	.000
STFORM	1640.657	3	546.886	131.188	.000
VAR * STFORM	664.405	3	221.468	53.126	.000
Error	100.050	24	4.169		
Total	8064.060	32			
Corrected Total	2835.240	31			

[a] R Squared = .965 (Adjusted R Squared = .954)

Tests of Between-Subjects Effects
Dependent Variable: *A. fasciculatus* WTLSS%79

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1975.056[a]	7	282.151	63.093	.000
Intercept	4424.119	1	4424.119	989.302	.000
VAR	.408	1	.408	.091	.765
STFORM	1548.755	3	516.252	115.442	.000
VAR * STFORM	425.893	3	141.964	31.745	.000
Error	107.327	24	4.472		
Total	6506.502	32			
Corrected Total	2082.383	31			

[a] R Squared = .948 (Adjusted R Squared = .933)

Appendix 7 **Analysis of variance of frass produced by *A. fasciculaltus* adults at 59, 69 and 79 days of storage**

Tests of Between-Subjects Effects
Dependent Variable: *A. fasciculaltus* frass59

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	404.379[a]	7	57.768	93.739	.000
Intercept	693.874	1	693.874	1125.930	.000
VAR	29.857	1	29.857	48.448	.000
STFORM	287.229	3	95.743	155.360	.000
VAR * STFORM	87.293	3	29.098	47.216	.000
Error	14.790	24	.616		
Total	1113.044	32			
Corrected Total	419.170	31			

[a] R Squared = .965 (Adjusted R Squared = .954)

Tests of Between-Subjects Effects
Dependent Variable: *A. fasciculaltus* frass69

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2432.341[a]	7	347.477	66.933	.000
Intercept	2843.900	1	2843.900	547.806	.000
VAR	514.643	1	514.643	99.133	.000
STFORM	1286.027	3	428.676	82.574	.000
VAR * STFORM	631.670	3	210.557	40.558	.000
Error	124.595	24	5.191		
Total	5400.835	32			
Corrected Total	2556.935	31			

[a] R Squared = .951 (Adjusted R Squared = .937)

Tests of Between-Subjects Effects
Dependent Variable: *A. fasciculaltus* frass79

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3757.925[a]	7	536.846	283.529	.000
Intercept	5404.569	1	5404.569	2854.361	.000
VAR	159.704	1	159.704	84.346	.000
STFORM	1884.101	3	628.034	331.689	.000
VAR * STFORM	1714.120	3	571.373	301.764	.000
Error	45.443	24	1.893		
Total	9207.936	32			
Corrected Total	3803.367	31			

[a] R Squared = .988 (Adjusted R Squared = .985)

Appendix 8 Nutritional content of Control, Uninfested and Infested treatments of two cassava varieties processed into four forms

Storage form	R-sugar	Non R-sug	Starch	Fats	Protein	Ash	Crude fiber	%MC
Control:*A. fasciculatus*								
Afisiafi								
Plain	2.81	4.75	81.32	0.50	1.51	2.51	1.61	12.35
Parboiled	6.86	0.52	76.43	0.58	1.27	2.67	1.40	12.40
Sundried	2.29	3.47	81.99	0.55	1.60	2.89	1.79	13.10
Fermented	4.35	3.03	78.12	0.38	1.63	2.15	1.66	12.85
Yebesi								
Plain	2.78	2.81	83.90	0.70	1.28	2.31	1.55	10.15
Parboiled	6.86	0.52	79.13	0.63	1.33	2.07	1.58	9.75
Sundried	2.19	3.21	81.84	0.53	1.41	2.45	1.70	9.60
Fermented	4.31	2.35	78.47	0.43	1.05	2.14	1.87	9.35
Control:*P. truncatus*								
Afisiafi								
Plain	2.78	4.25	82.98	0.53	1.55	2.60	1.59	12.35
Parboiled	6.83	1.28	76.84	0.60	1.27	2.60	1.38	12.40
Sundried	2.29	3.47	81.99	0.55	1.59	2.81	1.73	13.10
Fermented	4.35	3.03	78.68	0.45	1.66	2.16	1.66	12.85
Yebesi								
Plain	2.78	2.99	86.49	0.70	1.25	2.27	1.52	11.25
Parboiled	6.60	0.96	80.19	0.63	1.31	2.02	1.55	11.30
Sundried	2.18	3.05	84.22	0.63	1.30	2.53	1.71	11.05
Fermented	3.83	2.48	82.58	0.43	1.07	1.92	1.87	10.08
Uninfested treatment								
Afisiafi								
Plain	3.41	3.97	82.62	0.50	1.49	2.57	1.61	9.30
Parboiled	7.13	0.98	76.28	0.60	1.23	2.62	1.41	8.00
Sundried	2.36	3.40	83.12	0.60	1.64	2.82	1.78	8.60
Fermented	4.69	2.87	76.82	0.43	1.52	2.18	1.68	8.75
Yebesi								
Plain	2.78	3.17	84.66	0.75	1.27	2.30	1.54	8.95
Parboiled	7.13	0.44	79.82	0.83	1.25	2.04	1.56	8.65
Sundried	2.14	3.44	84.53	0.75	1.36	2.46	1.69	9.20
Fermented	3.83	2.48	78.75	0.45	1.08	1.74	1.86	9.25

Infested: *A. fasciculatus*								
Afisiafi	**R-sugar**	**Non R-sug**	**Starch**	**Fats**	**Protein**	**Ash**	**Crude fiber**	**%MC**
Plain	1.31	3.64	80.55	0.53	1.62	2.60	1.51	10.64
Parboiled	10.13	2.66	74.41	0.58	1.40	2.52	1.32	10.05
Sundried	1.31	3.10	81.65	0.60	1.94	2.86	1.00	10.55
Fermented	3.90	3.30	75.76	0.40	1.98	2.40	1.15	10.62
Yebesi								
Plain	1.39	3.02	79.00	0.68	1.27	2.59	1.27	10.20
Parboiled	8.14	1.94	76.28	0.58	1.31	2.04	1.16	10.95
Sundried	2.03	2.66	77.09	0.55	1.53	2.25	1.29	10.90
Fermented	3.41	1.45	72.73	0.43	2.23	2.17	1.62	9.30
Infested: *P. truncatus*								
Afisiafi								
Plain	2.70	3.24	79.97	0.50	1.73	2.96	1.36	12.40
Parboiled	9.38	2.51	74.12	0.55	1.86	2.79	1.34	11.75
Sundried	1.91	4.03	81.95	0.53	2.55	2.86	1.31	12.50
Fermented	4.13	3.26	72.11	0.43	2.22	2.53	1.11	13.25
Yebesi								
Plain	1.95	2.46	78.58	0.50	1.72	2.69	1.02	11.50
Parboiled	8.06	2.20	71.93	0.53	1.51	2.60	1.06	13.20
Sundried	1.65	3.03	75.42	0.50	2.86	2.67	1.01	12.35
Fermented	2.63	2.06	69.12	0.40	1.51	2.17	1.21	12.55

* Mean of four replicates
*Uninfested sample: Sample analysed before storage
*Control sample: Sample without insect during the storage period
*Infested sample: Sample attack by the insects during storage period