

**STUDIES ON DAMAGE BY *PROSTEPHANUS TRUNCATUS* (HORN)
(COLEOPTERA: BOSTRICHIDAE) AND *ARAECERUS FASCICULATUS* (DEGEER)
(COLEOPTERA: ANTHRIBIDAE) TO DRIED YAM CHIPS**

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ABSTRACT

In West Africa, especially Nigeria, Benin Republic, Togo and Ghana, dried yam chips constitute an important food material. The recent introduction of the larger grain borer into Africa and its devastating effect on cassava chips necessitated a study of the biology and damage caused by *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidea) and *Araecerus fasciculatus* (Degeer) (Coleoptera: Anthribidea) on dried yam chips in Ghana. Three yam varieties were investigated in the studies; these were: “Asaana” and “Pona” (*Dioscorea rotundata* Poir) and “Afasie” (*Dioscorea alata* L.). The dried yam chips were obtained following different treatments as follows: Parboiled oven-dried, Non-parboiled oven-dried, Parboiled sun-dried and Non-parboiled sun-dried. Two hundred grammes of each treatment of dried yam chips were placed in a glass jar and ten insects of *P. truncatus* and *A. fasciculatus* were placed in each separately as single cultures. Mixed cultures with a starting population of twenty insects: ten insects from each species of *P. truncatus* and *A. fasciculatus* and a control were also set up. The studies were carried out for three durations: one month, two months and three months at $30 \pm 3^{\circ}\text{c}$ and 70 – 92% R.H. The proximate compositions of dried yam chips were also investigated before and after infestation by *P. truncatus* and *A. fasciculatus*.

P. truncatus survived and established on all the treatments processed from the three varieties of yams. However, *A. fasciculatus* did not survive on oven-dried yam chips, but survived and established on sun-dried yam chips. Ten adults of *P. truncatus* (age 0-7days) produced 578 progeny and ten adults of *A. fasciculatus* (age 0-14 days) produced 328 progeny after three months of storage. The mixed culture with a starting population of twenty insects

produced 501 progeny (322 of *P. truncatus* and 179 of *A. fasciculatus*) after three months of storage. Based on varietal differences, “Afasie” dried yam chips supported the highest progeny of *P. truncatus* and *A. fasciculatus* which was significantly more than that supported by “Asaana” and “Pona”. There was no significant difference between the number of progeny supported by “Asaana” and “Pona”. Therefore, “Afasie” dried yam chips were the most susceptible to infestation by *P. truncatus* and *A. fasciculatus*.

P. truncatus survived and established more significantly on dried yam chips processed from the three varieties than *A. fasciculatus*. Consequently, the percentage damage and weight loss produced by *P. truncatus* was high. The highest percentage weight loss produced by *P. truncatus* was 94.91% while *A. fasciculatus* produced 91.51% after three months of storage. Parboiled sun-dried yam chips and non-parboiled sun-dried yam chips in all the varieties used recorded the highest weight loss by *P. truncatus* and *A. fasciculatus*. *P. truncatus* produced significant weight loss on parboiled oven-dried yam chips and non-parboiled oven-dried yam chips for all the varieties of yam used for the studies, while *A. fasciculatus* did not, as it was unable to survive and breed on these chips. Based on varietal differences, *P. truncatus* and *A. fasciculatus* produced the highest weight loss on Afasie dried yam chips which was significantly more than those produced on “Asaana” and “Pona”. There was no significant difference in weight loss produced between “Asaana” and “Pona”.

The proximate composition of the varieties of yam used for the studies showed slight differences after infestation by *P. truncatus* and *A. fasciculatus*. moisture increased significantly, while fat, ash, protein and fibre show no significant difference after


infestation. carbohydrate, decreased significantly. Reducing and non-reducing sugars decreases drastically after infestation. Decreases in proximate compositions may be due to degradation and use by the insects for their biological activities.

Based on these studies, *P. truncatus* was found to multiply rapidly and was more destructive than *A. fasciculatus*. Parboiled oven-dried yam chips and non-parboiled oven-dried yam chips were less damaged by *P. truncatus* but were not damaged by *A. fasciculatus*. *P. truncatus* and *A. fasciculatus* significantly damaged the parboiled sun-dried yam chips and non-parboiled sun-dried yam chips. Also the presence of insects on dried yam chips leads to increases or decreases in some proximate compositions. It can be concluded therefore that, “Asaana” and “Pona” are significantly better than “Afasie” for the production of yam chips that can be stored for longer periods.



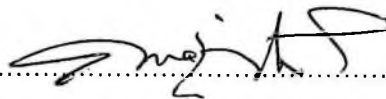
DECLARATION

I do hereby declare that the research work described in this dissertation was carried out by me and that except for the references to other peoples works that have been duly acknowledged, this thesis either in whole or in part has not been presented for any other degree elsewhere.



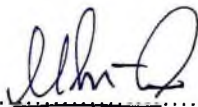
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DEDICATION

TO MY FAMILY

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CHAPTER ONE

1.0 INTRODUCTION

Yams are tropical crop plants that produce edible tubers. They are rich in carbohydrates but have low protein content. The major species of yams are indigenous to Africa, particularly West Africa. Yams have been the major source of carbohydrates before the introduction of exotic crops such as maize, white rice, cassava, and potato (Asuming-Brempong, 1991).

In 1995, yam production in Africa was estimated at almost 33 million tonnes per year, of which more than 31 million was produced in West Africa alone, and a large share being produced by Nigeria (23 million tonnes), Ghana (2.2 million tonnes) and Togo (375,000 tonnes). Between 1989/1991 and 1995, production in the continent increased steadily by 50% (FAO, 1996). Based on this statistics, Ghana is one of the major yam producing countries in the world. By the year 2000, yam production in Ghana had increased to 3,362,909 tonnes (SRID, 2001). Yam, a staple tuber in most parts of Ghana, is increasingly becoming an important non-traditional export crop. Among the horticultural crops exported, yam export comes only after pineapples in importance, both in volume exported and in product value (GEPC, 1989). Asuming-Brempong (1991) stated that Ghana yam has a growing demand in Europe and USA, both of which have a large population of immigrants from the humid and sub-humid tropics.

Six major species of yam are cultivated in Ghana and these are commonly grown in the light sandy soils of the interior Savannah and in the forest zone. These species include *Dioscorea rotundata* Poir (White yam) of which some 25 varieties are cultivated. *D.*

rotundata is also the principal commercial species in Ghana of which some 80% are produced for the market (Acquah *et al.*, 1991). Another important species is *D. esculenta* (Lour.) Burk (Chinese yam). These two species are common in the interior Savannah zone. In the forest zone four other species are most common: *D. cayenensis* Lam (yellow yam), *D. alata* L. (water yam), *D. bulbifera* L. (aerial yam) and *D. dumetorum* Pax (three-leaf yam) (Wallis 1962; Torto 1967).

The main centres of commercial yam production in Ghana are the districts of Mampong (Ashanti Region); Wenchi, Kintampo and Atebubu (Brong Ahafo Region); Yendi, Bimbilla, Tamale and Bole (Northern Region); Wa and Tumu (Upper West Region); Bolgatanga, Bawku and Navrongo (Upper East Region); Kete Krachi and Nkwanta (Volta Region). There are other areas where yam production is only semi commercial. These include Kpandu, Asesewa, Bawjiase and Mankesim areas on the fringes of the main forest belt; and Wiawso and Asankragwa in the forest zone (Nyanteng, 1978). Most harvested yam tubers (80%) are sometimes stored by the farmers for 2 to 4 months. The length of storage depends mostly on the variety. On the average, farmers store about 5200 tubers valued at USD 1,500 per year (FAO, 1998).

In Ghana, both rural and urban dwellers are fond of yam tubers, which they use in the preparation of many dishes because of the nutritional and dietary qualities. Yam is generally eaten fresh as pounded paste (*fufu*) or boiled, braised in the form of fresh tubers in Ghana. This situation presents a lot of disadvantages, which reduce the income of farmers. However, over the years it has been found that yams can be processed by a traditional sun drying method which enables farmers specifically in the Northern region

to recover damaged or rejected tubers (Personal communication by Mallam Mohammed Zakari, Tamale). Dried yam chips are crushed and ground into flour to make elastic dough called “kokonte” in Ghana (Coursey, 1967). In Nigeria and Benin Republic, where yam chips are common and are a major staple food, this elastic dough is called “amala” The flour can also be turned into granules (wassa-wassa) or mixed into biscuit as baby food (CIRAD – 11TA 1998).

Yam chips have numerous advantages over fresh tubers. Yam chips are stabilised products with low moisture content of about 12% - 14%. However, fresh tubers have moisture contents of about 65% - 70%. Dried yam chips can be kept for up to a year when stored under insect-proof conditions (CIRAD – 11TA, 1998). Dried yam chips are also cheaper to transport and less damaged by handling. Urban markets can be supplied with yam throughout the year. Market prices of chips are relatively steady and are well below those of fresh yams (for an equivalent dry matter content). During the time of yam tuber scarcity, dried yam chips are competitive with respect to other starchy products.

Yam production in Ghana faces a lot of pest problems. Pests attack the yam from the farm through to storage. These pests include rodents, bacteria, fungi and insects. Another physiological phenomenon is sprouting of yam tubers during storage, which is an index of loss. These factors cause considerable damage to yam leading to reduction in quantity, quality and farmers income.

The yam chips sector, though with numerous merits over fresh tubers, is also faced with some constraints, of which infestation by insect pests is the major one. Insect pests pose a

great menace to stored yam chips. During storage the chips are often infested by boring insects, which cause considerable damage in a few months (Adisa, 1985). The most common among these are *Sitophilus zeamais*, Motschulsky (Col: Curculionidae), *Dinoderus oblonguntatus* Lesne, *D. minutus* Fabricius (Col: Bostrichidae) and *Palorus subdepressus* Wollaston (Col: Tenebrionidae) (Goergen, G. quoted by Dumont *et al.*, 1997). Coursey (1967), also stated that *Araecerus fasciculatus* Degeer (Col.: Anthribidae) has been recorded in yam chips as a major pest causing considerable damage, while *Prostephanus truncatus* Horn (Col.: Bostrichidae) has been considered as a major pest of cereals and chips of root and tuber crops in Ghana (Stumpf, 1998).

1.2 JUSTIFICATION

In the early 1970s there was a developing awareness that total food availability could be improved through reduction of post harvest losses and attention was focused on this neglected area. A 50% reduction in post harvest food losses by 1985 was called for by the United Nation General Assembly in 1975 (Schulten, 1982). The greatest emphasis was placed on cereals, and it is only recently that root and tuber crops have been given more attention.

The major causes of losses to yam chips are insect pests. They attack the produce from the field during drying to the store. *P. truncatus* has been found to attack all forms of farm produce, but *A. fasciculatus* has been recorded as a serious pest of yam chips (Detmers, 1991; Coursey, 1967). The losses caused by these insects on yam chips have not been thoroughly examined as compared to other roots and tubers.

This study was carried out to draw the attention of administrators and other persons responsible for post-harvest matters to the fact that some losses are occurring, and there is need for more detailed studies.

1.3 OBJECTIVES

This research work was formulated with the following objectives:

- (a) To assess the weight loss due to *P. truncatus* and *A. fasciculatus* infestation singly, and in combination with each other, on yam chips.
- (b) To determine nutritional loss in yam chips due to *P. truncatus* and *A. fasciculatus* infestation.
- (c) To compare losses caused by *P. truncatus* and *A. fasciculatus* to yam chips.
- (d) To determine the potential of yam chips as a rearing medium for *P. truncatus* and *A. fasciculatus*.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Taxonomy of Yam

The genus *Dioscorea* was named by Linnaeus (1753) and, as created by him included two of the more important food yams (*D. alata* and *D. bulbifera*) and many other species of lesser importance. It includes some 600 species, of which 50 – 60 are cultivated or gathered for food or pharmaceutical purposes. However, there are only 12 species of economic significance as food plants (Coursey, 1976). Of these, *D. rotundata*, grown in Africa and *D. alata*, grown largely in Asia, are by far the most important, together making up to about 90% of world production of food yam (Alexander and Coursey, 1976). The genus is named in honour of the Greek physician Pendenios Dioscorides, a medical officer in the Roman army at the time of Nero, and the author of *De material medica libriquinque*, the best and most comprehensive of the herbals of classical times (Coursey, 1967).

The following taxonomic diagnosis, which is based on that of Coursey (1967), conveys the essential features of the nature of yam. It has rhizomes, which produce annual shoots, which are twining except in dwarf species, the direction of twining being specific. It is commonly enlarged as a storage organ, or modified into a cormous structure from which one or more annual tuberous storage organs develop. Stems consist of a main stem and branches. Leaves are petiolate, usually cordate, simple, palmately lobed or compound; usually tripli-nerved. Flowers are either hermaphrodite or dioecious, generally small, greenish and inconspicuous, but often strongly scented.

2.2.0 Chemical composition and nutritive value of yams

The tuber constitutes the edible portion of the yam. In most of the economically important species the main underground tuber is the organ, which is utilised, but in a few cases, notably *D. bulbifera*, the aerial tubers or bulbils, which are formed in the leaf axils, are the part used for food (Coursey, 1967). The chemical composition of the tuber varies with species and cultivars; even within the same cultivars, it may vary depending on the environmental conditions under which the tuber was produced. Climatic, cultural and edaphic factors of the environment under which they are cultivated, maturity at harvest and even storage method cause variation within the same cultivar (Bradbury *et al.*, 1988; Degras, 1993).

A considerable number of analyses for proximate composition of yams have been carried out in different parts of the world. The value of some of this work is limited by the fact that the results have been published with the material identified only by local names, or by invalid botanical names (Coursey, 1967). Abgo-Egbe and Treche (1995), analysed 98 cultivars of 8 yam species for minerals, lipids, sugar and cell wall constituents. They reported that for most of the nutrients, intra-specific variability was as high as inter-specific variability. Significant differences also existed between *Dioscorea alata*, *D. dumetorum*, *D. rotundata* and *D. cayenensis*. Afoakwa, (1999), also analysed two cultivars belonging to *D. dometorum* for moisture, ash, crude protein, crude fibre, fat, total carbohydrate, minerals (Calcium, Phosphorus and Iron) and vitamins (A & C). Taiye and Lartey (1999) analysed yam for nutrients, minerals, vitamins and moisture. They provided a general result for fresh yam and yam flour in their studies. A summary of the chemical compositions of yam species is given in Table 2.1.

Table 2.1: Chemical composition of some yam species (Fresh tuber)

Nutrient	<i>D.</i>	<i>D.</i>	<i>D.</i>	<i>D.</i>	Source
	<i>rotundata</i>	<i>alata</i>	<i>cayenensis</i>	<i>dumetorum</i>	
Moisture (%)*	58-80	65-73	60-85	67-79	1,2,5,6,7
Protein (%)*	1.1-2.0	1.1-2.8	1.1-1.5	2.8	1,2,5,6,7
Fat (%)*	0.05-0.1	0.03-0.3	0.06-0.2	0.3	1,2,5,6,7
Ash (%)*	0.7-2.6	0.7-2.6	0.41-0.53	0.7	1,2,6,7
Carbohydrate (%)*	15-23	22-29	16	17	1,2,7
Minerals (mg/100g)**					
Phosphorus	200	116	161-185	221-253	2,3,6,7
Calcium	29 – 30	24.1	60-75	41.8	2,3,5,6,7
Magnesium	27.2	33.2	67.73	57.1	2,3,5,6
Iron	12 – 15	5.5-11.6	10-11	26-62	2,3,5,6,7
Vitamins (ug/100g)					
Carotene or vit. A	20	80	-	20	2,3
Thiamine	120	150	-	140	2,3
Riboflavin	30	40	-	50	2,3
Niacin	400	500	-	800	2,3
Ascorbic acid	8,000	6,000		21,00	2,3

Source: Coursey (1967)¹ Oyenuga (1968)² Eka (1985)³ Osagie (1992)⁴ Muzac-Tucker *et al.* (1993)⁵ Agbor-Egbe & Treche (1995)⁶ Sackey (1998)⁷ Afoakwa (1999)⁸ *Wet weight basis **Dry weight basis.

2.2.1 Moisture content

The largest component of the fresh tuber is water, which accounts for about two-thirds of the fresh weight, varying between 60 – 85% (Coursey, 1967; Eka, 1985; Agbor-Egbe *et al*, 1995; Sackey, 1998; Afoakwa, 1999; and Taiye *et al*, 1999), and dry matter ranges from 20 – 40%. On the basis of dry matter content, yam species can be divided into 3 groups. These are:

- (i) Low dry matter (23 – 25%): *D. alata*, *D. dumetorum*, and *D. schimperiana*.
- (ii) Intermediate (28 – 30%): *D. esculenta* and *D. bulbifera*.
- (iii) High (32 – 37%): *D. cayenensis*, *D. rotundata* and *D. liebrechtsiana* (Agbor-Egbe *et al*, 1995; Afoakwa 1999).

2.2.2 Carbohydrate content

The major dry matter component of yams is carbohydrate. It accounts for approximately one quarter of the tuber's fresh weight. Most of this carbohydrate is starch, mainly amylopectin, and this exists in the cells in the form of starch grains. The size of each individual starch grain depends on the species, but the smaller the grains, the better the quality of the starch. Average starch content varies from 15 – 30% (wet weight) and 70 – 80% (dry weight) basis. Most of the yam varieties, however, have starch content between 20% and 25% (wet weight) (Coursey, 1967; Eka, 1985; Agbor-Egbe *et al*, 1995, Afoakwa, 1999; Taiye *et al*, 1999).

Agbor-Egbe *et al*, (1995) extracted the starch from eight yam species grown in Cameroun. They reported yield on dry matter basis ranging from 70.4% for *D. esculenta* to 80% for *D. liebrechtsiana*. It has been suggested that a wide variation of moisture

contents partially account for the variability in the species. As a commercial source of starch, *D. dumetorum* and *D. esculenta* would be the most ideal because of their smaller starch grain. Yam starches have not gained much economic importance because of cassava, which is a cheaper source of starch (Osisiogu and Ozo, 1973).

2.2.3 Sugar content

Sugars are only present in minute quantities in yam tubers. For most species, this accounts for less than 1% of the fresh weight (Coursey, 1967; Passam, 1978), but in *D. esculenta*, which is sweet, the percentage of sugar may be as high as 2 – 4% on a fresh weight basis (Coursey, 1967; Agbor-Egbe, 1995). They are intermediates in the formation and breakdown of sucrose, but small traces of glucose and fructose may also occur. Freshly harvested yams have lower free sugar levels than stored yam. During storage, starch metabolism leads to an increase in the amount of free sugar accompanied by a decrease in starch content. Agbor-Egbe *et al.*, (1995) reported an increase in free sugars of *D. rotundata* and *D. dumetorum* after 120 days of storage under ambient conditions (28 – 31%). Total carbohydrate decreased rapidly when sprouting started. The increase in sugar levels for stored yam gives a more desirable eating quality. Afoakwa (1999) working on *D. dumetorum*, stated that cultivar, sample treatment, storage condition and storage time significantly affected the total alcohol – soluble sugar levels in tubers during storage.

2.2.4 Protein content

The protein content of yams is rather low, ranging from 1.5 – 3.5% of the fresh weight and 3 – 11% on dry weight basis (Ologhobo, 1985; Ekpenyong, 1984). Protein content varies considerably between both species and cultivars within a particular species.

Because inter-cultivar variation is so wide, consistent variations between the species have not been reported. *D. opposita* has been reported to have very low protein levels which vary from 1% to 3% (dry weight). Species which have been reported to have high protein contents are *D. dumetorum*, *D. rotundata* and *D. alata* (Agbor-Egbe *et al.*, 1995; Muzac-Tucker *et al.*, 1993), ranging between 8% and 11% (dry matter basis). Spittstosser (1976) evaluated the free amino-acids in the total nitrogenous matter in *D. alata*, *D. esculenta*, *D. rotundata* and *D. trifida* and this was found to amount to an average of 1% of the dry matter content. However, the intra-specific variation seems to be as high (0.7 to 2.0 with *D. esculenta*, for example) as the inter-specific variation. Like most root crops, the limiting essential amino acids of yam proteins are methionine, cysteine which are sulphur containing amino acids and tryptophan (Ekpenyong, 1984; Treche *et al.*, 1996). An examination of yam proteins before and after storage showed that there was no significant change in the amino acid composition. Treche *et al.* (1996) found that the proteins of *D. dumetorum*, which are more balanced than those of *D. rotundata*, closely resemble the Food and Agriculture Organization (FAO) (1994) temporary typical combinations.

2.2.5 Crude fat content

Yam tuber is generally low in crude fat which ranges between 0.04 to 2.0% in terms of dry matter and between 0.05 and 0.3 in terms of wet weight (Coursey, 1967; Eka, 1985; Agbor-Egbe *et al.*, 1995; Sackey 1998; Afoakwa, 1999). Muzac-tucker, *et al.* (1993) reported a very low fat content in the cultivars of *D. rotundata* and *D. alata*. *D. rotundata* had the highest fat content of 0.27% and one cultivar of *D. alata* had 0.07%. Kouassi *et al.* (1988) reported on the fatty acid composition of the major edible species of yams.

The fatty acids reported were mainly linoleic and palmitic acids with small amounts of stearic, oleic and linolenic acids. On storage, total fatty acid content was found to increase slightly, though there was no significant change in the composition of fatty acids in yams stored for several months at ambient conditions. Afoakwa (1999) reported that, the mean fat contents in the two cultivars of *D. dumetorum* studied were similar. He stated further that, these were very low and comparable to values often found in other root and tuber crops; potato (0.4g / 100g; Bradbury and Halloway, 1988), edible aroids (0.2g/100g; Agbor-Egbe and Rickard, 1990) and cassava (0.3g / 100g; Rickard and Coursey, 1981).

2.2.6 Ash, minerals and vitamin content

Coursey (1967) reported that ash content of yams is an indication of how rich they are in minerals, and even though the amount varies from species to species and from cultivar to cultivar, it is always considerable. Total ash ranges from 500 – 1800 mg/100g wet weight (Eka, 1985). The variation in the values of the same species may be partially attributed to the methods of estimation and partially to factors such as cultural practices, time of planting and harvesting and the mineral content of the soil in which they were grown (Eka, 1985).

Watson (1971) reported the following composition: ash (1,700mg/100g), calcium (12mg/100g), phosphorus (70mg/100g) and iron (0.5mg/100g) for *D. alata*, and for *D. rotundata*: ash (1,200mg/100g), calcium (6mg/100g), phosphorus (61mg/100g) and iron (1.5mg/100g). The most abundant minerals reported by Agbor-Egbe *et al.* (1995) are phosphorus, potassium, calcium and magnesium. *D. dumetorum* had the highest mineral

content with potassium (41.8mg/100g), phosphorus (16/mg/100g), calcium (41.8mg/100g) and magnesium (57.1mg/100g) on dry weight basis. Afoakwa (1999) also reported the same figures for calcium and phosphorus of *D. dometorum*. These values were similar to those reported for Nigerian yams (Ologhobo, 1985). It was therefore suggested that if eaten in sufficient quantities it could supply an appreciable amount of the body's daily requirement for minerals. Boiling or conversions into flour for storage do not have any significant effect on the mineral content of edible yams (Bell and Favier, 1981).

Vitamins are one of the minor and most important constituents of the yam tuber (Coursey, 1967). Vitamins present in yam include carotene (pro-vitamin A), thiamine, riboflavin, niacin (nicotinic acid) and ascorbic acid (Oyenuga, 1968; Eka, 1978). Most yam tubers tend to be deficient in fat-soluble vitamins due to their very low lipid content. Ascorbic acid is the most abundant water-soluble vitamin found in yam (Degras, 1993). Values ranging from 200 – 1500mg/100g fresh weight have been reported for various species and the total ascorbic acid content is about 50% greater than that of cassava (Bradbury and Singh, 1986). The heat sensitivity of ascorbic acid causes a reduction of about 70% in its level when peeled yam is boiled. Drum drying also caused substantial losses though the residual ascorbic acid in drum dried yam flakes remains stable during subsequent storage (Onayemi and Potter, 1974). The reduction is less when yam is baked or boiled un-peeled. Boiled yam is therefore not likely to supply adequate quantities of ascorbic acid to the diet. Most varieties of yams have a fair amount of thiamine (50-150mg/100g), riboflavin (20-101mg/100g) and niacin (300 – 2200mg/100g) on fresh weight basis (Eka, 1978, 1985).

2.2.7 Toxic and anti-nutritional components of yam tubers

Yam tuber contains toxic components, which are known to have toxic effects on man and animals. However the levels of these components present in edible yams are usually not high enough to present health hazards (Eka, 1978). Martin (1980) reported the presence of toxic and anti-nutritional substances in the main edible species of yam. Eka, (1985) also reported the presence of oxalate, phytic acid and cyanhydric acid. Although they are not at toxic levels, they could change the assimilation of certain components, for example, tannins. All yam tubers tend to contain oxalic acid but the level of soluble oxalate, which is known to be toxic to man and animals is not high and ranges from 5.30–11.60mg/100g dry weight. The lethal dose of soluble oxalate for man is reported to range from 2 – 5g /100g dry weight (Eka, 1985). The level of phytic acid in yam tubers ranges from 3.70 - 9.70mg/100g. Thus, one has to consume excessively large amounts of the tuber to reach the lethal dose (Eka, 1985). The various methods of preparation of the tubers for food tend to reduce the level of toxic components (Esuabana, 1982; Oke, 1985). Phytates, like oxalates tend to limit the availability of calcium, magnesium, iron and phosphorus by formation of insoluble compounds or salts with the minerals. The tannin level ranges from 20mg/100g in *D. rotundata* to 75mg/100g dry weight in *D. alata*. Tannins are phenolic compounds, which can precipitate proteins and render them unavailable to the body. They tend to bind irreversibly with the proteins (Eka, 1985).

Toxic alkaloids, dioscorine and dihydrodioscorine have been isolated from *D. dumetorum*, *D. hispida*, *D. hiresuta*, and *D. bulbifera*. The alkaloid levels vary depending on cultivar and species, as well as cultural practices. At low levels, their main

disadvantage is the bitterness they impart to the tuber tissue (Coursey 1983). At high levels, general paralysis of the central nervous system results with convulsions in experimental animals (Jadhav *et al.*, 1981, Oke, 1985). Depending on the amount, bitter substances can have an effect on tuber acceptability. A furanoid diterpene is thought to be responsible for the bitterness of *D. bulbifera* species (Oke, 1985). The bitterness of *D. cayenensis* and *D. rotundata* varies to some degree and is more acute in cultivars with yellow flesh. This is caused by leucoanthocyanadine (Eka, 1985). Other bitter compounds, which occur in some yam species, are polyphenols, furanoid norditerpenes (diosbulbins), saponins and sapogenins. The bitterness and toxicity of many species may be caused by high levels of saponins. Their toxicity lies in their ability to haemolyse red blood cells. The hydrolytic products of saponins are the sapogenins. Trace amounts have been reported in *D. alata*, *D. esculenta*, *D. hispida* and *D. japonica* (Martin, 1980). The trace amounts found in edible yams are below the threshold levels necessary to cause the symptoms associated with acute toxicity (Samarajeewa *et al.*, 1988).

Another important component of the yam tuber is hydrocyanic acid. This arises presumably from the cyanogenic glycosides found in the tubers; it ranges from 1.0mg – 1.89mg/100g dry matter (Esuabana, 1982). The tubers are thus low in hydrocyanic acid content (HCN) (Chakraborty *et al.*, 1977). The minimum lethal dose of HCN for man is about 0.5mg/kg body weight (Eka, 1985). A lethal dose of 50 – 60mg for an adult has also been suggested (Bohlius, 1952). Oyenuga (1968) claims that *D. rotundata* and its peels are free from cyanogenic glycosides. Thus on the basis of available data, HCN does not seem to occur at lethal levels in yam tubers. The human body is also able to deal with the HCN consumed since the enzyme rhodanase is known to form thiocyanate from the

HCN and thiosulphate. The tannin level ranges from 20 – 75 mg/100g dry matter. Tannins are phenolic compounds, which can precipitate proteins and therefore render them unavailable to the body. They tend to bind irreversibly with the proteins (Oke, 1985).

2.3.0 Processing and utilisation of yam tuber

Osagie (1992) reported that yams are prepared for consumption in a variety of ways, including boiling, baking, frying and pounding, all of which are eaten immediately. Nevertheless, as a result of the combination of a high degree of perishability, bulkiness, distance from production areas to consuming centres, and the seasonal nature of production, attention has focussed on the processing of tubers into yam flour, yam flakes and yam chips (Vernier *et al.*, 1998; Osagie, 1992; Coursey, 1967). However, the quantity of yam consumed in these processed forms is relatively small. The well known processed forms of yam are the flour and flakes.

2.3.1 Yam flour

Yam flour is prepared by first peeling and then slicing the fresh tuber into thin pieces approximately 1cm in thickness. These pieces are dried in the sun for several days until the moisture content has been reduced to a safe level. In some cases, the slices are boiled or parboiled before sun drying which softens the tissues considerably, and gives a more palatable product (Coursey, 1967; Ige and Akintunde, 1981; Ezeh, 1992; FSA-UNB, 1998). This product is manufactured in considerable quantity in parts of West Africa, in Togo, Benin and Nigeria. After drying, the pieces of yam (which are now hard as wood) are ground in mortars or milled in corn mills to yield coarse flour. When required for

food, the flour is reconstituted by stirring in boiling water to form a pasty dough somewhat similar, but generally regarded as inferior, to “fufu” (Coursey 1967, Ige and Akintude, 1981; FSA-UNB 1998). This pasty dough is referred to as “amala” or “telibowo” in Nigeria, Benin, and Togo (CIRAD-IITA, 1998). In Ghana it is known as yam “kokonte” (Coursey 1967). In Benin, an elaborated dish such as wassa-wassa (flour granules) is produced from the flour, and in Ghana the flour is mixed with beans flour to produce a dish called “tubani” in the northern regions (Vernier *et al.*, 1998). The flour can be mixed into biscuits, and baby foods (FSA-UNB, 1998). Ige and Akintude (1981) reported that the parboiling stage was an essential part of the traditional process, because when the yam slices were not parboiled before drying, the reconstituted produce from the flour did not have the characteristic taste, texture and colour of “amala” but resembled a product from cassava known as “lafun”

Onayemi and Idowu (1988) determined that for optimum shelf stability, yam flours should have moisture content of 6.5 to 8%. Vernier *et al.*, (1998) gave a moisture range of 12% – 14% for the yam flour.

2.3.2 Yam flakes

Yam flakes are relatively new processed forms of yam and have no antecedent among traditional yam consumers. Onayemi and Potter (1974) produced drum-dried yam flakes and reported that a high degree of pastries in the reconstituted flakes was correlated with a high iodine blue value index of the yam flakes. Starch damage, which leads to a high iodine blue value index, is desirable for yam flakes that are to be used for fufu making because some pastries are desirable in “fufu”.

Ayernor *et al.* (1974) studied the effects of pre-cooking, comminution and drying conditions on the physical properties (including texture) of dough made from yam flour. They reported that increased cooking time and intense mashing procedures resulted in high starch damage, which gave a product of high starch damage with higher elasticity in the reconstituted flakes. This is a desirable characteristic of “fufu” Their results indicated that pre-cooking and comminution stages had the greatest influence on dough (fufu) characteristics. The processed material naturally suffers no autolytic deterioration, while the micro-organisms, which attack living tubers, being essentially plant pathogens, may sometimes occur. Insect infestation after several months of storage can also lead to losses (Coursey, 1967; Vernier, 1998; Vernier *et al.*, 1988).

2.3.3 Insect pests associated with root and tuber chips

The major cause of post-harvest losses during chip storage is infestation by insects. A wide range of species that feed directly on the dried chips have been reported as causes of weight loss in the stored produce. Pests which cause the greatest damage to the chips belong to the family Bostrichidae, whose members are characterised by the presence of powerful mandibles with which they can cut directly into wood and other vegetable material (Adesuyi, 1975). Some of the important species of insect pests are: *Rhyzopertha dominica* (Fabricius), *Araecerus fasciculatus* (Degeer), *Ahasverus advena* (Waltl), *Stegobium paniceum* (Linnaeus), *Tribolium castaneum* (Herbst), *Dinoderus minutus* (Fabricius) and *Prostephanus truncatus* (Horn) (Pingale *et al.*, 1954; Ingram and Humphies, 1972; Parker *et al.*, 1979; Hodges *et al.*, 1985; Balagopalan *et al.*, 1988; Katere and Giga, 1990). Preliminary investigations have shown that *P. truncatus* is able

to feed and multiply on cassava chips (Nyakunga, 1982; Magona, 1988; Marshed-kharusy, 1990). *Heterobostrychus brunneus* (Muray) and *Sinoxylon sp.* (Duftschmid) are known as material pests but were also mentioned in the literature as pests of dried cassava chips (Frappa, 1938; Lepesme, 1944; Mangoendihardjo; 1981, Dobie *et al.*, 1991 and Delobel, 1992). Corne (1964) and Adisa (1985) specifically stated that during storage, yam chips are often infested by boring insects, which cause considerable damage in a few months. The most common among these are *Sitophilus zeamais* (Motshulsky), *Dinoderus oblonguntatus* (Lesne), and *D. minutus* (Fabricius) as well as *Palorus subdepressus* (Wollaston) (Vernier, 1998). Coursey (1967) also stated that, *Araecerus fasciculatus* (Degeer) and *Sitophilus zeamais* (Motshulsky) are by far the commonest. Pieces of dried yam arriving at mills are often riddled with holes caused by the former insect, and stores where yam flour is kept in normal sacks, are usually heavily infested with one or both species.

2.4.0 Taxonomy of test insects

2.4.1 The larger grain borer: *Prostephanus truncatus* (Horn) (Coleoptera Bostrichidae)

The larger grain borer, *P. truncatus* is principally a woodborer (Detmers *et al.*, 1991), which commonly infests stored grains (Hodges *et al.*, 1983). The adults have the typical cylindrical bostrichid shape. The declivity is flattened and steep and over its surface there are many tubercles. The limits of the declivity, apically and laterally, are marked by a carina. The antennae are 10 – segmented and have a loose three-segmented club; the stem of the antenna is slender and clothed with long hairs and the apical club segment is as wide as, or wider than, the preceding segments. The body is 3 - 4.5 mm long. The larvae

are similar to those of *Rhyzopertha dominica* (Fabricius) but the thoracic segments are considerably larger than those of the abdomen (Haines, 1991).

2.4.2 Distribution of *P. truncatus*

The large grain borer, *P. truncatus* is a species originally native to Tropical Central and Northern South America, as a major but localized pest of farm-stored maize (Haines, 1991; Markham *et al.*, 1991). It presumably spread from Mexico after 1971 to East Africa (Mushi, 1984; Nissen *et al.*, 1991). Not until a considerable population density had been reached, was it identified in Tanzania in 1981 (Anonymous, 1981; Dunstan and Magazini, 1981). In the meantime, the beetle had crossed the borders into the neighbouring countries of Kenya (Kega and Warui, 1983), Burundi and Rwanda (Laborius, 1988).

At the beginning of 1984 *P. truncatus* was discovered in a completely different region of Africa – Togo in West Africa. A survey among farmers led to the assumption that it had first appeared in West Africa in 1981 (Krall, 1984; Harnisch and Krall, 1984). Today, the pest populations have already spread into the neighbouring states of Ghana (Dick *et al.*, 1989), Benin (Krall and Favi, 1986), Guinea (Kalivogui and Muck, 1990). In Nigeria the earliest report of *P. truncatus* indicated its presence in areas of Oyo, Ogun and Lagos states, mostly in areas near the border with Republic of Benin (Pike *et al.*, 1992). The extent of spread, degrees of damage are yet to be elucidated (Echendu *et al.*, 1997).

Transport of foodstuffs from surplus regions into deficit regions across the African continent and the exchange of goods in traditional market places promote the rapid spread of this pest, which is also able to fly (Richter and Biliwa, 1991).

2.4.3 Damage and economic importance of *P.truncatus*

P. truncatus is a pest of stored cereals, root and tuber crops. In several parts of Africa, it is a serious pest with a high damage potential. The beetle infests maize cobs shortly before as well as after harvesting. Attempts in the laboratory to rear the species on cowpea, haricot beans, cocoa and coffee beans, and rough rice have failed, although development was possible on a soft variety of wheat and adult feeding damage was caused to other commodities (Shires, 1977).

In Honduras and Nicaragua, weight losses of up to 40% have been recorded from maize cobs stored on the farm for six months (Hoppe, 1986; Giles and Leon, 1975). In Tanzania losses as high as 34% have been observed after 3 - 6 months farm storage with an average loss of 8.7% (Hodges et al., 1983). When compared with the damage caused by the more usual storage pests (e.g. *Sitophilus oryzae*, *S. zeamais* and *Sitotroga cerealella*) under similar circumstances, *P. truncatus* is obviously a very serious pest. During an entire storage season in Zambia, Kenya and Malawi maize losses due to these other pests were, respectively, 2-6%, 3-5% and 2-5% (Haines, 1991). Extensive damage was also recorded in Togo. In some maize stores there were holes bored by *P. truncatus* in 100% of the cobs after 9 months in storage (Krall, 1984). According to Pantenius (1988), an average weight loss of 30.2% occurred in maize stores after 6 months. Prior to the appearance of *P. truncatus*, the average overall loss in this region was 7.1%. The cobs

had been damaged so badly that they were no longer suitable for human consumption, cobs would not even be eaten by cattle (Pantenius, 1988). If the larger grain borer were to spread throughout all maize-growing areas in Kenya, projections show that an estimated 10% (100,000 tonnes) of all stored maize (1 million tonnes) would be lost annually. This would be enough to feed over 100,000 people for one year and corresponds to an economic loss of over DM 30 million per year (Laborius *et al.*, 1985).

P. truncatus also causes extensive damage to dried cassava roots (manioc). In a test store in Tanzania, losses of up to 70% in fermented and 50% in unfermented cassava were recorded after only 4 months of storage (Hodges *et al.*, 1985). Schulten, (1988) reported that infestation by *P. truncatus*, a Tanzanian strain, caused losses three to five times higher than those caused by indigenous pest. He attributed the enormous destructive potential of *P. truncatus* to its enormous frass potential and high reproductive rate in comparison to the other insect species. Also in Togo, Wright *et al.* (1993) assessed post-harvest losses of chips of up to 30% when *P. truncatus* attacked the dried chips. In addition, Wright *et al.* (1993) estimated that about 4% of the total national cassava production in Togo is lost during chip storage. This was about equivalent to 0.05% of the GNP in 1989.

2.4.4 Biology and behaviour of *P. truncatus*

P. truncatus behaves as a typical primary pest of farm-stored maize: The adults bore into a wide range of food stuffs and some other materials, e.g. wood. When infesting stored maize cobs, with sheaths intact the adults frequently initiate their attack by boring into the base of the maize cob cores, although they eventually gain access to the grain via the

apex of the cob by crawling between the sheathing leaves (Hodges and Meik, 1984). Adults bore into the maize, making neat round holes, and as they tunnel from grain to grain they generate large quantities of maize dust. Adult females lay a batch of 4 – 8 eggs in chambers bored at right angles to the main tunnels, egg laying on stabilized grain, like that on the maize cob, is more productive than on loose shelled grain, (Cowley *et al.*, 1980; Bell and Watters, 1982; Watters, 1984), and eggs are laid at greater rate.

Larvae hatch from the eggs after three days at 27°C and seem to thrive on the dust produced by boring adults, where they pupate (Haines, 1991). The life cycle has been investigated under a range of temperature and humidity conditions (Shires, 1979, 1980; Bell and Watters, 1982; Hodges and Meik, 1984). Development of the larva through to adult at the optimum temperature and relative humidity (32°C and 80% r.h), took only 27 days on a maize grain diet (Haines, 1991). Humidity within the range 50-80% r.h does not greatly affect the development period or mortality. (Shires, 1979; Bell and Watters, 1982; Haubruge, 1987). At 32°C, a drop in relative humidity from 80% - 50% extended the mean development period by just six days and increased the mean mortality by 13.3% only (Haines, 1991). This tolerance of dry conditions has been confirmed during field studies in Nicaragua and Tanzania (Giles and Leon, 1975; Hodges *et al.*, 1983) in which maize at 10.6% and 9% m.c, respectively, was heavily infested. The developmental period is between 32 – 40 days and the estimate for the intrinsic rate of increase of *P. truncatus*, under ideal conditions of temperature and humidity is in the order of 0.7 – 0.8 / week (Haines, 1991).

2.4.5 Control of *P. truncatus*

2.4.5.1 Chemical Control

The use of insecticide to control *P. truncatus* is made very difficult by the local method of storing maize. The cobs with husks are normally stored under the roofs of houses or openly on wooden frames so that they can dry.

Contact and / or stomach poison is spread on inert powder materials or as liquids. They do not penetrate the substrate treated and can only provide protection on the surface of the stored produce. *P. truncatus* individuals already inside the cob before application are thus able to escape affective control.

In 1981/82, initial experiments were carried out in Tanzania using the insecticides available there including pirimiphos methyl, fenitrothion and bromophos. These proved to be ineffective (Golob, 1984; Golob *et al.*, 1983). All the organophosphate insecticides proved ineffective against *P. truncatus*. In contrast, experiments using pyrethroids, like permethrin and deltamethrin on shelled maize grains, showed good results (Laborius *et al.*, 1985; Laborius, 1988). To provide additional protection from other pests, a pyrethroid was recommended in combination with a phosphorous acid-ester compound (Pirimiphosmethyl or Chlorpyrifos-methyl) (Golob, 1988).

Fumigating the stored produce using methyl bromide, a respiratory poison or hydrogen phosphide is effective (Haashem and Reichmuth, 1989; Detmers, 1990,1991.) but the method is unsuitable for use in stores at the farm level.

2.4.5.2 Biological control

In its native home, *P. truncatus* only occasionally causes considerable damage, whilst in Africa it has become a real threat to staple food (Keil, 1988; Pantenius, 1987, 1988; Laborius, 1990. Hymenopterous wasps (Pteromalidae): *Anisopteromalus calandrae* and *Choetospila elegans* were observed to be biological opponents of *P. truncatus* in Costa Rica (Bøye, 1988, 1990).

Described as the main, immediate antagonist of *P. truncatus* in Costa Rica was the predatory histerid beetles *Teretrius nigrescens*, Lewis (until recently *Teretriosoma nigrescen*) and a predatory bug (*Calliodis sp*). Neither of these predators had so far been recorded in Africa. Experiments showed that, in contrast to *T. Nigrescens*, *Calliodis sp* was only able to effectively reduce the number of eggs and larvae of *P. truncatus* when there was high population density (Bøye, 1988; Bøye, *et al.*, 1988). In laboratory experiments on the predatory behaviours of the beetle, evidence was found to confirm that not only the larvae of *T. nigrescens* but also the imagines are able to make use of the eggs and larvae of *P. truncatus*. According to Leliveldt (1990), one *T. nigrescens* imago eats an average of 5.7 eggs or 4.9 larvae of *P. truncatus* per day. Rees (1985) found a value of 1.7 *P. truncatus* larvae on average. Over the same period, the predator larvae ate up to 3.5 *P. truncatus* larvae. According to this, one *T. nigrescens* larva requires around 60 *P. truncatus* larvae up to the point when its development into an imago is complete. According to (Bøye, 1988), one *T. nigrescens* imago kills an average of 1.1 *P. truncatus* larvae in 24 hours.

2.5.0 Taxonomy of the Coffee bean weevil: *Araecerus fasciculatus* (Degeer) (Col: Anthribidae)

A. fasciculatus is the only member of this family (Anthribidae) that is of economic importance on stored products; most other insects belonging to this family feed on dead wood and fungi (Haines, 1991b). The adult is 3-5mm long and dark brown to grey brown in colour (Appert, 1992; Wrigley, 1988, Haines, 1991b). The prothorax and the elytra bear many light brown circular patches, the insect is oval and convex, it is covered with a pubescence and the elytra are slightly shorter than the abdominal segment. This leads to one abdominal segment getting exposed (Appert, 1992).

The antennae in the matured adults are long, thin and end in three thick blackish joints and are held forward. The head is somewhat pointed with prominent eyes. The larva is about 4.5 – 6 mm long. It is white with an ochre head, narrow, apodal and hairy (Wrigley, 1988; Appert, 1992).

2.5.1 Distribution and economic importance of *A. fasciculatus*

A. fasciculatus is found in most tropical regions of the world (Mphuru, 1974; Haines, 1991b). It was thought to have originated from India, East Indies etc. However, its occurrence is now more or less cosmopolitan (Mphuru, 1974). Degeer first described *A. fasciculatus* in 1775. Lucas in 1861 recorded it boring into branches of Chinese ginger in France. Now, *A. fasciculatus* is distributed worldwide in USA, Brazil, St Helena, Persia, Japan, Nigeria, Ghana, Kenya e.t.c (Sayed, 1935; Mphuru, 1974). This insect is known to attack coffee, cherries, coffee beans, copra, millet, cassava chips, maize, sorghum,

groundnut, rice etc (Mphuru, 1974; Wrigley, 1988; Appert, 1992). *A. fasciculatus* was recorded damaging the boll and seeds of cotton plant in Africa (Zacher, 1913), attacking cocoa in the Gold Coast during the drying stage and then in stores (Patterson 1928), in coffee berries in the Dutch East Indies (Friederichs, 1925) where it also attacked Brazil nut (Gater, 1925).

It is a very important pest of prepared and stored coffee. In several South American countries, it is a serious pest, causing considerable damage to harvested coffee (Wrigley, 1988). Currently, *A. fasciculatus* is a serious problem to the cocoa industry in Ghana. It infests cocoa beans of high moisture content. This insect causes damage to stored produce by feeding on the germ, thereby reducing their viability. It also feeds on the cotyledon and either reduces the product into powder or causes loss in weight to the produce (Appert, 1992). In a laboratory experiment, conducted by Williams (1999), it was found that 13.34% damage occurred in cocoa stored in jute sacks over a period of 4 months, apart from other forms of losses recorded. Both the adult and the larvae cause damage to stored produce. The larvae live inside the grain or bean for their entire development, consuming about a third of the grain or bean (Cotterell, 1934). A serious attack of cocoa by this insect is an indication of the fact that the beans are not adequately dried (Williams, 1999). This is because *A. fasciculatus* attacks products of high moisture content. This pest also causes severe quantitative damage to cassava and yam chips (Coursey, 1967; Haines, 1991b; Parker and Booth, 1979; Stumpf, 1998).



2.5.2 Biology of *A. fasciculatus*

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

The eggs take about a week to hatch. The larvae live within the seeds and feed on the cotyledon. There is always one larva per seed. When developing in cocoa beans one larva eats up to about one-third of the interior of the bean (Cotterell, 1934). When the larva is within the seed, it digs tunnels and fills the seed with its faeces and produces hidden infestation. Larvae pupate within the seed. The larval period is about one and half months while the pupation periods is about 6 - 9 days (Wrigley, 1988).

The total developmental period from egg to adult has been reported to be between 46 and 66 days at 28°C and 70-80% R.H (Cabal Concha, 1952). Rene (1992) reported a rather shorter developmental period of 29-40 days also on coffee at 25-30°C and 70% R.H It has been shown that on maize the insect develops most quickly at a high moisture content; development is severely affected by low humidities. All stages, except the pupae die when the R.H. is lower than 60%; and at 27°C the developmental period increases from 29 to 57 days on maize when the R.H. is reduced from 100% to 60% (Sayed, 1935;

1940). Adults live for more than 17 weeks, but longevity is severely reduced at low humidities. Each adult emerges from a hole 0.4 mm in diameter (Appert, 1992). The sex ratio is 1:1 for the adult that has emerged.

2.5.3 Control of *A. fasciculatus*

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

Dust containing 2% malathion or 1% tetra-chlorvinphos are effective against *A. fasciculatus* when applied at the rates of 8 and 20 ppm even after 210 days (Bitran, 1974). Malathion and Phoxim (Volaton) both with low mammalian toxicity when used as 50% emulsion concentrates in 0.25% solution give adequate protection to coffee stored in bags (Chackol *et al.*, 1979). Fumigation has been the most widely used control measure against *A. fasciculatus*. Fumigating with dichlorvos (DDVP) at a rate of 50g/m³ or with three tablets of phostoxin/m³ effectively controlled the pest (Lin, 1976). A complete control of all stages of *A. fasciculatus* was achieved when the jute sacks or the paper bags used to store coffee was fumigated for 48 hours or 72 hours with phosphine at 0.5g and 0.4g active ingredients/m³, respectively or for 24 hours with 20ml methyl bromide / m³ (Bitran, 1974).

2.6.0 Types of Losses

Boxall (1986) refers to damage as the superficial evidence of deterioration, for example, hole or broken grains from which loss may result. Loss on the other hand is a measurable decrease of food, which may be quantitative, or qualitative (Boxall, 1986; Appert, 1992). From the above, it can be said that losses come as a result of damage. Loss can also, be defined as any change in the availability, edibility, wholesomeness or quality of food that prevent it from being consumed or utilised by people (Harris and Lindblad, 1978). It is difficult to categorize loss. However, Boxall (1986) listed the following categories for convenience: weight loss, quality loss, nutritional loss commercial loss and loss of seed viability.

2.6.1 Weight Loss

Reduction in weight is obvious but does not always indicate loss. This may be due to reduced moisture content and this is recognised in commerce by a shrinkage factor. This may be an economic loss if it is taken into account by grading for price control, but it is an artificial loss (Boxall, 1986). True weight loss may result from the feeding of insects, rodents and birds or from spillage. When grains are eaten by insects, the insect themselves, their remains, moults, frass and the dust resulting from their feeding activity must be considered when estimating weight loss (Appert, 1992). At times loss due to insect infestation manifests in grain as increase in weight of the produce. This is because the powdery residue or the impurity produced by the insects are more hygroscopic and absorb more moisture from the atmosphere (Hall, 1970).

2.6.2 Quality Loss

Quality of produce is assessed in different ways, according to the factors considered important by the local population and traders concerned, therefore, this is subjective in nature. Generally, quality is assessed and products graded on basis of appearance, shape, and size etc., but smell and flavour are sometimes included (Boxall, 1986; Appert, 1992).

For chips, insect activities create a moist microclimate within the infested chips, however, which might lead to increasing moisture content levels and to possible increase of insect pests and occurrence of mould infestation. Moreover, chips are likely to decrease in consumption quality due to insect infestation (Wright *et al.*, 1993; Stumpf, 1994).

2.6.3 Nutritional Loss

Nutritional loss, in a sense, is the product of the quantitative and qualitative losses, but more specifically, it is the loss in terms of nutritional value to the human population concerned (Boxall, 1986). Appert, (1992) stated that, these losses represent a reduction in the food value of grain as a result of a lowering of its protein, hydrocarbon and vitamin contents.

Wright *et al.* (1993) reported that the nutritional quality of chips is less likely to decrease, instead, some nutritional variables might even be enhanced due to pest infestation. Stumpf (1994) stated that this is probably caused by the addition of protein to the damaged chips by the cast skins and insect bodies, which remain in the chips during the chemical analysis.

Nevertheless, over drying or cover-exposure to sunlight also destroys certain nutrients, especially vitamins. High temperatures during artificial drying cause loss of thiamine content in rice (Christensen, 1974). Pingale *et al.*, (1954) reported that losses of thiamine in rice stored for eight months were 10 – 15% greater in infested than uninfested.

2.6.4 Commercial Loss

Commercial losses may occur as a direct consequence of any of the foregoing factors or indirectly as the cost of preventive or remedial actions required, including that of the necessary equipment (Boxall, 1986; Appert, 1992).

2.7.0 Loss assessment methods

Loss assessment is the determination of the measurable decrease of foodstuff, which may be quantitative or qualitative. It is a necessary step that helps to ascertain the effectiveness of a specific storage method in reducing losses during storage. It determines the effectiveness of protectants used to reduce pests attack.

Loss assessment may involve calculating the percentage of damaged foodstuff, percentage weight loss and change in the nutrients of the product concerned. There is a correlation among the number of insects present in stored produce, the percentage of insect damage and percentage weight loss (Hall, 1970; Stumpf, 1994). Davies (1960) reported that 10% bored samples of maize represented 2.7% loss in weight in Uganda. In India, Rao *et al.*, (1958) found that the percentage of sorghum grain holed by weevils was two to three times the percentage weight loss. Their values show that the percentage of holed grains or foodstuff does not give even a rough estimate of percentage loss in

weight. The same applies to change in nutrient content. For this reason, procedures had been set or developed to provide these estimates. There are two main methods of loss assessment. These are simple and complex methods (Boxall, 1986).

The simple methods include: (a) Count and weigh method, (b) Converted percentage method.

The complex methods are (a) Volumetric method; which comprise of (i) Standard volume/ weight method (ii) Modified standard volume/ weight method. (b) Thousand grain mass method.

Adams and Schulten, (1978) suggested three methods of determining losses in grains. These are: (a) Volumetric method, (b) Gravimetric or count and weigh method, and (c) Converted percentage damage method.

Wright (1991, 1993) and Compton (1991) developed some loss assessment methods for root and tuber crops, these are: visual damage scale method, gravimetric method, volumetric / gravimetric method. Stumpf *et al.* (1998) developed the monometric method. These methods are related to the loss assessment methods for grains.

2.7.1 Gravimetric Method

This method has been tested for cassava by surveying in various locations throughout Africa and Asia (Wright *et al.*, 1993; Wright, 1995; Stumpf, 1998). The method is based

simply on the comparison of the weights of infested and uninfested dried cassava chips. The result is determined in terms of percentage weight loss.

The assessment of the moisture content (m.c.) of each chip is a prerequisite to calculate the dry weight (Wright *et al.*, (1993). In most cases, a sample of chips is selected for the determination of the average moisture content. This could lead to a slight over or underestimation of weight loss (%) of chips (Stumpf 1998). The gravimetric method is easy to perform and leads to fairly precise measuring of weight losses. This method is more precise and reliable (Wright *et al.*, 1993; Stumpf, 1998).

This is similar to standard volume / weight method as described by Adam *et al.* (1977) and Schulten (1972). The only difference is in the use of standard volume, because root and tuber chips do not have approximate shape as other cereals.

2.7.2 Modified Gravimetric Method

This method is similar to the modified standard volume / weight method, which has been used for determination of loss in cereals. The only difference is that, there would be no determination of baseline data and moisture content of the chips. But a standard weight of chips used for the experiment will be determined (weight of uninfested chip) and this will be compared against weight of infested chip. This weight loss will then be converted to percentage weight loss.

2.7.2 Visual Damage Scale Method

The method of assessing damage by visual damage scales was used by Compton (1991) in Togo. Damage scales are well known from pre-harvest assessments of crops for

relation to pest damages (Stumpf, 1998). Compton (1991) developed a method, which is simple, quick and does not require baseline data but is much less precise than the described gravimetric methods. The outer appearance of the chips are the main criterion for the classification of chips into five damage scales (I – V).

The classification is as follows:

- I = undamaged (0 holes/cm²)
- II = light damage (up to 2 holes / cm²)
- III = medium damage (2 – 7 holes / cm²)
- IV = medium-high damage (4-9 holes / cm²), and light physical destruction of the chips surface.
- V = Severe damage and the chips surface is physically destroyed so that bored holes are no longer countable.

The determination of the average number of holes / cm, is a supplementary factor for classifying chips into different damage scales. The chip surface will be divided into small sections prior to counting the boreholes. This technique requires experience in the classification procedure and is in use for many crops but rather subjective (Stumpf, 1998). The respective damage scales can be calibrated by using the gravimetric methods or any other method to assess weight losses related to a certain apparent damage of a chip (Compton, 1991). Compton *et al.* (1993) calibrated the damage scales against measured weight loss from a survey in Togo, the visual damage scale method revealed that cassava chips in scale II sustained weight losses of about 16%, chips classified in scale III about 29%, chips classified in scale IV about 42% and chips classified in scale V about 50%. Stumpf, (1998), working on cassava in Ghana, recorded the percentage weight losses, 0-

0.1%, 3.6-4.3% and 6.3-10% for scale I, II and III respectively. No data are available for damage scales IV and V.

2.7.3 Volumetric / Gravimetric Method (VGM)

This method was used by Wright (1991) and Stumpf (1998) in assessing losses in cassava in Togo and Ghana respectively. Wright (1991) found throughout his trials in Togo that there was a good and relatively constant relationship between the weight of an individual dry cassava chip and its outer volume of about 0.9, but a figure for the standard deviation was not indicated by Wright. This suggests that for a given variety of cassava chips the magnitude of loss can be expressed in terms of volume. The cassava chips were weighted and their volume measured by displacing water in a scaled vessel. The relationship can be drawn as a graph or simply expressed as:

A = weight of a dried cassava chip (g)

B = outer volume of a dried chip (ml)

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 STUDY SITES

The yam chips were prepared at the Department of Crop Science, University of Ghana and Food Research Institute, Ghana. The experimental set-up and weight loss analysis was carried out at the insectary of the Ministry of Food and Agriculture / Plant Protection and Regulatory Service (MOFA/PPRS) Pokuase. The experiments were conducted under temperature ranges of 28 – 33°C and 70 – 92% R.H (Room temperature and relative humidity). The proximate analysis and biochemical changes were carried out at the Departments of Biochemistry; Nutrition and Food Science and Geography (Ecological Laboratory) of the University of Ghana.

3.2 EXPERIMENTAL DESIGN

The experimental design was completely randomised design (CRD). Glass jars containing 200g yam chips each were arranged on shelves. Each treatment and the control were replicated 5 times. The treatments were assigned randomly.

3.3 YAM SPECIES USED FOR THE STUDY

Two species of yam were used in this study. These are; *Dioscorea rotundata* and *D. alata*. The varieties considered for the studies in each species of yam are; “Asaana” and “Pona” (*D. rotundata*) and “Afasie” (*D. alata*). One hundred and fifty fresh tubers of the yam varieties were purchased from the market with identification carried out by the staff of the MOFA / PPRS, Pokuase. The numbers of tubers for each variety are as follows 58

tubers for “Afasie”, 47 tubers for “Asaana” and 45 tubers for “Pona” Tuber weight ranged between 3 – 7kg (wet weight per tuber).

3.4 PREPARATION OF YAM TUBERS INTO DRIED CHIPS

The yam tubers as described in section 3.3 were prepared into chips at the Department of Crop Science, University of Ghana, Legon, and Food Research Institute, Ghana. For each variety, the tubers were divided into two, after peeling and chipping, one part was parboiled and the other was not parboiled. These two treatments were further dried in two different ways, that is, oven drying or sun drying, to give a total of four treatments.

The treatments were as follows:

- (i) Parboiled Oven-dried
- (ii) Parboiled Sun-dried
- (iii) Non-Parboiled Oven-dried
- (iv) Non-Parboiled Sun-dried

After preparation, the chips were stored at the Department of Crop Science cold room for a period of two weeks.

The procedures adopted for the preparation of yam tubers into parboiled and non-parboiled chips are illustrated in the following charts (figs 3.1 and 3.2).

Fig. 3.1 Processing of Parboiled Chips

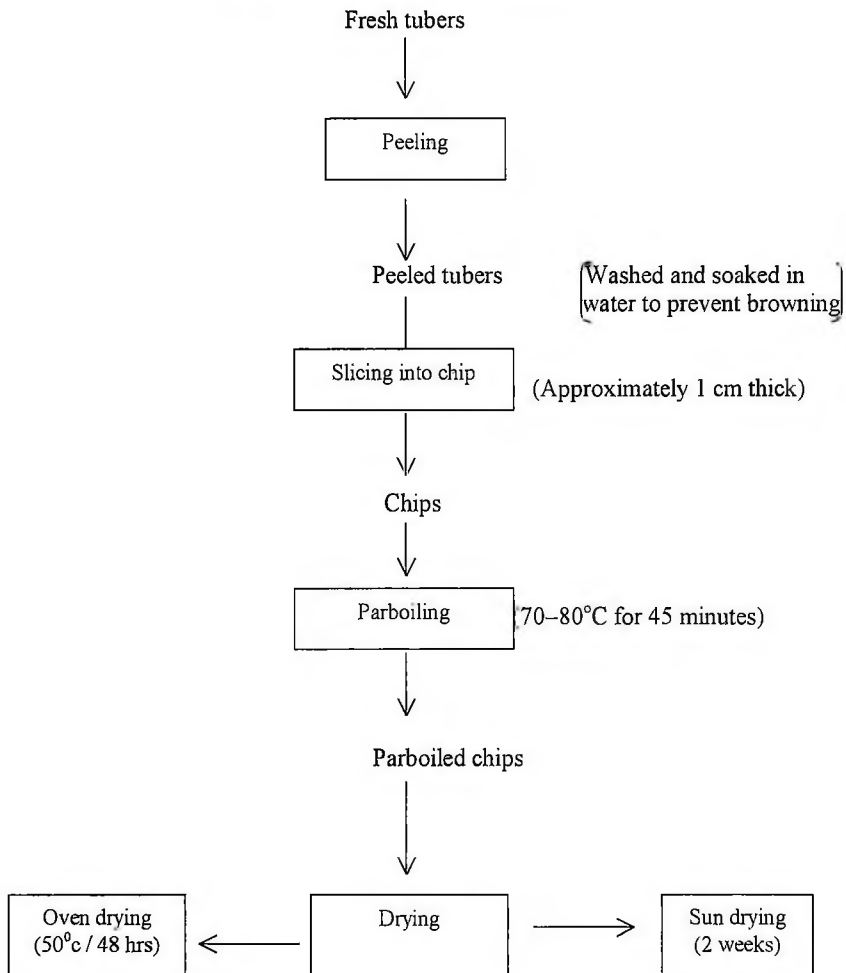
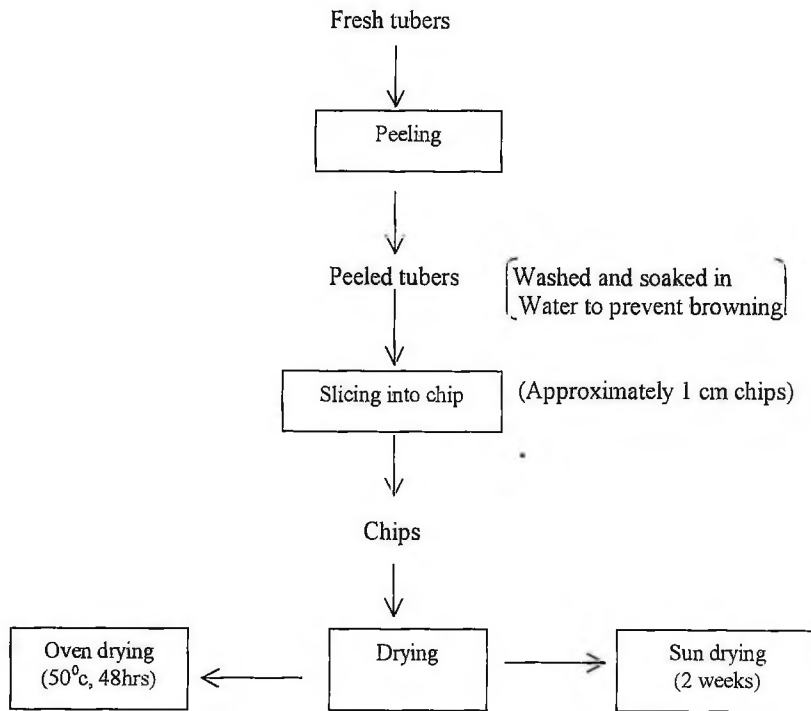


Fig. 3.2 Processing of Non-Parboiled Chips



Ezeh (1992) has described a traditional method by which yams are prepared into chips. This technique involves peeling the tubers, parboiling them in water containing natural substances, which later act as fungicides and insecticides. Parboiling temperature is determined crudely by using fingers. The tubers are then dried in the sun, preferably during harmattan, as whole or sliced into two, depending on the size of the tuber. It is not in all cases that the tubers are parboiled. Where this is case, the possibility of preservation is limited to a few weeks while they can last for more than one year when the tubers are parboiled before being dried.

3.5 CULTURING OF *P. truncatus*

The culture jars used for this study were sterilised in the oven at 70°C for 2 hours before experimentation. *P. truncatus* and *A. fasciculatus* were the insects used for the study. The insects were collected and reared at the PPRS insectary at 30 ± 3°C and 70 – 92% R.H.

Adult *P. tuncatus* (Plate 1) was obtained from MOFA (*P. truncatus* Project laboratory) Kpeve. This was used in raising the stock culture from which experimental insects were taken. *P. truncatus* was collected from maize culture by sieving and fifty adults were transferred into one-litre Kilner jars containing 400g slightly crushed yam chips. This was replicated twice. They were then placed in a tray containing frytol oil to prevent entry of crawling insects. These were kept for three weeks and sieved to remove the adult insects. The procedure was repeated for three consecutive days. The culture was kept for two more weeks and sieved to remove the adults that had emerged. These adults were 0 – 14 days old. The culture was repeated and replicated 8 times with 300g of slightly

crushed yam chips placed in each glass jar where fifty adults *P. truncatus* were transferred into each glass jar and placed in tray containing frytol for three weeks. The chips were sieved and all adult insects seen were removed. The chips were later returned into their respective jars covered with a wire mesh held firmly by a lid with a hole of 2cm in radius. The sieving process was repeated for three consecutive days to make sure that all adults were removed from the chips. Seven days later, the chips were sieved again to remove adults that have emerged. These adults were 0 - 7days old. These were the insects used for the experiment.

3.6 CULTURING OF *A. fasciculatus*

Adult *A fasciculatus* (Plate 2) was collected from the cocoa shed at Tema port and reared at the PPRS insectary at $30 \pm 3^{\circ}\text{C}$ and 70 – 92%r.h. *A fasciculatus* were collected by handpicking the adult insects from the surface of the cocoa bags at various sheds and were reared on crushed cocoa beans and cassava chips. Later *A. fasciculatus* were also collected from Nima market where they were found on yam chips sold at the market. The *A. fasciculatus* collected from Tema did not do well on the cocoa bean, but those collected from Nima market multiplied rapidly on yam chips. Therefore the stock culture was subsequently reared from it.

Fifty adults of *A. fasciculatus* were introduced into a one-litre Kilner jar containing 400g of dried yam chips. This was replicated twice. The culture jars were covered with wire mesh held firmly by lid with a hole of 2cm radius. The set up was kept in a tray filled with frytol oil to prevent undesirable insects from entering the culture. After 4 weeks the adult insects were removed by sieving and the contents was poured back into their

respective glass jars. The adult insects that emerged after fourteen days of sieving were used to raise the progeny required for the study. Fifty adults of *A. fasciculatus* were picked with age range of 0 – 14 days. These are reared on 300g of yam chips in a glass jar covered with wire mesh. This was replicated 8 times. After 4 weeks, the insects were removed from the culture. Fourteen days later, newly emerged adults were seen and these were used for the experiment.

Plate 1. *P. truncatus* Adult



Plate 2. *A. fasciculatus* Adult



3.7 EXPERIMENTAL SET-UP

Glass jars containing 200g of yam chips were covered with a lid at the middle of which is a wire mesh (2 cm in radius) to allow air into the culture. These were then arranged into three groups, with each treatment replicated 5 times as well as the control and the mixed culture. The whole arrangement was on a wooden shelf, 10 insects of each species were introduced separately into each glass jar. In the mixed culture insects of both species were introduced, 10 insects from each species, thus giving a starting population of 20 for the two insects. The insects were introduced with the aid of an aspirator. The set-ups were left for 3 months (Plates 3 and 4).

Plate 3. Culture jars



Plate 4. Experimental set-up



3.8 ASSESSMENT OF DAMAGE ON DRIED YAM CHIPS

The assessment was determined on three occasions: after 1, 2 and 3 months after storage. During assessment, the contents of each glass jar were poured on serially arranged sieves with mesh sizes of 2.00mm, 1.00mm, 500 μ m, 250 μ m and 125 μ m respectively to allow for the separation of insects and contaminants comprising of feeding residues, frass and fragments and yam chips. The contaminants were removed, critically observed and weighed. Dead and live insects were counted. The yam chips were assessed for weight loss. The methods that were used are Dry weight method and Visual damage scale method. The dry weight method was used to determine the percentage weight loss and the Visual damage scale method was used to determine the percentage damage over the period of storage.

The dry weight method was used by plotting baseline data for the chips before infestation. Dry weights of chips were plotted against corresponding moisture contents. The regression equations of the baseline curves for each variety of yam chips are: Asaana $y = -1.8636x + 197.95$ and $R^2 = 0.9988$, Pona $y = -1.9705x + 203.78$ and $R^2 = 0.9963$ and Afasie $y = -1.8159x + 192.88$ and $R^2 = 0.947$

The percentage weight loss was calculated as follows:

$$\% \text{ wt loss} = \frac{\text{Dwt. graph} - \text{Dwt. Sample}}{\text{Dwt. Graph}} \times 100$$

Where;

Dwt graph = Dry weight graph

Dwt sample = Dry weight sample

3.9. MOISTURE DETERMINATION

The hot air oven method was used for the moisture determination (Osborne and Voogt, 1978). The sample was dried to a constant weight in a hot air oven. The difference in weight of the sample before and after drying is the moisture content, which was then converted to percentage moisture content. To achieve this, clean and marked aluminum dishes were dried to a constant weight in an air-oven for 20 minutes at 100°C. The dishes were then transferred to a dessicator to cool. The empty dishes were then weighed. Two grammes of the sample were weighed into the dishes and dried at 130°C for 2 hours with covers slightly left ajar. The dishes were then removed from the oven and the lids replaced and then cooled in a dessicator. The weight was recorded after cooling. These were transferred into the oven for further drying over a period of 1 hour, cooled in a dessicator, and then re-weighed. This is to ensure that a constant weight is achieved.

Calculation:

$$\begin{aligned}\text{Weight (g) of sample} &= W_1 \\ \text{Weight (g) after drying} &= W_2 \\ (\%) \text{ Moisture} &= (W_1 - W_2 / W_1) \times 100.\end{aligned}$$

In the Visual damage scale method (Plate 5), it is the outer appearance of the chips that was used for classifying the chips into five damage scales.

The Visual damage scales for classification of chips into various damage levels are as follows:

- I = Undamaged (0 hole/cm²)
- II = Light damage (up to 2 holes / cm²)
- III = Medium damage (2 – 7 holes / cm²)
- IV = Medium high damage (4 – 9 holes / cm²) and light physical destruction of the chips surface.
- V = Severe damage and the chips surface is physically destroyed so that bored holes are no longer countable.

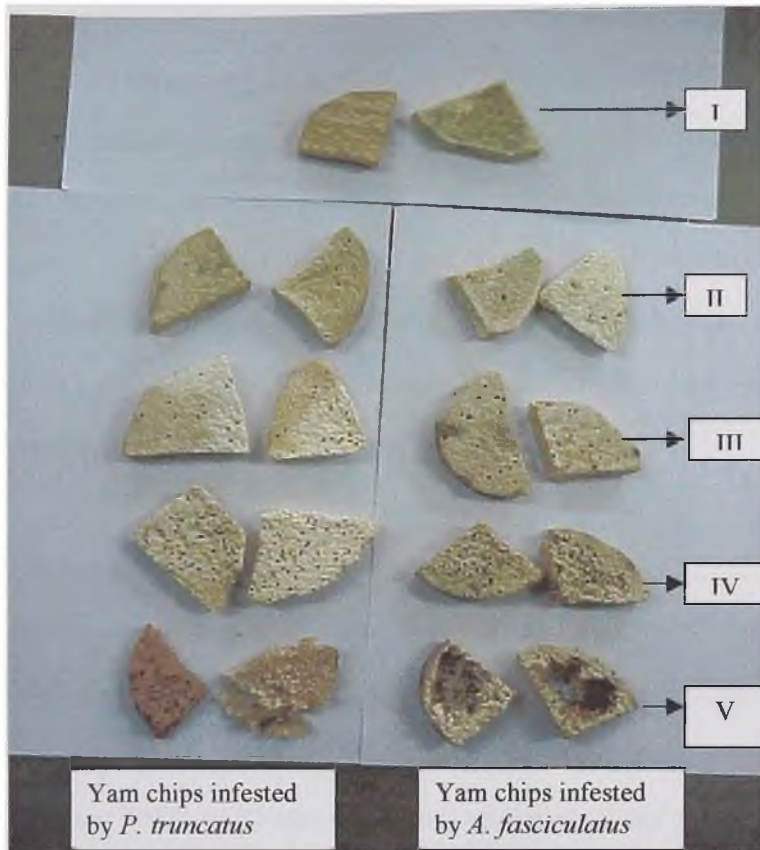


Plate 5: Visual Damage scale used for classification of chips into various damage levels.

3.9 PROXIMATE ANALYSIS OF NUTRIENT COMPOSITION

Proximate analysis was carried out on the yam chips before and after infestation. These determinations were carried out at the Departments of Biochemistry, Nutrition and Food science, and Geography (Ecological Laboratory) University of Ghana, Legon. The yam contents analysed for were; Moisture, Protein, Carbohydrate, Fibre, Fat, Ash, Reducing Sugar and Non-reducing Sugar. The method used for moisture determination is described in section 3.9.

3.10.1 Ash determination

The dry ashing method was used (Osborne and Voogt, 1978). Organic matter in the sample was burned off at as low a temperature as possible, and inorganic material remaining was cooled and weighed. To achieve this, crucibles were heated in a muffle furnace at 600°C for 30 minutes, cooled in a desiccator and weighed. Two grammes of the yam flours were weighed into the each crucible and ashed at 600°C in the muffle furnace for 6 hours. The crucibles were removed and cooled in a desiccator to room temperature. Weight was taken and percentage ash was calculated.

Calculation:

$$\begin{aligned}\text{Weight (g) of sample} &= W_1 \\ \text{Weight (g) of ash} &= W_2 \\ \text{Ash value (\%)} &= (W_2 / W_1) \times 100.\end{aligned}$$

3.10.2 Carbohydrate determination

The Manual Clegg Anthrone Method was used (Helrick, 1991). The material was digested with hydrochloric acid. In this method, hydrolysed starches together with

soluble sugars are determined colorimetrically. One gramme of the sample was transferred into a 250ml conical flask, 40ml of 1M HCl was added to it and the mixture was stirred with a stirring rod. The content of the flask was refluxed for 2 hours. Forty milliliter of 1M NaOH was added to the heated sample after cooling and then filtered with a glass fibre funnel. One milliliter of the sample was pipetted into a test tube and nine milliliter of water were added. From this another one milliliter was pipetted into another test tube to which five milliliter of Anthrone reagent was added. The test tubes were then placed in boiling water bath for 12 minutes and cooled quickly to room temperature. The solution was transferred into 1cm glass cuvettes, and the absorbance was read with the aid of a spectrophotometer at 630nm against a reagent blank. A standard curve of glucose was also obtained. The hydrolysed sugar content was determined as percentage carbohydrate using the standard curve.

3.10.3 Fat determination

The method used for fat determination was as described by Radin (1981). Samples were dissolved in hexane and isopropanol (3:2), heated, cooled and weighed. Here, five grammes of the sample were transferred into a 250ml conical flask, and 50ml of hexane - isopropanol (3:2) added and warmed on a hot plate in a hood for 15 minutes, with thorough mixing while heating. The extraction mixture was filtered rapidly through fluted Whatman filter paper (12.5cm) and additional 20ml of warm hexane – isopropanol (2:3) was poured through the solid residue in the Whatman filter paper. The solvent was removed from the extract by concentration of the extract using a vacuum rotary evaporator to which was attached a reflux condenser. The flask was heated with a warm water bath at 60°C. The fats were seen as yellow oil and / or off-white solid on the

surface of the flask. The flask was removed, cooled and weighed. The weight of the fat was calculated by difference.

Calculation:

$$\begin{aligned}\text{Weight of sample (g)} &= W_1 \\ \text{Weight of flask (g)} &= W_2 \\ \text{Weight of flask + evaporated} \\ \text{sample (g)} &= W_3 \\ \text{Weight of sample (g)} &= W_3 - W_2 \\ \% \text{ fat} &= \frac{W_3 - W_2}{W_1} \times 100\end{aligned}$$

3.10.4 Determination of Reducing and Non-Reducing Sugars

The spectrophotometric method was used (AOAC, 1984). The extraction of the soluble sugar was carried out first and the Anthrone method was used for the determination of the sugars.

One gramme of the sample was transferred into a 250ml conical flask and 150ml of warm water, five milliliters of both carrez I and II each were added. Distilled water was added to make up to 200ml. After cooling, the content was filtered by using a glass fibre funnel powered by suction pump.

To determine reducing sugar, one milliliter of the extract was pipetted into a glass test tube and nine milliliters of water was added. Some one milliliter was taken from this and transferred into a test tube and five milliliters of Anthrone reagent was added, and the mixture was heated in a hot water bath for 12 minutes. The absorbance was taken at

630nm using a spectrophotometer. In order to determine non-reducing sugar, five milliliters of the extract was transferred into a measuring cylinder, two milliliters of 1M HCl was and distilled water was added to make it up to twenty milliliters. This was then transferred into a refluxing flask and refluxed for 10 minutes, two milliliters of 1MNaOH and 3ml of water was added after refluxing. Some one milliliter of the refluxed sample was transferred into a test tube and nine milliliets of water was added. Again one milliliter was taken from this and five milliliters of Anthrone reagent was added in another test tube and heated in a hot water bath for 12 minutes. The absorbance was taken with the aid of a spectrophotometer at 630nm. The absorbance values for both reducing and non-reducing were compared to the glucose standard curve and their percentages determined by calculations.

3.10.5 Crude fibre determination

The method of the International Starch Institute (1999) was used. A fat-free sample was treated with boiling sulphuric acid and subsequently with boiling sodium hydroxide. The residue after subtraction of the ash is regarded as fibre.

Some two and half grammes of each sample was transferred into a beaker, 200ml of boiling sulphuric acid was added and this was connected to the digestion apparatus, boiled for 30 minutes and filtered through filtering cloth. The filtrate was washed with hot water until it was free from acid. The residue was transferred into a flask and 200ml boiling sodium hydroxide solution was added and boiled for further 30 minutes. The flask was removed and filtered immediately through Gooch crucible, washed with hot water until it was free from alkali and then with 10ml of alcohol. This was dried at 105 – 110°C

in an air oven for about two hours, cooled to room temperature in a desiccator and weighed. The 30 minutes drying, cooling and weighing was repeated until the difference between two successive weightings was less than 1 mg. The contents were transferred into a crucible and incinerated in electric muffle furnace at 600°C for 30 minutes, and then cooled to room temperature in a desiccator and weighed. The 30 minutes incinerating, cooling and weighing process was repeated until the difference between successive weightings was less than 1 mg.

Calculation:

Weight (g) of sample	=	W
Weight (g) of crucible and contents after drying	=	W ₁
Weight (g) of crucible and ash after incinerating	=	W ₂
% Crude fibre by weight	=	$\frac{W_1 - W_2}{W} \times 100$

3.10.6 Protein determination

Micro Kjeldahl Method was used (Osborne and Voogt, 1978). In this method, the sample was digested with concentrated sulphuric acid, using copper sulphate as a catalyst, to convert organic nitrogen to ammonium ions. Alkali is added and the liberated ammonium distilled into an excess of boric acid solution. The distillate is titrated with hydrochloric acid to determine the ammonia absorbed in the boric acid.

Some one gramme of the yam flour was weighed into a digesting test tube, a catalyst tablet and eight milliliters of concentrated H₂SO₄ were added and digested until the sample was clear. About thirty milliliters of distilled water and thirty milliliters of 40% NaOH were added and distillation was carried out. Forty milliliters of the distillate was

received in a 100ml conical flask containing ten millilitre of 0.1MHCl and titrated with 0.1M NaOH.

Calculation:

Weight (g) of the test portion	=	W
Volume (ml) of Hcl required for the blank	=	V1
Volume (ml) of Hcl required for the test portion	=	V2
Normality of Hcl	=	N
Crude protein (%)	=	$\frac{(V2 - V1) \times N \times 1.4 \times 6.25}{W}$

NB: The general factor for the conversion of nitrogen protein to crude protein and total protein is 6.25.

3.11 STATISTICAL ANALYSIS

Datas generated from the study was analysed by using Minitab Statistical Package version 13.0. Percentages were transformed using arcsine and insect counts were transformed using logarithm [$\text{Log}_{10}(n+1)$] to meet ANOVA assumptions of normality and homogeneity of variances. Proximate datas were adjusted for by using the weight loss datas. Tukey's pairwise comparison was used to separate the means.

CHAPTER FOUR

4.0 RESULTS

4.1 ASSESSMENT OF DAMAGE

Visual Damage scale method was used to classify chips into various damage levels as described by Compton (1991) section 2.7.2. Visual damage scale picture used is on page 49.

The level of damage caused by *P. truncatus* and *A. fasciculatus* to yam chips during the three months' study period were significantly different (Tables 4.1 and 4.2). Damage increased with time; the lowest damage was recorded on dried yam chips in the first month and the highest in the third month. No damage was recorded on the control chips.

The highest damage was recorded on yam chips infested by *P. truncatus*. The highest percentage damage recorded at the end of the third month were $100 \pm 00\%$ and $90.12 \pm 10.09\%$ for *P. truncatus* and *A. fasciculatus* respectively (Table 4.1 and 4.2). It was observed that by the second and third months, the yam chips and residues had got clumped together while in the first month only holed chips and residues, which were apart were present. This was well pronounced on yam chips infested by *A. fasciculatus*.

The feeding lesions that lead to damage are different for both insects. Holes bored by *P. truncatus* were tiny, numerous and characterized by zigzag patterns within the chips while holes bored by *A. fasciculatus* were wider.

Table 4.1: Percentage damage caused by *P. truncatus* to yam chips.

Variety	Treatment	Percentage damage \pm SE*		
		Month 1	Month 2	Month 3
Asaana	PO	41.56 \pm 2.55 ^b	51.40 \pm 6.19 ^c	61.68 \pm 2.43 ^{cd}
	NO	41.78 \pm 1.78 ^b	54.92 \pm 1.80 ^c	69.22 \pm 3.79 ^d
	PS	46.14 \pm 2.37 ^b	66.20 \pm 4.79 ^{cd}	70.50 \pm 4.99 ^d
	NS	44.20 \pm 2.40 ^b	72.60 \pm 5.80 ^d	75.34 \pm 4.96 ^d
Pona	PO	33.34 \pm 2.41 ^a	35.52 \pm 1.88 ^a	54.86 \pm 1.53 ^c
	NO	30.96 \pm 4.20 ^a	46.52 \pm 7.30 ^{bc}	60.00 \pm 3.54 ^c
	PS	43.40 \pm 3.11 ^b	65.36 \pm 3.39 ^{cd}	66.82 \pm 2.71 ^{cd}
	NS	46.74 \pm 1.97 ^{bc}	51.10 \pm 2.86 ^c	82.08 \pm 5.81 ^{de}
Afasie	PO	49.60 \pm 2.80 ^{bc}	90.28 \pm 5.48 ^e	93.62 \pm 3.29 ^e
	NO	50.74 \pm 1.99 ^c	83.42 \pm 6.35 ^{de}	96.80 \pm 3.20 ^e
	PS	42.48 \pm 2.40 ^b	83.44 \pm 7.84 ^{de}	98.86 \pm 1.14 ^e
	NS	37.96 \pm 1.78 ^b	92.62 \pm 2.66 ^e	100.00 \pm 0.00 ^e

PO: Parboiled oven-dried

NO: Non-parboiled oven-dried

PS: Parboiled sun-dried

NS: Non-parboiled sun-dried

*Values are means of five replicates

Means followed by different letter(s) in both columns and rows are significantly ($P < 0.05$) different from each other at 5% significance level.

Table 4.2: Percentage damage caused by *A. fasciculatus* to yam chips.

Variety	Treatment	Percentage damage \pm SE*		
		Month 1	Month 2	Month 3
Asaana	PO	0.0 ^a	0.0 ^a	0.0 ^a
	NO	0.0 ^a	0.0 ^a	0.0 ^a
	PS	23.06 \pm 2.14 ^b	48.38 \pm 8.19 ^c	61.26 \pm 7.82 ^d
	NS	31.18 \pm 2.43 ^b	85.78 \pm 3.15 ^c	92.00 \pm 4.90 ^e
Pona	PO	0.0 ^a	0.0 ^a	0.0 ^a
	NO	0.0 ^a	0.0 ^a	0.0 ^a
	PS	31.14 \pm 1.90 ^b	52.34 \pm 4.43 ^c	77.38 \pm 5.04 ^d
	NS	28.22 \pm 2.64 ^b	67.70 \pm 9.91 ^d	73.64 \pm 3.25 ^d
Afasie	PO	0.0 ^a	0.0 ^a	0.0 ^a
	NO	0.0 ^a	0.0 ^a	0.0 ^a
	PS	26.50 \pm 2.40 ^b	62.54 \pm 1.35 ^d	84.55 \pm 9.00 ^e
	NS	52.50 \pm 2.26 ^b	70.56 \pm 1.51 ^d	90.12 \pm 10.09 ^e

PO: Parboiled oven-dried

NO: Non-parboiled oven-dried

PS: Parboiled sun-dried

NS: Non-parboiled sun-dried

*Values are means of five replicates

Means followed by different letter(s) in both columns and rows are significantly ($P < 0.05$) different from each other at 5% significance level.

4.2: WEIGHT LOSS DUE TO INFESTATION

Dry weight method was used to calculate for weight loss as described in section 3.8. Weight losses caused by *P. truncatus* and *A. fasciculatus* on dried yam chips over the period of the study were significantly different (Figures 4.1, 4.2, 4.3, 4.4, 4.5 and 4.6). Weight loss increased with time. The lowest percentage weight loss was recorded in the first month and the highest in the third month there was no weight loss recorded on the control chips (Figures 4.1, 4.2, 4.3, 4.4, 4.5 and 4.6). The highest percentage weight losses were $94.91 \pm 1.14\text{g}$ and $91.51 \pm 0.71\text{g}$ for *P. truncatus* and *A. fasciculatus* respectively. But *A. fasciculatus* was not able to survived on Parboiled and Non-parboiled oven-dried yam chips for all the varieties of yam used. A cumulative percentage weight loss of $25.39 \pm 11.30\%$ and $18.98 \pm 11.05\%$ for *P. truncatus* and *A. fasciculatus* respectively were observed at the end of the study period for all the treatments.

Significance different was observed in the percentage weight loss among the varieties of yam used for the study. “Afasie” recorded the highest percentage weight loss and this was significantly more than weight loss observed for “Asaana” and “Pona” No significant difference was observed between the weight loss of “Asaana” and “Pona”
Table 4.3.

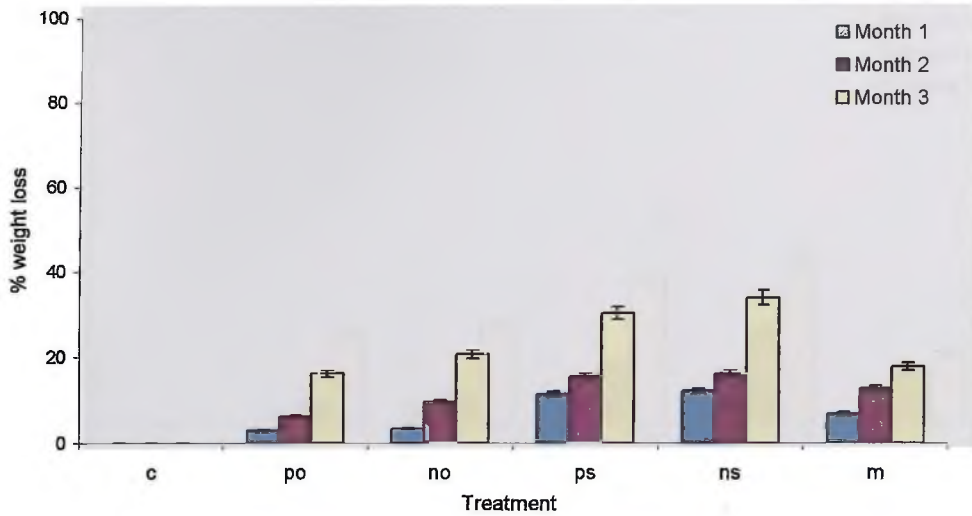


Figure 4.1: Percentage weight loss recorded on "Asaana" dried chips infested by *P. truncatus*

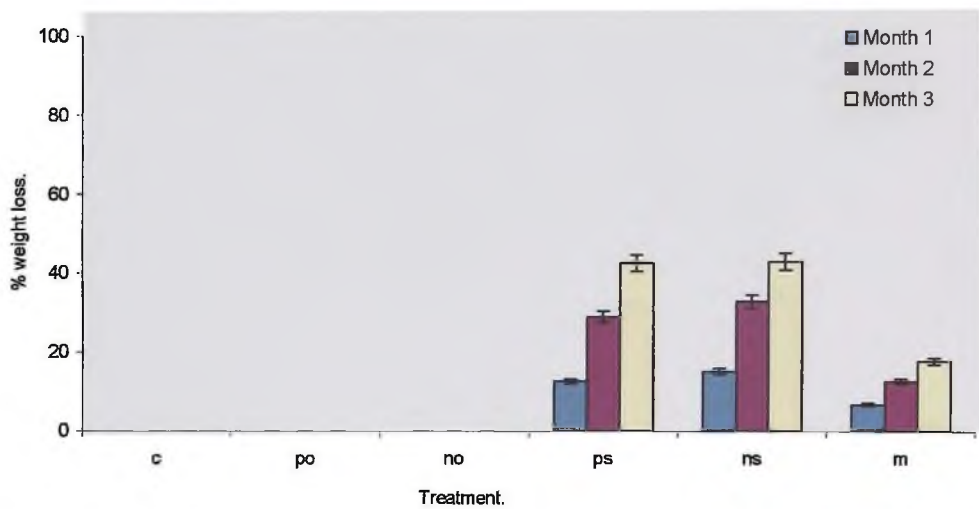


Figure 4.2: Percentage weight loss recorded on "Asaana" dried chips infested by *A. fasciculatus*

KEY

CO: Control chips. PO: Parboiled oven-dried chips. NO: Non-parboiled oven-dried chips. PS: Parboiled sun-dried chips. NS: Non-parboiled sun-dried chips. M: Mixed culture.

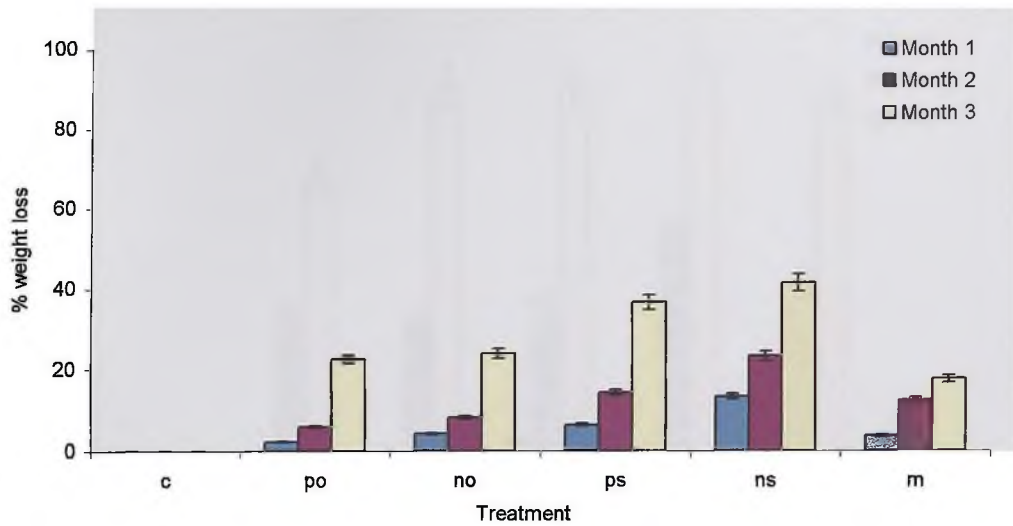


Figure 4.3: Percentage weight loss recorded on "Pona" dried chips infested by *P. truncatus*

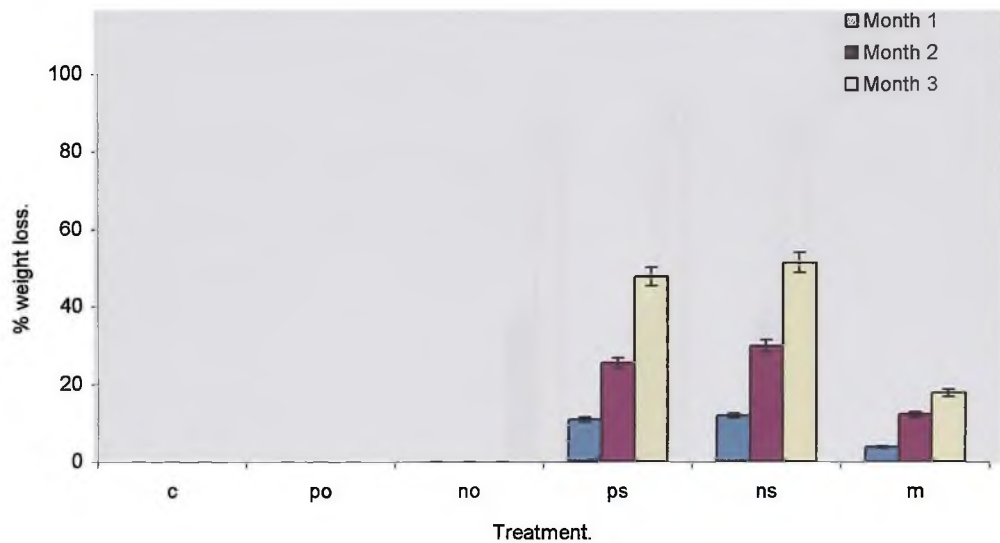


Figure 4.4: Percentage weight loss recorded on "Pona" dried chips infested by *A. fasciculatus*

KEY

CO: Control chips. PO: Parboiled oven-dried chips. NO: Non-parboiled oven-dried chips. PS: Parboiled sun-dried chips. NS: Non-parboiled sun-dried chips. M: Mixed culture.

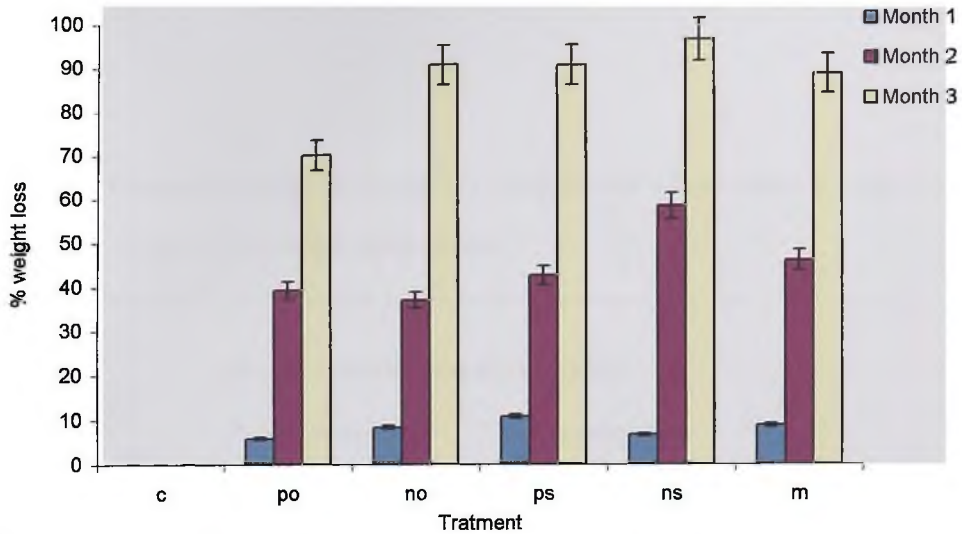


Figure 4.5: Percentage weight loss recorded on "Afasie" dried chips infested by *P. truncatus*

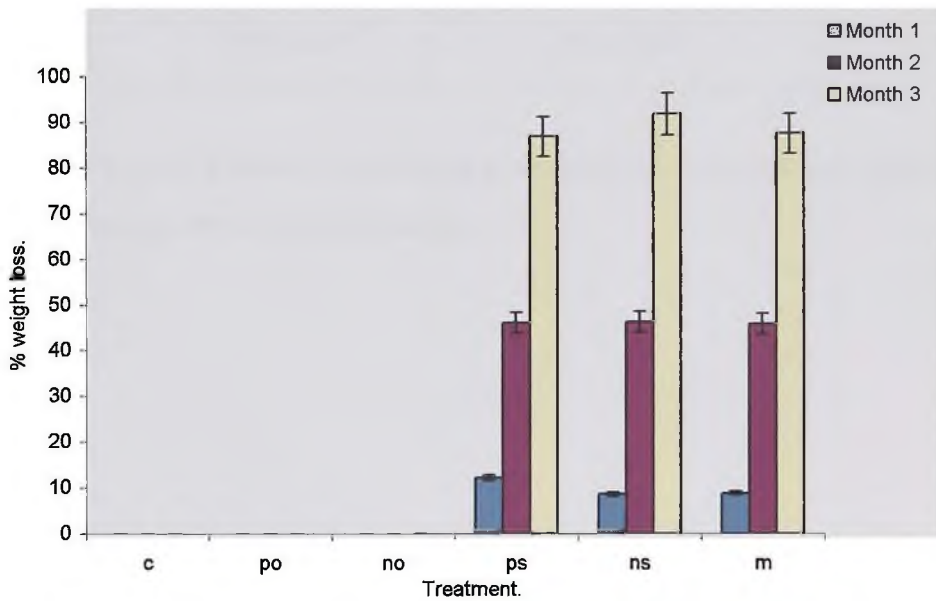


Figure 4.6: percentage weight loss recorded on "Afasie" dried chips infested by *A. fasciculatus*

KEY

CO: Control chips. PO: Parboiled oven-dried chips. NO: Non-parboiled oven-dried chips. PS: Parboiled sun-dried chips. NS: Non-parboiled sun-dried chips. M: Mixed culture.

Table 4.3: Percentage weight loss caused by *P. truncatus* and *A. fasciculatus* to varieties of yams over a period of three months.

Variety	Pooled percentage weight loss \pm SE*	
	<i>P. truncatus</i>	<i>A. fasciculatus</i>
Asaana	14.79 \pm 2.68 ^a	14.54 \pm 4.86 ^a
Pona	16.80 \pm 3.52 ^a	14.71 \pm 5.33 ^a
Afasie	45.95 \pm 9.46 ^c	24.23 \pm 9.62 ^b

Means followed by different letter(s) in both columns and rows are significantly ($P < 0.05$) different from each other at 5% significance level.

4.3 SURVIVAL AND ESTABLISHMENT OF *P. truncatus* AND *A. fasciculatus* ON DRIED YAM CHIPS.

During the laboratory study on the yam chips, significant differences were observed among the mean number of insects that survived and established on the various treatments of yam chips produced from “Asaana”, “Pona” and “Afasie”. Insect survival and establishment increased over time for all the treatments. The highest number of insects was recorded in the third month; 577.6 ± 58.11 and 328.0 ± 16.90 for *P. truncatus* and *A. fasciculatus* respectively (Tables 4.4 and 4.5). Significant difference was observed among the mixed culture of the insects on the variety of yams. *P. truncatus* was more than *A. fasciculatus* in the mixed culture. Number of insects recorded on “Afasie” was significantly more than those recorded on “Asaana” and “Pona” (Table 4.6).

Significant differences in the mean number of insects were observed on the varieties of yams used. The number of insects recorded on “Afasie” were significantly more than those recorded on “Asaana” and “Pona”, while no significant differences was observed for the number of insects recorded between “Asaana” and “Pona”. “Afasie” recorded the highest number of insects for both *P. truncatus* and *A. fasciculatus* (Table 4.6).

A. fasciculatus did not survive on Parboiled and Non-Parboiled oven-dried treatments, for all the yam varieties.



Table 4.4: Mean number of *P. truncatus* recorded on different treatments of dried yam chips.

Variety	Treatment	Mean number of insects \pm SE*		
		Month 1	Month 2	Month 3
Asaana	PO	24.85 \pm 2.01 ^a	87.23 \pm 3.56 ^c	194.00 \pm 13.53 ^{de}
	NO	32.24 \pm 3.25 ^a	91.62 \pm 3.11 ^c	226.44 \pm 21.70 ^e
	PS	31.49 \pm 2.63 ^a	152.66 \pm 7.11 ^d	249.28 \pm 12.65 ^{ef}
	NS	34.67 \pm 3.12 ^a	169.22 \pm 6.24 ^{de}	230.60 \pm 14.85 ^{ef}
Pona	PO	22.64 \pm 3.02 ^a	84.21 \pm 5.58 ^c	238.26 \pm 9.91 ^{ef}
	NO	23.47 \pm 2.28 ^a	74.84 \pm 7.31 ^b	232.05 \pm 19.27 ^{ef}
	PS	47.41 \pm 2.26 ^{ab}	141.20 \pm 5.32 ^d	279.22 \pm 31.95 ^g
	NS	30.42 \pm 2.35 ^a	168.27 \pm 3.31 ^{de}	312.88 \pm 40.65 ^h
Afasie	PO	46.63 \pm 4.62 ^{ab}	226.26 \pm 15.47 ^{ef}	435.21 \pm 22.11 ⁱ
	NO	37.80 \pm 2.53 ^a	249.66 \pm 20.28 ^{ef}	577.60 \pm 58.15 ^j
	PS	43.05 \pm 4.02 ^{ab}	243.69 \pm 27.41 ^{ef}	556.84 \pm 24.87 ^j
	NS	41.25 \pm 2.76 ^{ab}	290.84 \pm 37.84 ^{gh}	536.88 \pm 18.24 ^j

PO: Parboiled oven-dried

NO: Non-parboiled oven-dried

PS: Parboiled sun-dried

NS: Non-parboiled sun-dried

*Values are means of five replicates

Means followed by different letter(s) in both columns and rows are significantly ($P < 0.05$) different from each other at 5% significance level.

Table 4.5: Mean number of *A. fasciculatus* recorded on different treatments of the dried yam chips.

Variety	Treatment	Mean number of insects \pm SE*		
		Month 1	Month 2	Month 3
Asaana	PO	0.0 ^a	0.0 ^a	0.0 ^a
	NO	0.0 ^a	0.0 ^a	0.0 ^a
	PS	25.23 \pm 5.16 ^a	114.25 \pm 4.82 ^b	205.69 \pm 13.27 ^c
	NS	30.28 \pm 7.78 ^a	122.09 \pm 7.59 ^b	236.47 \pm 39.53 ^c
Pona	PO	0.0 ^a	0.0 ^a	0.0 ^a
	NO	0.0 ^a	0.0 ^a	0.0 ^a
	PS	32.00 \pm 6.31 ^a	97.45 \pm 5.45 ^b	211.05 \pm 5.12 ^c
	NS	43.00 \pm 6.77 ^a	133.69 \pm 32.81 ^b	273.62 \pm 32.19 ^d
Afasie	PO	0.0 ^a	0.0 ^a	0.0 ^a
	NO	0.0 ^a	0.0 ^a	0.0 ^a
	PS	32.49 \pm 1.56 ^a	234.00 \pm 18.33 ^c	315.25 \pm 32.14 ^d
	NS	40.88 \pm 5.17 ^a	214.47 \pm 15.69 ^c	328.07 \pm 16.97 ^d

PO: Parboiled oven-dried

NO: Non-parboiled oven-dried

PS: Parboiled sun-dried

NS: Non-parboiled sun-dried

*Values are means of five replicates

Means followed by different letter(s) in both columns and rows are significantly ($P < 0.05$) different from each other at 5% significance level.

Table 4.6: Mean number of *P. truncatus* and *A. fasciculatus* recorded on mixed culture of dried yam chips

Variety	Mean number of insects \pm SE*		
	Month 1	Month 2	Month 3
Asaana	65.23 \pm 6.87 ^a	122.63 \pm 11.46 ^b	209.60 \pm 20.71 ^c
Pona	52.00 \pm 3.97 ^a	114.82 \pm 15.00 ^b	190.24 \pm 20.44 ^c
Afasie	110.26 \pm 7.81 ^b	263.63 \pm 16.76 ^d	501.82 \pm 37.85 ^e

*Values are means of five replicates

Means followed by different letter(s) in both columns and rows are significantly ($P < 0.05$) different from each other at 5% significance level

4.4: CONTAMINANTS PRODUCED BY *P. truncatus* AND *A. fasciculatus* ON YAM CHIPS

P. truncatus and *A. fasciculatus* produced contaminants through their biological processes. Contaminants such as powdery residues of damaged yam chips were produced through their feeding, excrement through defecation, insect fragments through moulting and death (Table 4.7).

There were variations in the frass contaminants and this increased with time for both insects. The highest frass contamination was recorded at the end of the third month.

The parboiled and non-parboiled oven-dried yam chips infested with *P. truncatus* recorded the lowest amount of frass, while infestation with *A. fasciculatus* recorded no frass from these treatments, because the insects did not survive on them.

Yam chips infested with *P. truncatus* recorded high levels of powdery residues and *A. fasciculatus* recorded relatively low levels of powdery residues. The highest weight of powdery residues produced by the insects were $178.32 \pm 6.57\text{g}$ and $134.22 \pm 179\text{g}$ for *P. truncatus* and *A. fasciculatus* respectively.

At the end of the second and third months of the study, characteristic pungent odour and clumpiness was observed in the powdery residues produced. These varied with time and was more pronounced for *A. fasciculatus* than for *P. truncatus*.

Variations occurred in the levels of contamination for the different varieties. “Afasié” recorded the highest contaminants while there was insignificant variation in that of “Asana” and “Pona”.

Table 4.7: Types of contaminants produced with time by *P. truncatus* and *A. fasciculatus* in cultures.

Insect	1 month	2 months	3 months
Control	No contaminants	No contaminants	No contaminants
<i>P. truncatus</i>	Powdery residue and frass	Powdery residue, frass, insect fragments and odour	Powdery residue, frass, insect fragments, odour and clumpiness
<i>A. fasciculatus</i>	Powdery residue, frass and insect fragments	Powdery residue, frass, insect fragments, odour and clumpiness	Powdery residue, frass, insect fragments, odour and clumpiness
Mixed culture (<i>A. fasciculatus</i> and <i>P. truncatus</i>)	Powdery residue, frass and insect fragments	Powdery residue, frass, insect fragments, odour and clumpiness	Powdery residue, frass, insect fragments, odour and clumpiness

When the weight of frass produced from the different treatments were taken, significant difference were observed in the weight of these frass contaminants produced by the insects on the various treatments over the period of the study. The weight of frass contaminants increased with time. (Tables 4.8 and 4.9).

The highest weight of frass was recorded at the end of the third month. Frass weights of $25.63 \pm 2.71\text{g}$ and $19.55 \pm 1.66\text{g}$ were recorded for *P. truncatus* and *A. fasciculatus*

respectively. Therefore *P. truncatus* recorded the highest frass contaminants (Tables 4.8 and 4.9).

The weight of frass recorded for “Afasie” was significantly more than those recorded on “Asaana” and “Pona” There was no significant difference in the weight of frass recorded on “Asaana” and “Pona”

Table 4.8: Percentage frass contaminants produced by *P. truncatus* on yam chips.

Variety	Treatment	Percentage frass contaminants \pm SE*		
		Month 1	Month 2	Month 3
Asaana	PO	0.29 \pm 0.22 ^a	1.91 \pm 0.48 ^{ab}	8.82 \pm 0.98 ^{cd}
	NO	0.33 \pm 0.06 ^a	3.13 \pm 0.51 ^b	10.10 \pm 0.96 ^d
	PS	0.99 \pm 0.16 ^b	3.34 \pm 0.47 ^b	12.33 \pm 1.16 ^e
	NS	0.92 \pm 0.26 ^{ab}	4.65 \pm 0.88 ^c	8.01 \pm 1.75 ^{cd}
Pona	PO	0.25 \pm 0.05 ^a	1.39 \pm 0.14 ^{ab}	4.44 \pm 0.87 ^c
	NO	0.46 \pm 0.09 ^a	1.55 \pm 0.36 ^{ab}	8.45 \pm 1.17 ^{c^d}
	PS	0.68 \pm 0.17 ^a	2.82 \pm 0.47 ^b	11.63 \pm 0.74 ^e
	NS	1.39 \pm 0.18 ^{ab}	7.91 \pm 0.48 ^c	17.27 \pm 0.99 ^f
Afasie	PO	0.61 \pm 0.12 ^a	4.01 \pm 0.78 ^b	10.98 \pm 1.05 ^d
	NO	0.82 \pm 0.14 ^a	3.73 \pm 0.58 ^b	15.56 \pm 2.47 ^f
	PS	0.60 \pm 0.12 ^a	6.91 \pm 0.77 ^c	20.97 \pm 1.09 ^e
	NS	1.53 \pm 0.23 ^{ab}	6.81 \pm 0.84 ^c	25.63 \pm 2.71 ^h

PO: Parboiled oven-dried

NO: Non-parboiled oven-dried

PS: Parboiled sun-dried

NS: Non-parboiled sun-dried

*Values are means of five replicates

Means followed by different letter(s) in both columns and rows are significantly ($P < 0.05$) different from each other at 5% significance level.

Table 4.9: Percentage frass contaminants produced by *A. fasciculatus* on yam chips.

Variety	Treatment	Percentage frass contaminants \pm SE*		
		Month 1	Month 2	Month 3
Asaana	PO	0.0 ^a	0.0 ^a	0.0 ^a
	NO	0.0 ^a	0.0 ^a	0.0 ^a
	PS	1.25 \pm 0.09 ^b	9.89 \pm 0.46 ^c	14.27 \pm 0.23 ^d
	NS	1.51 \pm 0.07 ^b	7.28 \pm 0.62 ^c	17.69 \pm 0.39 ^d
Pona	PO	0.0 ^a	0.0 ^a	0.0 ^a
	NO	0.0 ^a	0.0 ^a	0.0 ^a
	PS	1.07 \pm 0.06 ^b	6.24 \pm 0.93 ^c	12.76 \pm 0.21 ^{cd}
	NS	1.18 \pm 0.13 ^b	4.37 \pm 0.59 ^c	11.11 \pm 0.44 ^{cd}
Afasie	PO	0.0 ^a	0.0 ^a	0.0 ^a
	NO	0.0 ^a	0.0 ^a	0.0 ^a
	PS	1.21 \pm 0.08 ^b	15.34 \pm 0.72 ^d	18.66 \pm 0.88 ^e
	NS	0.85 \pm 0.06 ^b	17.01 \pm 0.95 ^d	19.55 \pm 1.66 ^e

PO: Parboiled oven-dried

NO: Non-parboiled oven-dried

PS: Parboiled sun-dried

NS: Non-parboiled sun-dried

*Values are means of five replicates

Means followed by different letter(s) in both columns and rows are significantly ($P < 0.05$) different from each other at 5% significance level.

4.5: THE RELATIONSHIP BETWEEN INSECT DENSITY AND DAMAGE CAUSED.

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

It was observed that, there was positive correlation between treatments, percentage weight loss, percentage damage and percentage frass. A negative correlation coefficient was observed for percentage damage in the first month. (Table 4.10). There was smooth correlation between insect number and treatments, percentage weight loss, percentage frass and percentage of damaged yam chips, but this relationship fluctuates for all these parameters.

The correlation was significantly different for all the months (Table 4.10). However, this relation was not significantly ($P>0.05$) different for percentage damage in the first month for *P. truncatus*.

Table 4.10: Correlation between insect number and; treatments, percentage damage, percentage weight loss and percentage frass.

Insect no	Correlation coefficient ®			
	Treatments	%damage	%weight loss	%frass
A ₁	0.582**	-0.159	0.779**	0.566**
A ₂	0.381**	0.497**	0.928**	0.581**
A ₃	0.293**	0.668**	0.806**	0.548**
B ₁	0.916**	0.889**	0.860**	0.831**
B ₂	0.657**	0.927**	0.918**	0.892**
B ₃	0.738**	0.881**	0.941**	0.904**

A₁ – A₃: Number of *P. truncatus* in the 1st – 3rd month.

B₁ – B₃: Number of *A. fasciculatus* in the 1st – 3rd month.

*Correlation is significant at the 0.01 level.

**Correlation is significant at the 0.05 level.

- Negative correlation.

75 sample were used for each month in each parameter considered for *P. truncatus* and *A. fasciculatus* respectively.

4.6: PROXIMATE COMPOSITION OF YAM VARIETIES USED FOR THE STUDIES

Ranges of mean values obtained for the *D. rotundata* and *D. alata* varieties studied in g/100g dry weight basis were: moisture 8.88% – 12.09%, ash 2.63% – 2.92%, crude protein 3.59% – 3.74%, crude fibre 1.50% – 1.62%, total fats 0.23% – 0.31%, total carbohydrates 60.59% – 67.46%, reducing sugar 7.31% – 8.09% and non-reducing sugar 7.10% – 9.60% (Table 4.13).

On the basis of moisture content recorded, the *D. alata* (Afasie) was observed to be slightly higher than the *D. rotundata* (Asaana and Pona) while no difference was observed between the varieties of *D. rotundata*. The levels of total carbohydrate obtained for all the varieties were similar, but mean value for “Asaana” was significantly higher than the mean values of “Pona” and “Afasie” while no difference was observed between the mean values of “Asaana” and “Afasie” (Table 4.11).

The following compositions: fats, reducing sugar, non-reducing sugar, ash, fibre and crude protein showed similarities in their mean values and so no significant differences were observed (Table 4.11).

Based on the treatments applied to the varieties of yams studied, slight variations in their compositions were observed. The variations observed were significant in some cases and insignificant in others (Tables 4.12, 4.13 and 4.14).

When a comparison was made of the composition of chips subjected to different treatments it was found that the moisture content for “Asaana” was slightly high for

parboiled oven-dried chips, this was significantly different from the moisture contents of other treatments. The values for the fat content were similar for all the treatments. Therefore, significant difference was not observed for the fat contents of all the treatments. A similar trend was observed for reducing and non-reducing sugars. In both cases, parboiled and non-parboiled sun-dried chips were significantly higher than the other treatments. The carbohydrate content was high for non-parboiled oven-dried and non-parboiled sun-dried. Ash content for parboiled oven-dried treatments was significantly lower compared to all other treatments while the crude protein and crude fibre content values showed similarities for all the treatments (Table 4.12).

The moisture content for “Pona” was significantly higher for both parboiled and non-parboiled oven-dried treatments. Non-parboiled oven-dried chips were significantly higher in reducing sugar. Significantly higher values of non-reducing sugar were observed for non-parboiled oven-dried and parboiled sun-dried. The following: ash, fat, carbohydrate, fibre and protein show no significant differences in the values observed for all the treatments (Table 4.13).

Under the “Afasie” yam variety, a significantly higher moisture content was observed in non-parboiled sun-dried chips. A significantly higher value was observed for reducing sugars in parboiled and non-parboiled oven-dried chips. Parboiled oven-dried chips show a significantly high value for non-reducing sugar. The carbohydrate content of parboiled and non-parboiled sun-dried chips was significantly higher than the remaining treatments. No significant difference was observed among the following compositions; Fat, ash, fibre and protein for all the treatments (Table 4.14).

Table 4.11: Proximate composition of *D. rotundata* and *D. alata* dried chips.

Composition	% Composition \pm SE*		
	<i>D. rotundata</i>		<i>D. alata</i>
	Asaana	Pona	Afasie
Moisture	8.88 \pm 0.27 ^a	9.05 \pm 0.32 ^a	12.09 \pm 2.00 ^b
Fats	0.31 \pm 0.21 ^a	0.23 \pm 0.14 ^a	0.29 \pm 0.08 ^a
R/Sugar	7.53 \pm 1.05 ^a	8.09 \pm 1.56 ^a	7.31 \pm 0.90 ^a
N/Sugar	7.10 \pm 0.82 ^a	9.60 \pm 0.81 ^a	9.04 \pm 1.29 ^a
Carbohydrate	67.46 \pm 1.17 ^b	60.59 \pm 0.72 ^a	64.37 \pm 2.51 ^{ab}
Ash	2.92 \pm 0.21 ^a	2.63 \pm 0.13 ^a	2.78 \pm 0.09 ^a
Fibre	1.62 \pm 0.06 ^a	1.50 \pm 0.05 ^a	1.59 \pm 0.07 ^a
Protein	3.74 \pm 0.09 ^a	3.59 \pm 0.15 ^a	3.61 \pm 0.07 ^a

Mean values (g/100g dry matter basis) from triplicate analysis \pm standard error

Means followed by different letters in the rows are significantly ($P < 0.05$) different from each other at 5% significance level.

Table 4.12: Proximate composition of “Asaana” (*D. rotundata*) dried chips.

Composition	% Composition \pm SE*			
	PO	NO	PS	NS
Moisture	9.79 \pm 0.28 ^b	8.69 \pm 0.28 ^{ab}	8.43 \pm 0.15 ^a	8.60 \pm 0.03 ^a
Fats	0.32 \pm 0.05 ^a	0.30 \pm 0.07 ^a	0.31 \pm 0.06 ^a	0.33 \pm 0.13 ^a
R/Sugar	8.26 \pm 1.69 ^b	10.63 \pm 0.35 ^b	5.77 \pm 0.48 ^a	5.45 \pm 0.27 ^a
N/Sugar	8.56 \pm 0.53 ^b	8.85 \pm 0.36 ^b	5.14 \pm 0.55 ^a	5.83 \pm 0.21 ^a
Carbohydrate	63.56 \pm 1.45 ^a	69.18 \pm 2.00 ^b	67.74 \pm 2.21 ^b	69.36 \pm 0.76 ^b
Ash	2.22 \pm 0.05 ^a	3.01 \pm 0.07 ^b	3.07 \pm 0.05 ^b	3.17 \pm 0.06 ^b
Fibre	1.42 \pm 0.07 ^a	1.63 \pm 0.10 ^a	1.66 \pm 0.09 ^a	1.75 \pm 0.09 ^a
Protein	3.90 \pm 0.28 ^a	3.43 \pm 0.14 ^a	3.83 \pm 0.11 ^a	3.81 \pm 0.10 ^a

Mean values (g/100g dry matter basis) from triplicate analysis \pm standard error

PO = Parboiled oven dried

NO = Non-parboiled oven dried

PS = Parboiled sun-dried

NS = Non-parboiled sun-dried

Means followed by different letters in the rows are significantly ($P < 0.05$) different from each other at 5% significance level.

Table 4.13: Proximate composition of “Pona” (*D. rotundata*) dried chips.

Composition	% Composition \pm SE*			
	PO	NO	PS	NS
Moisture	9.39 \pm 0.15 ^b	9.82 \pm 0.42 ^b	8.49 \pm 0.34 ^a	8.41 \pm 0.09 ^a
Fats	0.22 \pm 0.02 ^a	0.27 \pm 0.15 ^a	0.20 \pm 0.02 ^a	0.25 \pm 0.12 ^a
R/Sugar	10.06 \pm 0.42 ^b	12.14 \pm 0.12 ^c	4.65 \pm 0.87 ^a	5.49 \pm 0.92 ^a
N/Sugar	9.09 \pm 0.59 ^b	11.24 \pm 0.26 ^c	10.90 \pm 1.50 ^b	7.16 \pm 1.13 ^a
Carbohydrate	60.90 \pm 1.70 ^a	58.60 \pm 1.56 ^a	62.63 \pm 3.69 ^a	60.22 \pm 0.41 ^a
Ash	2.35 \pm 0.10 ^a	2.83 \pm 0.02 ^a	2.94 \pm 0.01 ^a	2.39 \pm 0.11 ^a
Fibre	1.47 \pm 0.13 ^a	1.66 \pm 0.09 ^a	1.40 \pm 0.21 ^a	1.45 \pm 0.28 ^a
Protein	4.10 \pm 0.62 ^a	3.31 \pm 0.13 ^a	3.40 \pm 0.24 ^a	3.55 \pm 0.12 ^a

Mean values (g/100g dry matter basis) from triplicate analysis \pm standard error

PO = Parboiled oven dried

NO = Non-parboiled oven dried

PS = Parboiled sun-dried

NS = Non-parboiled sun-dried

Means followed by different letters in the rows are significantly ($P < 0.05$) different from each other at 5% significance level.

Table 4.14: Proximate composition of “Afasie” (*D. alata*) dried chips.

Composition	% Composition \pm SE*			
	PO	NO	PS	NS
Moisture	9.25 \pm 0.05 ^a	11.80 \pm 0.15 ^b	12.37 \pm 0.36 ^{bc}	14.94 \pm 1.59 ^c
Fats	0.29 \pm 0.01 ^a	0.26 \pm 0.06 ^a	0.29 \pm 0.02 ^a	0.31 \pm 0.07 ^a
R/Sugar	8.91 \pm 0.65 ^b	9.01 \pm 0.48 ^b	4.68 \pm 0.75 ^a	6.63 \pm 1.31 ^a
N/Sugar	13.01 \pm 1.56 ^c	9.86 \pm 0.33 ^b	6.32 \pm 0.85 ^a	7.28 \pm 1.82 ^a
Carbohydrate	59.17 \pm 1.70 ^a	59.57 \pm 2.34 ^a	69.81 \pm 3.51 ^b	68.94 \pm 2.29 ^b
Ash	2.69 \pm 0.29 ^a	2.54 \pm 0.26 ^a	2.93 \pm 0.11 ^a	2.96 \pm 0.12 ^a
Fibre	1.37 \pm 0.12 ^a	1.60 \pm 0.10 ^a	1.65 \pm 0.09 ^a	1.72 \pm 0.07 ^a
Protein	3.69 \pm 0.14 ^a	3.57 \pm 0.23 ^a	3.38 \pm 0.16 ^a	3.78 \pm 0.26 ^a

Mean values (g/100g dry matter basis) from triplicate analysis \pm standard error

PO = Parboiled oven dried

NO = Non-parboiled oven dried

PS = Parboiled sun-dried

NS = Non-parboiled sun-dried

Means followed by different letters in the rows are significantly ($P < 0.05$) different from each other at 5% significance level.

4.7: BIOCHEMICAL CHANGES IN YAM CHIPS AFTER INFESTATION BY

P. truncatus* AND *A. fasciculatus

Infestation of yam chips by *P. truncatus* and *A. fasciculatus* resulted in quality loss and product deterioration. Such deterioration also resulted from inadvertent deleterious biochemical reactions and changes in environmental factors. In order to ascertain the levels of quality loss (biochemical composition of the chips), investigations were carried out into the biochemical changes associated with the dried yam chips after infestation. Analysed samples were taken from damaged chips and powdery residues after grinding.

4.7.1 Moisture content of the dried yam chips after infestation by *P. truncatus* and *A. fasciculatus*.

Infestation by the two insects led to an increase in the moisture content of the damage chips and to a large extent in the powdery residue produced from the chips due to their biological activities. It was observed that significant ($P < 0.01$) differences existed among the moisture content values of the various treatments (Appendices II and IV). The percentage moisture content value increased significantly with time and level of infestation (Tables 4.15 and 4.16).

The percentage moisture content values recorded ranged from 12.73% - 20.00%. The lowest moisture contents were recorded in the first month while the highest were recorded in the third month. The lowest moisture content of 12.73% was recorded on parboiled oven-dried "Pona" infested by *A. fasciculatus* and the highest value of 20.00% was recorded in some of the treatments in both cases for the insects studied (Tables 4.15 and 4.16).

The moisture content values before infestation ranged from 8.88% 12.09%. The increase in % moisture content value of infested chips with respect to the un-infested chips was significantly high for both insects.

It was observed that no significant differences existed among the percentage moisture contents of the varieties (Asaana, Pona and Afasie) infested by *P. truncatus* and *A. fasciculatus*.

Table 4.15: Percentage moisture content of dried yam chips with different treatments after infestation by *P. truncatus* over a period of three months.

Variety	Treatment	Percentage means \pm SE*		
		Month 1	Month 2	Month 3
Asaana	PO	15.00 \pm 0.00 ^{ab}	14.53 \pm 0.40 ^{ab}	17.50 \pm 2.50 ^{bc}
	NO	14.13 \pm 0.76 ^a	14.73 \pm 0.38 ^{ab}	15.00 \pm 0.00 ^{ab}
	PS	17.17 \pm 2.02 ^{bc}	18.17 \pm 2.75 ^{bc}	19.50 \pm 0.50 ^c
	NS	17.37 \pm 2.51 ^{bc}	15.07 \pm 0.12 ^{ab}	19.33 \pm 0.58 ^c
Pona	PO	14.23 \pm 0.71 ^{ab}	14.97 \pm 0.25 ^{ab}	15.00 \pm 0.10 ^{ab}
	NO	15.00 \pm 0.00 ^{ab}	14.67 \pm 0.35 ^{ab}	16.93 \pm 2.27 ^b
	PS	12.93 \pm 1.22 ^a	14.70 \pm 0.36 ^{ab}	15.67 \pm 1.41 ^{ab}
	NS	18.23 \pm 0.75 ^{bc}	17.50 \pm 2.50 ^{bc}	20.00 \pm 0.00 ^c
Afasie	PO	12.47 \pm 2.40 ^a	20.03 \pm 0.95 ^c	19.97 \pm 0.06 ^c
	NO	14.70 \pm 0.36 ^{ab}	15.00 \pm 0.00 ^{ab}	15.00 \pm 0.00 ^{ab}
	PS	15.00 \pm 0.00 ^{ab}	15.00 \pm 0.00 ^{ab}	15.00 \pm 0.00 ^{ab}
	NS	14.10 \pm 1.02 ^{ab}	17.67 \pm 2.45 ^{bc}	17.50 \pm 2.50 ^{bc}

*Mean values (g/100g dry matter basis) from triplicate analysis \pm standard error

PO: Parboiled oven-dried

NO: Non-parboiled oven-dried

PS: Parboiled sun-dried

NS: Non-parboiled sun-dried

Means followed by different letter(s) in both columns and rows are significantly ($P < 0.05$) different from each other at 5% significance level.

Table 4.16: Percentage moisture content of dried yam chips with different treatments after infestation by *A. fasciculatus* over a period of three months.

Variety	Treatment	Percentage means \pm SE*		
		Month 1	Month 2	Month 3
Asaana	PO	14.67 \pm 0.29 ^{ab}	14.97 \pm 0.06 ^{ab}	16.50 \pm 1.41 ^{bc}
	NO	14.70 \pm 0.36 ^{ab}	14.07 \pm 0.78 ^{ab}	15.00 \pm 0.00 ^{ab}
	PS	17.37 \pm 2.51 ^{bc}	15.00 \pm 0.00 ^{ab}	19.40 \pm 0.53 ^c
	NS	15.00 \pm 0.00 ^{ab}	18.10 \pm 0.46 ^{bc}	20.00 \pm 0.00 ^c
Pona	PO	14.23 \pm 1.08 ^{ab}	15.13 \pm 0.91 ^{ab}	14.60 \pm 0.46 ^{ab}
	NO	13.90 \pm 0.69 ^{ab}	12.73 \pm 2.38 ^a	14.63 \pm 0.55 ^{ab}
	PS	15.87 \pm 2.80 ^b	17.33 \pm 1.56 ^{bc}	18.17 \pm 2.75 ^{bc}
	NS	18.60 \pm 0.69 ^{bc}	18.33 \pm 5.77 ^{bc}	18.00 \pm 1.80 ^{bc}
Afasie	PO	12.57 \pm 0.91 ^a	12.60 \pm 2.51 ^a	14.07 \pm 0.57 ^{ab}
	NO	12.30 \pm 0.44 ^a	13.73 \pm 0.91 ^{ab}	14.77 \pm 0.40 ^{ab}
	PS	15.33 \pm 0.76 ^{ab}	17.47 \pm 2.21 ^{b^c}	20.00 \pm 0.00 ^c
	NS	15.43 \pm 0.70 ^{ab}	15.93 \pm 1.48 ^b	20.00 \pm 0.00 ^c

*Mean values (g/100g dry matter basis) from triplicate analysis \pm standard error

PO: Parboiled oven-dried

NO: Non-parboiled oven-dried

PS: Parboiled sun-dried

NS: Non-parboiled sun-dried

Means followed by different letter(s) in both columns and rows are significantly ($P < 0.05$) different from each other at 5% significance level.

4.7.2: Percentage total fats of the dried yam chips after infestation by *P. truncatus* and *A. fasciculatus*.

The fat content of the yam chips after infestation by *P.truncatus* and *A. fasciculatus*, was not significantly ($P>0.05$) different for all the various form of treatments (Appendices II and IV).

Value for uninfested yam chips ranged from 0.23% - 0.31%. Values for percentage total fat recorded for the various treatments ranged from 0.42% - 0.91%. The lowest values were recorded in the first month and the highest values in the third month. The lowest value of 0.42% was recorded on the yam chips infested by *P truncatus* and the highest value of 0.91% was recorded on chips infested by *A. fasciculatus*.

No significant ($P>0.05$) difference was observed for the percentage total fat contents for the varieties (Asaana, Pona and Afasie) of yams used for the study (Appendix V). The percentage total fats recorded for varieties ranged from 0.56% - 0.78% for *P. truncatus* and *A. fasciculatus*.

4.7.3 Percentage reducing sugar in the dried yam chips after infestation by *P. truncatus* and *A. fasciculatus*

Significantly ($P < 0.05$) higher values were observed for reducing sugar in the first month and these decreased significantly with the level of infestation in the second and third months after infestation by *P. truncatus* (Table 4.17). Levels of reducing sugar in dried yam chips infested by *A. fasciculatus* were not consistent. Parboiled and non-parboiled oven-dried for all variety showed significantly ($P < 0.05$) higher values for the duration of the study, these values were not significantly different from the initial reducing sugar observed before infestation (Appendices II and IV). Parboiled sun-dried chips and non-parboiled sun-dried chips showed a significant drastic reduction in reducing sugar over the period of three months (Table 4.18).

The values observed ranged from 0.31% - 11.63% for *P. truncatus*. The lowest value was recorded in the third month and the highest in the first month. The values observed for *A. fasciculatus* ranged from 0.52% - 10.83%, lowest values were observed for the yam chips infested and high values were observed for the chips that are uninfested.

The initial values observed for all treatments before infestation ranged from 4.65% - 12.14% (Table 4.13). In contrast with values observed after infestation (Tables 4.17 and 4.18), these indicated that there were greater variations in the various treatments between the levels of reducing sugar before and after infestation. The reducing sugar content reduced with time without infestation and infestation by *P. truncatus* and *A. fasciculatus* led to a drastic reduction..

Table 4.17: Percentage reducing sugar content of dried yam chips with different treatments after infestation by *P.truncatus* over a period of three months.

Variety	Treatment	Percentage means \pm SE*		
		Month 1	Month 2	Month 3
Asaana	PO	8.02 \pm 1.36 ^d	6.13 \pm 1.36 ^c	4.15 \pm 1.37 ^b
	NO	10.27 \pm 1.13 ^d	6.13 \pm 1.60 ^c	5.72 \pm 1.67 ^{bc}
	PS	5.11 \pm 1.57 ^{bc}	5.08 \pm 1.48 ^{bc}	4.32 \pm 1.75 ^b
	NS	4.79 \pm 0.39 ^b	4.59 \pm 1.29 ^b	3.76 \pm 1.20 ^b
Pona	PO	9.83 \pm 1.44 ^d	6.37 \pm 1.82 ^c	3.92 \pm 1.89 ^b
	NO	11.63 \pm 1.04 ^d	5.64 \pm 1.59 ^{bc}	6.12 \pm 1.37 ^c
	PS	4.35 \pm 1.43 ^b	6.00 \pm 0.95 ^c	4.38 \pm 0.87 ^b
	NS	4.76 \pm 0.39 ^b	4.20 \pm 1.29 ^b	3.35 \pm 1.20 ^b
Afasie	PO	8.39 \pm 1.33 ^d	7.42 \pm 1.09 ^{cd}	3.40 \pm 0.08 ^b
	NO	8.26 \pm 1.30 ^d	3.75 \pm 0.54 ^b	0.72 \pm 0.18 ^a
	PS	4.18 \pm 1.06 ^b	3.71 \pm 0.43 ^b	1.01 \pm 0.70 ^a
	NS	6.19 \pm 1.54 ^c	3.00 \pm 0.75 ^b	0.31 \pm 0.16 ^a

*Mean values (g/100g dry matter basis) from triplicate analysis \pm standard error

PO: Parboiled oven-dried

NO: Non-parboiled oven-dried

PS: Parboiled sun-dried

NS: Non-parboiled sun-dried

Means followed by different letter(s) in both columns and rows are significantly ($P < 0.05$) different from each other at 5% significance level.

Table 4.18: Percentage reducing sugar content of dried yam chips with different treatments after infestation by *A. fasciculatus* over a period of three months.

Percentage means \pm SE*				
Variety	Treatment	Month 1	Month 2	Month 3
Asaana	PO	10.74 \pm 2.25 ^c	10.83 \pm 2.06 ^c	9.06 \pm 1.64 ^c
	NO	9.50 \pm 1.93 ^c	8.93 \pm 1.80 ^c	10.13 \pm 1.10 ^c
	PS	5.37 \pm 0.82 ^c	5.06 \pm 0.99 ^c	4.64 \pm 0.70 ^c
	NS	4.63 \pm 1.91 ^c	4.53 \pm 1.59 ^c	2.82 \pm 0.23 ^b
Pona	PO	9.20 \pm 1.03 ^e	10.24 \pm 1.94 ^e	8.25 \pm 1.83 ^c
	NO	10.43 \pm 1.23 ^e	9.07 \pm 2.61 ^e	10.50 \pm 0.51 ^e
	PS	4.15 \pm 0.86 ^c	4.72 \pm 0.25 ^c	3.61 \pm 1.05 ^c
	NS	4.84 \pm 1.35 ^c	3.50 \pm 1.33 ^c	3.14 \pm 1.09 ^c
Afasie	PO	8.39 \pm 1.40 ^e	10.49 \pm 1.58 ^e	9.08 \pm 1.40 ^e
	NO	8.01 \pm 1.93 ^e	8.63 \pm 1.22 ^e	7.39 \pm 1.59 ^e
	PS	4.11 \pm 1.36 ^c	2.84 \pm 0.73 ^b	0.89 \pm 0.07 ^a
	NS	6.06 \pm 1.15 ^d	3.83 \pm 1.14 ^c	0.52 \pm 0.37 ^a

*Mean values (g/100g dry matter basis) from triplicate analysis \pm standard error

PO: Parboiled oven-dried

NO: Non-parboiled oven-dried

PS: Parboiled sun-dried

NS: Non-parboiled sun-dried

Means followed by different letter(s) in both columns and rows are significantly ($P < 0.05$) different from each other at 5% significance level.

4.7.4 Percentage non-reducing sugar of the dried yam chips after infestation by *P. truncatus* and *A. fasciculatus*.

Infestation by *P. truncatus* showed significant reduction in the percentage non-reducing sugar values of the dried yam chips over the three-month period. The values observed were significantly ($P < 0.05$) different (Appendices II and IV) among the treatments for both *P. truncatus* and *A. fasciculatus* (Tables 4.19 and 4.20). The values observed for *P. truncatus* reduced significantly as time and infestation level increases for all the treatments (Table 4.19). In the parboiled oven dried and non-parboiled oven dried chips infested by *A. fasciculatus*, the level of non-reducing sugar showed no different from the initial values as infestation do not occur, while in parboiled sun-dried and non-parboiled sun-dried the level reduced drastically with time and level of infestation (Table 4.20).

The percentage non-reducing sugar values recorded was 0.50% - 12.25% after infestation by *P. truncatus*. The lowest value was recorded on yam chips infested for two and three months and high values on chips infested for one month. The values recorded for *A. fasciculatus* was 0.72% - 12.58%, lower values were observed on chips infested and high values were observed on chips, which were not damage. In contrast with the initial values, which ranged from 5.14% - 13.01% there was a drastic reduction in the level of non-reducing sugar after infestation by *P. truncatus* and *A. fasciculatus*.

Table 4.19: Percentage non-reducing sugar content of dried yam chips with different treatments after infestation by *P. truncatus* over a period of three months.

Variety	Treatment	Percentage means \pm SE*		
		Month 1	Month 2	Month 3
Asaana	PO	8.31 \pm 1.19 ^d	8.67 \pm 2.95 ^d	7.01 \pm 1.79 ^{cd}
	NO	8.55 \pm 0.94 ^d	8.17 \pm 1.69 ^d	7.98 \pm 1.64 ^{cd}
	PS	4.56 \pm 1.96 ^{bc}	4.23 \pm 1.84 ^{bc}	4.14 \pm 1.82 ^{bc}
	NS	5.05 \pm 1.78 ^c	5.12 \pm 0.60 ^c	4.69 \pm 0.71 ^{bc}
Pona	PO	8.78 \pm 1.41 ^d	8.94 \pm 1.76 ^d	7.25 \pm 1.00 ^{cd}
	NO	10.76 \pm 1.58 ^d	5.70 \pm 1.19 ^c	6.85 \pm 1.60 ^c
	PS	10.20 \pm 1.73 ^d	7.76 \pm 1.62 ^{cd}	6.07 \pm 1.65 ^c
	NS	6.20 \pm 1.08 ^c	5.48 \pm 1.62 ^c	5.06 \pm 1.97 ^c
Afasie	PO	12.25 \pm 1.97 ^d	5.84 \pm 0.80 ^c	3.59 \pm 0.81 ^b
	NO	9.04 \pm 0.85 ^d	6.37 \pm 1.95 ^c	1.10 \pm 0.79 ^a
	PS	5.64 \pm 1.42 ^c	3.32 \pm 0.48 ^b	0.96 \pm 0.28 ^a
	NS	6.80 \pm 0.76 ^c	2.35 \pm 0.65 ^{ab}	0.50 \pm 0.08 ^a

*Mean values (g/100g dry matter basis) from triplicate analysis \pm standard error

PO: Parboiled oven-dried

NO: Non-parboiled oven-dried

PS: Parboiled sun-dried

NS: Non-parboiled sun-dried

Means followed by different letter(s) in both columns and rows are significantly ($P < 0.05$) different from each other at 5% significance level.

Table 4.20: Percentage non-reducing sugar content of dried yam chips with different treatments after infestation by *A. fasciculatus* over a period of three months.

Variety	Treatment	Percentage means \pm SE*		
		Month 1	Month 2	Month 3
Asaana	PO	8.79 \pm 0.88 ^d	7.81 \pm 1.99 ^{od}	8.24 \pm 1.60 ^d
	NO	8.42 \pm 1.13 ^d	8.12 \pm 1.45 ^d	8.83 \pm 1.38 ^d
	PS	4.50 \pm 1.76 ^b	4.11 \pm 0.86 ^b	4.14 \pm 1.15 ^b
	NS	4.95 \pm 1.52 ^b	4.70 \pm 1.17 ^b	4.13 \pm 1.14 ^b
Pona	PO	8.97 \pm 1.09 ^d	9.01 \pm 1.30 ^d	8.74 \pm 1.92 ^d
	NO	11.13 \pm 0.49 ^d	10.66 \pm 1.32 ^d	10.79 \pm 0.75 ^d
	PS	9.73 \pm 1.68 ^d	6.53 \pm 1.50 ^c	4.68 \pm 1.18 ^b
	NS	6.31 \pm 0.87 ^c	4.61 \pm 0.51 ^b	3.34 \pm 1.03 ^b
Afasie	PO	12.53 \pm 1.27 ^d	12.58 \pm 0.46 ^d	11.22 \pm 0.99 ^d
	NO	8.46 \pm 1.13 ^d	9.03 \pm 0.96 ^d	9.60 \pm 0.98 ^d
	PS	5.55 \pm 1.69 ^c	3.96 \pm 1.02 ^b	0.99 \pm 0.15 ^a
	NS	6.66 \pm 1.11 ^c	3.18 \pm 0.93 ^b	0.72 \pm 0.05 ^a

*Mean values (g/100g dry matter basis) from triplicate analysis \pm standard error

PO: Parboiled oven-dried

NO: Non-parboiled oven-dried

PS: Parboiled sun-dried

NS: Non-parboiled sun-dried

Means followed by different letter(s) in both columns and rows are significantly ($P < 0.05$) different from each other at 5% significance level.

4.7.5 Percentage carbohydrate in dried yam chips after infestation by *P. truncatus* and *A. fasciculatus*.

No significant ($P>0.05$) differences were observed among the percentage carbohydrate values of the various treatments after infestation by *P. truncatus* and *A. fasciculatus* (Appendices II and IV). Infestation of yam chips by *P. truncatus* and *A. fasciculatus* led to significantly lower carbohydrate content when compared with the values observed for uninfested chips; the levels of the carbohydrate for all the treatments reduced after infestations by *P. truncatus* and *A. fasciculatus*.

The percentage carbohydrate values recorded ranged from 52.63% - 66.13% after infestation. The lowest value was recorded on Parboiled oven-dried “Pona” infested for three months by *P. truncatus* and the highest value was recorded on “Afasie” infested for three months by *A. fasciculatus*. The initial carbohydrate values before infestation ranged from 58.60% - 69.81%.

There were no significant ($P>0.05$) differences among the varieties (Asaana, Pona and Afasie) studied (Appendix V). The % carbohydrate observed for the varieties ranged from 55.88% - 62.15%. The lowest value was recorded on “Pona” infested by *P. truncatus* for three months and the highest value was recorded on “Afasie” infested by *A. fasciculatus* for two months.

4.7.6 Percentage ash in dried yam chips after infestation by *P. truncatus* and *A. fasciculatus*

Infestation due to *P. truncatus* and *A. fasciculatus* led to slight increase in the values of the ash observed for the study in most treatments. The increase was not significantly ($P>0.05$) different and it was observed among the percentage ash for Parboiled sun-dried yam chips and non-parboiled sun-dried yam chips infested by *A. fasciculatus* for the third month (Appendices II and IV).

The percentage ash values recorded ranged from 1.76% - 5.82%. The lowest percentage ash value was recorded in the first month under the yam chips (Asaana non-parboiled oven-dried) infested by *P. truncatus* and the highest in the third month under the yam chips (Afasie non-parboiled sun-dried) infested by *A. fasciculatus*.

There were no significant ($P>0.05$) differences in percentage ash among yam varieties (Asaana, Pona and Afasie) used for the study (Appendix V). The percentage ash recorded for the different varieties ranged from 1.99% - 4.52%. The lowest value was recorded on Asaana yam chips infested by *P. truncatus* for one month and the highest value was recorded on Afasie yam chips infested by *A. fasciculatus* for three months.

4.7.7 Percentage fibre content in dried yam chips after infestation by *P. truncatus* and *A. fasciculatus*.

After infestation by *P. truncatus* and *A. fasciculatus*, there was no increase in level of the percentage fibre. No significant ($P>0.05$) differences existed among the values of the various treatments of the yam chips (Appendices II and IV).

The percentage fibre contents recorded ranged from 1.12% - 2.55%. The lowest percentage fibre value was observed for the yam chips (Pona parboiled sun-dried) infested by *A. fasciculatus* and the highest value was also observed for yam chips (Afasie parboiled sun-dried) infested by *A. fasciculatus*.

There was no significant ($P>0.05$) difference among the percentage fibre contents recorded for the varieties (Asaana, Pona and Afasie) used for the study (Appendix V). The percentage crude fibre recorded for varieties ranged from 1.28% - 2.15%. The lowest was recorded on “Pona” yam chips infested for one month and the highest on “Asaana” yam chips infested for three months by *A. fasciculatus*.

4.7.8: Percentage crude protein content after infestation by *P. truncatus* and *A. fasciculatus*.

No significant ($P>0.05$) differences were observed for the percentage crude protein values for the various treatments of the dried yam chips (Appendices II and IV).

The percentage crude protein contents recorded for the various treatments ranged from 2.99% - 5.90%. The lowest percentage crude protein was recorded under yam chips (Asaana non-parboiled oven-dried) infested by *P. truncatus*, and the highest was recorded under the yam chips (Afasie non-parboiled sun-dried) infested by *A. fasciculatus*.

The percentage crude protein contents were not significantly ($P>0.05$) different for the varieties (Asaana, Pona and Afasie) of yam studied (Appendix V). The recorded value ranged from 3.21% - 5.03%. The lowest value was observed in “Pona” yam chips infested by *P. truncatus* for three months and the highest was observed in “Afasie” infested by *A. fasciculatus* for three months.

CHAPTER FIVE

5.0 DISCUSSION.

5.1 Survival and establishment of *P. truncatus* and *A. fasciculatus* on dried yam chips.

The establishment of an insect on its host is not determined only by its ability to survive and grow on its host, but by its ability to breed on the host (Krishna and Mishra, 1985). A significant increase in the numbers of an insect on a specific food is an indication of the suitability of such product as a host for the insect. Insects are therefore known to cause considerable damage to products that are suitable to them as food (Williams, 1999).

From the study, the results of the establishment and survival experiment for *P. truncatus* and *A. fasciculatus* show that the yam chips were suitable hosts for the insects.

It was realised that the number of *P. truncatus* recorded on the various treatments processed from the varieties (Asaana, Pona and Afasie) of yams used for the study was high throughout the study period of three months. *P. truncatus* was found to establish, survive and breed on all the treatments. Lower numbers of *P. truncatus* were recorded on both parboiled oven-dried yam chips and non-parboiled oven-dried yam chips while high numbers were recorded for both parboiled sun-dried yam chips and non-parboiled sun-dried yam chips for all categories of the varieties used for the study. Based on varietal differences, it was found that the “Afasie” dried chips recorded the highest number of *P. truncatus* for the duration of the study, an indication that *P. truncatus* established, survived and bred well on the “Afasie” chips. There was no significant difference between the population of *P. truncatus* recorded on “Asaana” and “Pona” dried chips.

A. fasciculatus was found not to establish on both parboiled and non-parboiled oven-dried yam chips in all the categories of the varieties considered for the study for all the durations. *A. fasciculatus* on the other hand was able to establish, survive and breed on both parboiled and non-parboiled sun-dried yam chips for all the varieties. The inability of *A. fasciculatus* to survive on the former may be due to the very low moisture content and method of drying the yam chips. Meanwhile *A. fasciculatus* is known to survive on produce with moisture content of 8.5% and above (Haines, 1991b). Similarly, in contrast with Haines, Williams (1999) working on cocoa shows that *A. fasciculatus* could not establish on cocoa bean at 7.5% moisture content. Based on varietal differences, “Afasie” dried chips recorded the highest number of *A. fasciculatus* while “Pona” and “Asaana” shows no significant differences.

The ability of *P. truncatus* and *A. fasciculatus* to establish, survive and breed on “Afasie” may probably be due to its high moisture contents and its soft characteristics after drying which support the insects’ developmental activities. The mixed culture shows that *P. truncatus* established, survived and bred better than *A. fasciculatus*. However, the increase in the number of *P. truncatus* was not as high as in the case of when it was cultured alone. This suggests some forms of competition between the two insects. Williams (1999) also observed such relationship between *Corcyra cephalonica* Stantion (Lepidoptera) and *A. fasciculatus* on cocoa beans. Stumpf (1994) also observed a similar situation in mixed culture of *P. truncatus*, *Rhyzopertha dominica* (Fabricius), *Dinoderus bifoveolatus* (Wallaston) and *Tribolium castaneum* (Herbst) on dried cassava chips. It was found that the developmental rate of *P. truncatus* was reduced in comparison to the single

culture of 100g cassava chips but *P. truncatus* still out competed all other species in numbers. The reduction in numbers of *P. truncatus* in experiments with mixed infestation is referred to as an effect of interspecific competition (Giga and Canhao, 1993).

No insect population was recorded on the control dried yam chips throughout the duration of study. *P. truncatus* established and bred better than *A. fasciculatus* on the various treatments; this may be due to its ability to survive on diverse forms of produce, and its high reproductive rate in comparison to the other insect species (Schulten, 1988).

5.2 Contaminants produced by *P. truncatus* and *A. fasciculatus* on dried yam chips.

Based on the results obtained from the study, it was observed that the weight and complexity of the contaminants produced by *P. truncatus* and *A. fasciculatus* increased with time. This may be due to the fact that as the insect number increased their biological activities also increased. The major contaminants during the study period for the insects were: powdery residues, dead insects, frass and insect fragments. These categories of contaminants, which caused damage to them, tended to vary for the various treatments, type of insect and length of infestation.

Low contaminants were recorded on both parboiled oven-dried yam chips and non-parboiled oven-dried yam chips and high contaminants on parboiled sun-dried yam chips and non-parboiled sun-dried. The chips for mixed culture also recorded low contaminants as compared to the single culture chips. The level of the contaminants also increased with time for both insects. The variation in the weight of the contaminants especially for the

first month suggests that insect activity depended on how well adapted the insects were and their population. *P. truncatus* adapted well on dried yam chips and produced more contaminants than *A. fasciculatus*. The contaminants produced on the mixed culture was expected to be more than those produced by the single species insect culture, since 10 of each insect was introduced given a population of 20 insects. However, contaminants observed for the duration of the study was low, this may be due to some kind of competition between the two insects, which led to a low biological activities.

In the second and third months, the level of contaminants increased and this was accompanied by a pungent odour and contaminants were clumped. This situation was well pronounced in yam chips infested by *A. fasciculatus*. The pungent odour might be due to formation of ammonia products through heavy infestation and insect activities such as defeacation, excretion, reproduction and even congestion (Mullins and Cochran, 1972).

5.3 Percentage damage and percentage weight loss on dried yam chips recorded for *P. truncatus* and *A. fasciculatus*.

This study shows that *P. truncatus* caused considerable damage and weight loss to dried yam chips. No matter how dry the yam chips were, the presence of *P. truncatus* still posed a serious threat to the wholesomeness and marketability of the dried yam chips. This tolerance of dry conditions has been confirmed during field studies in Nicaragua and Tanzania (Giles and Leon, 1975; Hodges, 1983). *A. fasciculatus* on the other hand can cause a serious damage to yam chips that are not adequately dried. *A. fasciculatus* has been recorded on dried yam chips as a major pest causing considerable damage and

weight loss (Coursey, 1967). The factor of high moisture has been found to be the cause of high damage by this pest to cassava chips (Haines *et al.*, 1991a; Parker and Booth, 1979 and Stumpf, 1998).

Based on this study, the percentage damage after one month was 40.16% and 19.07%, resulting in a weight loss of 6.32% and 6.01% for *P. truncatus* and *A. fasciculus* respectively. By the third month, percentage damage values were 75.38% and 45.32% and weight losses were 46.05% and 32.34% for *P. truncatus* and *A. fasciculus* respectively. Therefore, based on quality standards which companies are already introducing for cassava chips, such as 12% - 14% mc, minimum 70% starch, and composition free of pests, extraneous materials and aflatoxin (Stumpf, 1994; Laryea, 1995), the acceptability and marketability of the yam chips infested by pests is already threatened. This study also shows that when *P. truncatus* and *A. fasciculatus* are left uncontrolled on dried yam chips for more than one month, the chips will be considered sub-standard and attract low market value.

The percentage damage and percentage weight loss caused by the introduction of ten *P. truncatus* and ten *A. fasciculatus* adults combined in the same culture were low compared to the single culture. The percentage damage / percentage weight loss recorded in this category for the first month was 31.15% / 6.41% while that for the third month was 69.97% / 40.86%. It was observed that a large number of damaged chips led to only a small amount of weight loss. This is similar to the findings of Davies (1960) and Williams (1999) on cocoa beans.

“Afasie” dried chips recorded the highest percentage damage and weight loss. On “Afasie”, *P. truncatus* caused a percentage damage and weight loss of 73.12% / 45.95% while *A. fasciculatus* caused a percentage damage and weight loss of 37.58% / 24.23%. *P. truncatus* on “Pona” led to a percentage damage and percentage weight loss of 49.32 / 16.80% while *A. fasciculatus* caused a percentage damage and weight loss of 30.23% / 14.71%. On “Asaana”, *P. truncatus* caused a percentage damage and weight loss of 55.85% / 14.79% while *A. fasciculatus* caused a percentage damage and weight loss of 32.26% / 14.54%.

5.4 The relationship between pest density and; treatments, percentage damage, and percentage weight loss.

It is important to know the level at which control measures should be implemented to prevent an increasing pest population from reaching the economic injury level (Stern *et al.*, 1959). Because of this it is important to know the relationship between pest density, treatments, percentage damage and percentage weight loss.

Pest density correlated with percentage damage in the second and third months. It also correlated with treatments and percentage weight loss for all the durations. This finding implies that pest density determines the percentage damage and percentage weight loss, and the treatments affected the establishment and survival of the insects. Furthermore, this confirms the suggestion of a correlation between insect numbers found in a produce and the damage to grains and the percentage weight loss caused (Hall, 1970). This means that the damage and weight loss suffered by yam chips depended on the density of the insects.

In the study it was found that parboiled oven-dried yam chips and non-parboiled oven-dried yam chips suffered less damage and weight loss, therefore, giving lower population of *P. truncatus* and *A. fasciculatus*.

5.5 Biochemical changes in dried yam chips after infestation by *P. truncatus* and *A. fasciculatus*.

It was found that dried yam chips absorb moisture rapidly from the humid environment and from insect excreta to reach equilibrium moisture levels. At room temperature and relative humidity ($30\pm 3^{\circ}\text{C}$ and $90\pm 2\%$ R.H.), chips had moisture contents that ranged from 15% - 20% as compared to the initial moisture content with a range of 8% - 12% before the cultures were set-up. This is more than the 14% acceptable upper limit for safe storage for dried root and tuber chips (Anon. 1952; Anon, 1965; CIRAD-IITA, 1998). Therefore, high moisture contents observed in the chips after infestation enhances insect activities and the growth of micro organisms such as fungi and bacteria which led to deterioration of the chips (Stumpf, 1998).

Yam is known to have a very low fat content with values similar to other root and tuber crops (Bradbury and Halloway, 1988; Agbor-Egbe and Rickard, 1990; Rickard and Coursey, 1981). The fat content of the chips initially ranged from 0.23% - 0.31%, this range was found to have changed after infestation by *P. truncatus* and *A. fasciculatus* to a range of 0.42% - 0.91%. It was found that *A. fasciculatus* infested chips produced slight increase percentage values. This increase may be due to the presence of insect parts in the analysed samples, since the increase was observed to have changed with time and level of

infestation. This increase may also be attributed to the fact that fats in the produce are likely to be broken down by lipases into free fatty acids and glycerol during storage, particularly when the temperature and moisture contents are high (Christensen, 1974). This type of change is greatly accelerated by moulds (Christensen, 1974). It is therefore, possible that, these insects carried on them some storage moulds and introduced them into the yam chips. This supports the findings of Christensen and Kaufman (1969), that, at least some of the common stored produce insects regularly carry into the products they infest a large load of inoculum of storage fungi. As the insect develops, conditions within the chips become suitable for the development of the fungi.

The reducing and non-reducing sugar levels were observed to have showed no significant change for chips that were not damaged by *A. fasciculatus*, while those infested by these insects were drastically reduced. It has been confirmed that storage of yam tubers led to a rapid increase in sugar levels. (Agbor-Egbe, 1996). Afoakwa (1999) reported that the different treatments given to the tubers prior to storage such as cooking and chopping of tubers into pieces, however, showed varied changes in sugar levels with storage time and temperature. Marked increases in sugars were noted in tubers chopped into pieces before storage than in the whole tubers. This increase in the levels of the sugars may be due to the breakdown of starch molecules during storage under high temperatures (Afoakwa, 1999). This finding is in contrast with the above, this may be due to the low moisture content of the dried chips which prevents any biological processes from taking place. The reduction in percentage sugar levels observed on infested chips may be due to the fact that the sugars were used up by the insects for their biological activities.

Slight reduction in percentage carbohydrate was recorded. The carbohydrate contents of the chips decreased in the range of 1% - 8% with respect to all treatments used for the processing of chips. This decrease is largely due to infestation by *P. truncatus* and *A. fasciculatus*, and the breakdown of carbohydrate into sugars. This result confirms the finding of Wright *et al.* (1993) that *P. truncatus* infestation reduced starch levels by about 4% in station trials in Togo and referred to it as negligible loss. Kumar *et al.* (1991) found that in trials under control conditions, about 7% reduction of the starch level was measured on plain dried chips. In contrast, losses measured during field studies in Ghana, gave only a slight decrease of 0.3% of starch levels of local cassava varieties (Stumpf, 1998).

Coursey (1967) reported that ash content of yam makes it rich in minerals and even though the amount varies from species to species and from cultivar to cultivar, it is always considerable. In this study, it was found that the ash content increased slightly for the chips infested by *P. truncatus* and *A. fasciculatus* as compared to the chips, which were not infested by the insects. This may be due to the presence of insect parts and other products in the chips.

The percentage crude fibre recorded for this study ranged from 1.12% - 2.55%. It was found that the crude fibre content of the dried yam chips increased slightly for the duration of the study. The changes observed may possibly be due to treatments and infestation by insects. This confirms the finding of Afoakwa (1999) that the fibre content of tubers chopped into pieces prior to storage were observed to increase rapidly. It was also reported that sample treatment, cultivars, storage condition and storage time had

significant effects on the fibre contents of *D. dumetorum* during storage. Earlier studies reported very high increases in fibre content of *D. rotundata* and *D. dumetorum* during storage (Brillouet *et. al.*, 1985; Sealy *et al.*, 1985; Treche and Delpeuch, 1982; Treche and Agbor-agbe, 1996).

The protein levels found in this study ranged from 2.99% - 5.90%. The protein levels were observed to show no significant difference with time; this can be attributed to treatments and infestation by insects.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

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

1. Insect survival and establishment showed significant differences for the two insects. *P. truncatus* survived established and bred better on the various treatments of yam chips than *A. fasciculatus*.
2. *A. fasciculatus* could not survive on parboiled and non-parboiled oven-dried yam chips even though *P. truncatus* did get established and survived on these treatments. Both *P. truncatus* and *A. fasciculatus* established, survived and bred well on parboiled and non-parboiled sun-dried yam chips.
3. More damage and weight loss was caused by *P. truncatus* to the chips than did *A. fasciculatus*.
4. For all the varieties of yams used, the damage and weight loss due to infestation, between parboiled and non-parboiled oven-dried yam chips was not considerable.
5. “Afasie” recorded the highest damage and weight loss when compared to “Asaana” and “Pona” However, the differences in damage and weight loss recorded for “Asaana” and “Pona” were not considerable.
6. There were positive correlations between insect numbers, treatments, damage and weight loss.
7. Processing of yam chips into different treatments led to drastic decrease in the moisture content, which enhances long storage time. But infestation by insects led to significant increase in the moisture contents of dried yam chips. The levels of reducing and non-reducing sugar reduced drastically with level of infestation. But it should be noted that chips that were not damaged by insects recorded no change in

the levels of sugars when compared with the initial values observed before infestation. Carbohydrate content reduced with processing and infestation by insects. Fat, ash, protein and fibre show no significant difference after infestation.

From the results of this study, it will be advisable for farmers to ensure that their chips are parboiled before storage. This will minimise *P. truncatus* damage and weight loss, and eliminate *A. fasciculatus* infestation. Furthermore, any sign of infestation by *P. truncatus* and *A. fasciculatus* should be controlled thoroughly to avoid extensive damage over a long period.

Infestation due to insects on dried yam chips lead to damage, weight loss and changes in biochemical composition of the chips. Most farmers do not dispose some of the damage chips and the powdery residues, which they sell at a lower price or consume within the household. Based on this attitude of farmers the safety of such product should be ascertained. Therefore, it is important to recommend that an aspect worth considering relate to quality of yam chips after infestation by insects. The presence of insects on yam chips lead to contamination by their products and by-products such as; uric acid, fungi and bacteria inoculates, faecal matter and cast-off skins in and on the chips, creating a foul odour. The potential harmful effects of fungi and bacterial metabolites on consumers have so far not been really appreciated in developing countries (Majumder, 1982; Coker, 1994).

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APPENDIX I

ANALYSIS OF VARIANCE TABLES FOR *PRHOSTEPHANUS TRUNCATUS* INFESTATION ON DRIED YAM CHIPS OVER A PERIOD OF THREE MONTH

Analysis of Variance for %wtloss

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treat.	4	5856.5	5856.5	1464.1	7.94	0.000
var	2	49948.0	49948.0	24974.0	135.50	0.000
month	2	56811.1	56811.1	28405.6	154.12	0.000
treats*var	8	588.2	588.2	73.5	0.40	0.920
treats*month	8	1562.3	1562.3	195.3	1.06	0.393
Error	200	36862.3	36862.3	184.3		
Total	224	151628.4				

Analysis of Variance for number of insects

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treat.	4	2.9085	2.9085	0.7271	34.53	0.000
var	2	6.8874	6.8874	3.4437	163.54	0.000
month	2	21.8358	21.8358	10.9179	518.48	0.000
treats*var	8	0.1684	0.1684	0.0210	1.00	0.438
treats*month	8	0.3245	0.3245	0.0406	1.93	0.058
Error	200	4.2115	4.2115	0.0211		
Total	224	36.3361				

Analysis of Variance for percentage damage over a period of three months

Source	DF	SS	MS	F	P
Treat.	44	93273.2	2119.8	33.24	0.000
Error	180	11479.9	63.8		
Total	224	104753.1			

Analysis of Variance for percentage frass over a period of three months

Source	DF	SS	MS	F	P
Treat.	44	7276.76	165.38	36.63	0.000
Error	180	812.70	4.52		
Total	224	8089.46			

APPENDIX II

ANOVA TABLE AFTER INFESTATION OF DRIED YAM CHIPS BY *PROSTEPHANUS TRUNCATUS*

Analysis of Variance for %moisture content

Source	DF	Seq SS	Adj SS	Adj MS	F	P
treatment	3	3.4390	3.4390	1.1463	12.82	0.002
Error	8	0.7156	0.7156	0.0895		
Total	11	4.1546				

Analysis of Variance for %fat content

Source	DF	Seq SS	Adj SS	Adj MS	F	P
treatment	3	2.09317	2.09317	0.69772	66.66	0.070
Error	8	0.08373	0.08373	0.01047		
Total	11	2.17690				

Analysis of Variance for %reducing sugar content

Source	DF	Seq SS	Adj SS	Adj MS	F	P
treatment	3	50.121	50.121	16.707	14.62	0.001
Error	8	9.143	9.143	1.143		
Total	11	59.264				

Analysis of Variance for %non-reducing sugar content

Source	DF	Seq SS	Adj SS	Adj MS	F	P
treatment	3	33.287	33.287	11.096	5.81	0.021
Error	8	15.279	15.279	1.910		
Total	11	48.566				

Analysis of Variance for %carbohydrate content

Source	DF	Seq SS	Adj SS	Adj MS	F	P
treatment	3	65.578	65.578	21.859	5.05	0.090
Error	8	34.658	34.658	4.332		
Total	11	100.237				

Analysis of Variance for %ash content

Source	DF	Seq SS	Adj SS	Adj MS	F	P
treatment	3	2.14860	2.14860	0.71620	142.29	0.082
Error	8	0.04027	0.04027	0.00503		
Total	11	2.18887				

Analysis of Variance for %fibre content

Source	DF	Seq SS	Adj SS	Adj MS	F	P
treatment	3	0.17349	0.17349	0.05783	1.64	0.255
Error	8	0.28133	0.28133	0.03517		
Total	11	0.45482				

Analysis of Variance for %protein content

Source	DF	Seq SS	Adj SS	Adj MS	F	P
treatment	3	0.4133	0.4133	0.1378	1.03	0.428
Error	8	1.0650	1.0650	0.1331		
Total	11	1.4783				

APPENDIX III

ANALYSIS OF VARIANCE TABLES FOR *ARAECERUS FASCICULATUS* INFESTATION ON DRIED YAM CHIPS OVER A PERIOD OF THREE MONTH

Analysis of Variance for %WT LOSS

Source	DF	Seq SS	Adj SS	Adj MS	F	P
TREATS	4	60755.0	60755.0	15188.7	111.79	0.000
VAR	2	5824.2	5824.2	2912.1	21.43	0.000
MONTH	2	26128.8	26128.8	13064.4	96.16	0.000
TREATS*VAR	8	8761.2	8761.2	1095.1	8.06	0.000
TREATS*MONTH	8	18752.9	18752.9	2344.1	17.25	0.000
Error	200	27173.0	27173.0	135.9		
Total	224	147395.1				

Analysis of Variance for Number of insects

Source	DF	Seq SS	Adj SS	Adj MS	F	P
TREATS	4	142.0587	142.0587	35.5147	1345.66	0.000
VAR	2	0.9793	0.9793	0.4897	18.55	0.000
MONTH	2	9.7807	9.7807	4.8904	185.30	0.000
TREATS*VAR	8	0.8005	0.8005	0.1001	3.79	0.000
TREATS*MONTH	8	7.8953	7.8953	0.9869	37.39	0.000
Error	200	5.2784	5.2784	0.0264		
Total	224	166.7930				

Analysis of Variance for Percentage damage over a period of three months

Source	DF	SS	MS	F	P
treat	44	338261	7688	6.86	0.000
Error	180	201731	1121		
Total	224	539992			

Analysis of Variance for percentage frass over a period of three months

Source	DF	SS	MS	F	P
treat	44	2610.37	59.33	54.64	0.000
Error	180	195.43	1.09		
Total	224	2805.80			

APPENDIX IV

ANOVA TABLE AFTER INFESTATION OF DRIED YAM CHIPS BY *ARAECERUS FASCICULATUS*

Analysis of Variance for %moisture content

Source	DF	Seq SS	Adj SS	Adj MS	F	P
treatment	3	49.052	49.052	16.351	16.27	0.001
Error	8	8.042	8.042	1.005		
Total	11	57.094				

Analysis of Variance for %fat content

Source	DF	Seq SS	Adj SS	Adj MS	F	P
treatment	3	0.86383	0.86383	0.28794	129.41	0.230
Error	8	0.01780	0.01780	0.00223		
Total	11	0.88163				

Analysis of Variance for %reducing sugar content

Source	DF	Seq SS	Adj SS	Adj MS	F	P
treatment	3	34.949	34.949	11.650	28.52	0.000
Error	8	3.267	3.267	0.408		
Total	11	38.216				

Analysis of Variance for %non-reducing sugar content

Source	DF	Seq SS	Adj SS	Adj MS	F	P
treatment	3	80.872	80.872	26.957	10.88	0.003
Error	8	19.815	19.815	2.477		
Total	11	100.686				

Analysis of Variance for %carbohydrate content

Source	DF	Seq SS	Adj SS	Adj MS	F	P
treatment	3	300.87	300.87	100.29	10.31	0.084
Error	8	77.81	77.81	9.73		
Total	11	378.68				

Analysis of Variance for %ash content

Source	DF	Seq SS	Adj SS	Adj MS	F	P
treatment	3	0.63989	0.63989	0.21330	5.50	0.124
Error	8	0.31000	0.31000	0.03875		
Total	11	0.94989				

Analysis of Variance for %fibre content

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	3	0.20802	0.20802	0.06934	1.59	0.267
Error	8	0.34940	0.34940	0.04367		
Total	11	0.55742				

Analysis of Variance for %protein content

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	3	0.63342	0.63342	0.21114	15.05	0.231
Error	8	0.11220	0.11220	0.01403		
Total	11	0.74562				

APPENDIX V

ANOVA TABLES FOR VARIETY NUTRIENT CONTENT AFTER FERMENTATION BY *PROSTEPHANUS TRUNCATUS* AND *ARAECERUS FASCICULATUS*.

Analysis of Variance for %moisture content

Source	DF	SS	MS	F	P
var	2	78.41	39.20	19.30	0.000
Error	33	67.02	2.03		
Total	35	145.43			

Analysis of Variance for %fat

Source	DF	SS	MS	F	P
var	2	0.1414	0.0707	2.29	0.105
Error	132	4.0679	0.0308		
Total	134	4.2093			

Analysis of Variance for %reducing sugar

Source	DF	SS	MS	F	P
var	2	5.7	2.8	0.10	0.906
Error	132	3762.1	28.5		
Total	134	3767.7			

Analysis of Variance for %non-reducing sugar

Source	DF	SS	MS	F	P
var	2	25.29	12.64	2.07	0.130
Error	132	806.39	6.11		
Total	134	831.68			

Analysis of Variance for %carbohydrate

Source	DF	SS	MS	F	P
var	2	276.0	138.0	7.72	0.081
Error	132	2359.6	17.9		
Total	134	2635.6			

Analysis of Variance for %ash

Source	DF	SS	MS	F	P
var	2	4.313	2.157	10.09	0.146
Error	132	28.224	0.214		
Total	134	32.537			

Analysis of Variance for %fibre

Source	DF	SS	MS	F	P
var	2	0.0367	0.0183	0.39	0.679
Error	33	1.5441	0.0468		
Total	35	1.5807			

Analysis of Variance for %protein

Source	DF	SS	MS	F	P
var	2	0.397	0.198	0.87	0.429
Error	33	7.548	0.229		
Total	35	7.945			