THE PERFORMANCE OF *PROSTEPHANUS TRUNCATUS* (HORN) ON DIFFERENT SORGHUM VARIETIES GROWN IN GHANA

By

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ABSTRACT

Studies were carried out under ambient laboratory conditions of 32 °C ± 2 and 74 - 87 % r.h. to determine the suitability of sorghum grain as a substrate that would support both the feeding and breeding of *Prostephanus truncatus* (Horn). Three sorghum varieties (Framida, Mankaraga and Naga-White) and one maize variety (Obatanpa) grown in Ghana were used in the study. Three forms of the substrates: Whole grain, Coarsely-ground grain and Grain flour were used for bioassays. The F_1 progeny and mean developmental periods recorded were used to determine susceptibility index for the different grain varieties. Mean weight of the insect progeny that emerged was also determined. Percentage damage due to *P. truncatus* infestation was assessed on the different grain varieties. Similarly, weight loss due to this beetle on the different grain varieties was determined using both the standard volume/weight method and the count and weigh method for comparison. The effects of commodity compaction in storage, as well as disturbance on damage and weight loss were also determined. Furthermore, physical properties of grain, such as size, density, 100-grain weight, endosperm texture and grain hardness were determined to asses their influence on grain infestation by *P. truncatus*. Insect preference for the different grain varieties was also assessed.

The results of the investigations revealed that *P. truncatus* can both feed and breed on sorghum grains. The mean developmental period and the mean weight of *P. truncatus*, as well as the grain susceptibility index were significantly (P<0.05) different. Mean developmental periods recorded were: 36-37 days on the high-yielding sorghum varieties (Framida and Naga-White), 46 days on a local low yielding variety (Mankaraga) and 21 days on the maize variety. Mean insect weight assessed were: 2.98 3.02 mg on high-yielding sorghum varieties, 2.49 mg on a local low-yielding sorghum variety and 4.91mg on maize. The high-yielding sorghum varieties (Framida and Naga-White) were more susceptible to *P. truncatus* infestation than the local low-yielding variety (Mankaraga), with the susceptibility index between 7.06 7.14 and 2.28, respectively. Obatanpa maize grains were the most susceptible, showing the highest susceptibility index of 19.09.

Damage, weight loss, frass and progeny production were significantly ($P<0.05$) different among the grain varieties; highest mean values were recorded on Obatanpa (maize variety), followed by Framida and Naga-White (high-yielding sorghum varieties) and the least mean values assessed were on Mankaraga (local low-yielding sorghum variety). The mean values of these factors also increased with storage duration. Greater levels of compaction in storage significantly ($P<0.05$) provided favourable conditions for *P. truncatus* to thrive. Grains left undisturbed in storage, showed significant ($P<0.05$) differences, giving higher mean damage and loss values than those disturbed. The study showed that grains disturbed at a later stage in storage experienced less damage and loss than those disturbed early in storage.

Grain size ($r = 0.968$, $P = 0.032$), grain hardness ($r = -0.989$. $P = 0.093$) and endosperm texture ($r = 1.000$, $P = 0.019$) had some influence on grain infestation by *P. truncatus*. Large grains provided the beetle with more carrying capacity for its activities. Grains with soft pericarp and soft endosperm (grain hardness) offered low resistance to the boring and tunneling activities of these beetles. These results show that, with the spread of the Larger Grain Borer in the sorghum growing areas of West Africa, sorghum is at risk of infestation in storage. Appropriate control measures should therefore be applied to keep this pest in check.

DECLARATION

I hereby declare that this work is my own research, conducted at the Plant Protection and Regulatory Services Directorate (PPRSD) of the Ministry of Food and Agriculture (MOFA), Pokuase, Ghana. Other researchers cited have been duly acknowledged. No part of this work has been presented for any degree elsewhere.

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DEDICATION

To my parents

All that I am and hope to be, I owe to them.

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CHAPTER ONE

1.0 INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is the fifth most important world cereal and an important native cereal in Africa (FAO, 1995; FAO and ICRISAT, 1996; Murty and Renard, 2001). Total world production of sorghum in the year 2002 was estimated at about 54 million tonnes; with Ghana producing about 316,070 tonnes (FAO, 2003). Worldwide, sorghum serves as a staple food for more than seven hundred million people (Sahnkhe *et. al.,* 1984). Sorghum is also an important staple food that contributes to the socio-economic development of many local people of sub-Saharan Africa, and ensures national food security. Sorghum is also a principal food grain cultivated throughout the savannah agro-ecological zones of northern Ghana, covering about 41 % of the total land area of the country (Atokpele *et. al.*, Unpublished).

Sorghum is a principal source of energy and also provides protein, vitamins and minerals to the poorest people of the arid and semi-arid tropics. In Ghana, it is a crop of diverse utility and is in great demand. It is used to prepare stiff porridge (tuwo zaafi), thin porridge (koko) or fried dumpling (maasa). It is also used in the brewing of local opaque beer (pito); the leaves provide fodder for farm animals and the stalks are used in fencing, roofing, weaving baskets and mats and also as fuel wood (Obilana, 1995).

However, a major constraint to sorghum production is damage and losses due to insect pests. According to Sharma *et. al.* (1997), over 150 species of insects cause damage to sorghum, with annual losses (in monetary terms) estimated at over US $1000 million in the semi-arid tropics, out of which over 20 % of these losses which occur in Africa are avoidable. Nwanze (1985) and Seshu Reddy (1991) have recorded over 100 insect pest species on sorghum in Africa. In Ghana, sorghum has been reported as one of the five most favourite hosts associated with stored products pests (Ayertey and Padi, 1996).

The Larger Grain Borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) originated from Mexico and Central America. After its accidental introduction into Africa in the late 1970s and early 1980s, the Larger Grain Borer has since spread to many parts of Africa. Its presence has been reported in at least 14 countries on the continent, including Ghana. Semakor (1996), Boxall and Compton (1996) and Ayertey (2002) reported the spread of P. *truncatus* to all regions of Ghana; from the Volta region in the south, bordering Togo, to the drier parts of the north, including the Northern, Upper West and Upper East Regions where sorghum cultivation is more predominant than maize. This beetle is a devastating pest of stored maize and cassava; however its existence outside the maize and cassava ecosystem has been established (Ayertey and Brempong-Yeboah, 1991). *Prostephanus truncatus* has been reported also to attack a wide range of foodstuff, including sorghum, other cereals and their products (Lesne, 1939; Genel, 1960; Mushi, 1984; Verma and Lal, 1987; Dick, 1988; Li, 1988; Verma *et. al.*, 1988; Poschko, 1994).

Should *P. truncatus* become an important pest of sorghum, it may have serious consequences. Being the second most important staple cereal after maize throughout sub-Saharan Africa (FAO, 1995) and being an important food security grain crop, due to its drought tolerance, it was considered important to conduct laboratory investigations to evaluate the potential threat that *P. truncatus* can pose in the sorghum growing areas of Ghana and West Africa, should its pest status on sorghum be confirmed.

1.1 Objectives

The main objective of this work was to determine the suitability of sorghum grains to serve both as feeding and breeding substrates to support the development of *P. truncatus* (Horn). Specific objectives were:

1. To determine F_1 progeny production, rate of development, mean weight of adult *P. truncatus on* the different grain varieties, as well as the susceptibility index of these grain varieties;

2. To determine percentage grain damage, dust production, weight loss and progeny production due to *P. truncatus* infestation after storage periods of one, two and three months;

3. To determine physical grain properties such as grain size, grain weight, grain density, grain hardness and endosperm texture which may influence *P. truncatus* infestation

CHAPTER TWO

2.0 REVIEW OF LITERATURE

2.1 Sorghum

Sorghum (*Sorghum bicolor* (L.) Moench) is an important staple cereal in the semi-arid tropics (SAT) of China, India and Africa, grown mostly by low-income farmers (FAO, 1995). The sorghum producing countries in Africa are Nigeria, Sudan, Ethiopia, Burkina Faso, Tanzania, Niger, Uganda and Ghana. Grain yields of subsistent farmers in the West African sub-region are generally between 500 – 800 kg ha^{-1} (Sharma *et. al.,* 1992).

Sorghum is extensively cultivated throughout the savannah belt and on a small scale in the forest–savannah transitional zone of Ghana (Agyen-Sampong, 1978). The vegetation of these areas consists of the Guinea and Sudan savannah. The climate of the zone is semi-arid with long-term average rainfall ranging from 922 mm per annum in the Sudan savanna to over 1000 mm in the Guinea Savanna (Atokpele, 1997). Sorghum does best under temperature conditions of 28 ^{o}C ± 3 but can be grown in harsh environments where most crops cannot grow or yield poorly. It also grows with limited water resource, usually without the application of inorganic fertilizer (FAO, 1995; Murty and Renard, 2001).

The air-dried whole grain contains approximately 1.5 - 2.0 ash (Onwueme and Sinha, 1991), 10 % water, 74.1 % carbohydrate, 11.1 % protein, 3.2 % fat, 2.4 % fiber, 26 mg calcium, 10.2 mg iron, 0.35 mg thiamine, 0.14 mg riboflavin, 3.3 mg niacin and 15 µg β-carotene (FAO, 1995; Tayie and Lartey, 1999).

Dry sorghum grains are usually ground into flour and are used to prepare thin porridge, thick paste or dough by boiling in water. In Africa, sorghum is widely used for brewing beer, which usually contains 2-10 % alcohol. Sorghum grains are also used industrially in the manufacture of items such as wax, starch, syrup, alcohol, dextrose agar, edible oil and gluten feed. In addition, it is used to manufacture gypsum lath, paper and cloth sizing and adhesives (Onwueme and Sinha, 1991; Komlaga *et. al.*, 2001; Murty and Renard, 2001; Atokple *et. al.*, Unpublished).

2.2 Storage Pests of Sorghum

Like most other crops, the major constraint to sorghum production and storage are insect pests. Approximately 150 insect species have been recorded in different parts of the world to attack sorghum at different stages, from sowing to crop harvest and storage (Jotwani *et. al.,* 1980). Some of the major pests of stored sorghum are *Rhizopertha dominica* (F.) *Sitophilus oryzae* (L.) (Howe, 1952; N.A.S., 1981) and *Sitotroga cerealella* (Oliv.) (Giles, 1964). Other pests of sorghum grains are *Carpophilus* spp, *Cryptolestes ugandae* (Steel and Howe), *Lasioderma serricone* (F), *Oryzaephilus mercator* (Fauv.), *Palorus* spp, *Tribolium castaneum* Herbst and *T. confusum* (Duval) (Giles, 1965).

After harvest, unthreshed sorghum is suspended in bunches from the branches of trees and poles or under roofs of houses, hanging from the roof timbers or spread out on a grid above the fire. The heat and smoke minimize insect damage and reduce moisture content to a safe level. Small quantities of threshed or unthreshed grains are also stored in containers such as jute sacks, baskets, clay pots, gourds or drums. Large quantities of threshed grains are stored in jute sacks or mud silos.

2.3 *PROSTEPHANUS TRUNCATUS*

2.3.1 Taxonomy

The Larger Grain Borer (LGB), *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) is a member of the superfamily Bostrichoidea. The species was first described by Horn (1878) as *Dinoderus truncatus* (Horn) and has also been referred to as *Stephanopachys truncatus* by Lesne (1897). The species of the family Bostrichidae are principally woodborers, but some (such as *P. truncatus* and *Rhizopertha dominica* (Fabricius)) can infest other stored products. 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 *R. dominica* but the thoracic segments are considerably larger than those of the abdomen (Haines, 1991). There are detailed descriptions of both the adult beetle (Horn, 1878; Lesne, 1897; Fisher, 1950) and of the larva and pupa (Hodges, 1986).

2.3.2 Distribution in Africa

According to Ayertey (1993), the LGB is speculated to have been introduced into the African continent through a consignment of food aid, probably in the 1970's. It was identified in Tanzania in 1981, after a considerable population level had been reached (Anonymous, 1981). It has since spread so far to Burundi (Gilman, 1984), Togo (Harnisch and Krall, 1984), Benin (Anonymous, 1986), Guinea (Kalivogui and Muck, 1991), Ghana (Dick *et. al.*, 1989), Burkina Faso (Bosque-Perez *et. al.*, 1991), Malawi (GTZ, Unpublished), Nigeria (Pike *et. al.*, 1992), Rwanda (Bonzi and Ntambabazi, 1993), Zambia (Malombo *et. al.*, 1997), Niger (Adda *et. al.*, 1996). There are also unconfirmed reports of its establishment in Cameroon, Democratic Republic of Congo and Guinea Bissau. The presence of *P. truncatus* was reported in Uganda by Riwa (1998) and in Namibia by Bell *et. al.*.(1999). This exotic pest is considered a real threat to staple food in Africa, responsible for severe damage and losses of stored produce, particularly maize and dry cassava in the hot humid tropical areas (Pantenius, 1987; 1988; Keil, 1988; Laborious, 1990).

2.3.3 Spread in Ghana

In Ghana, the LGB spread slowly from the Volta Region, where it was first detected by Dick *et. al* (1989). By 1995, results of a survey conducted by a team from the Post-Harvest Development Unit (PHDU) of Ghana's Ministry of Food and Agriculture revealed the presence of the LGB in all regions of the country; Ashanti, Brong-Ahafo, Central, Eastern, Greater Accra, Northern, Upper East, Upper West, Volta and Western Regions (Boxall and Compton, 1996; Semakor, 1996), but the insect pest was more established in parts of the Volta, Greater Accra, Eastern and the Northern Regions. It is thought that trade and transportation of foodstuffs across the country are the most important means of spread; the first few infestations detected were near trader's stores. In addition, the LGB is capable of dispersal by flight (Richter and Biliwa, 1991). Ayertey and Brempong-Yeboah (1991) reported considerably high numbers of *P. truncatus* in places where few numbers had been recorded in surveys preceding theirs.

2.3.4 Life History

2.3.4.1 Oviposition

According to Shires (1980), females of *P. truncatus* have a pre-oviposition period of 5-10 days. After mating, the adult females lay most of their eggs in batches of up to 20 per clutch in blind ending tunnels, bored at right angles to the main tunnel within the grains and covered with finely chewed maize dust or flour (Li, 1988; Vowotor *et. al.*, 1998). Howard (1983) reported that the number of eggs laid is proportional to the weight of flour produced by boring, which suggests that the adults produce flour for the offspring. Peak oviposition is attained at about 15-20 days, after which there is a gradual decline to zero by 95-100 days (Shires, 1980; Bell and Watters, 1982; Howard, 1983). Mean lifetime fecundity per female was recorded at 50.5 eggs (Shires, 1980; Hodges, 1986) and the maximum number of eggs laid by a single female recorded was 154 (Rios, 1991). Records have shown that the quantity of food available to the female also influences the rate of oviposition. Simillarly, females maintained on loose grains laid fewer eggs than those on cobs, which explains the higher population growth rate on cobs than those on loose grains (Hodges, 1986; Li, 1988).

2.3.4.2 Egg to adult development

Prostephanus truncatus has been reported to complete its life cycle within 4-6 weeks (Genel, 1960; NRI, 1996) and in about 6½ weeks in warm weather (Chittenden, 1911). LGB is a long-lived species, their eggs hatch into larvae after an average of 4.1 days (Bell and Watters, 1982). There are 3 non-mobile larval instars, which live inside grains and/or in the flour produced by the adult. According to Vowotor *et. al.* (1998) different larval instars show significant preference for distinct feeding sites; first instar larva feeds mainly on the floury endosperm while the second and third instar larvae feed on the germ tissue. Mean larval period has been reported to last for about 16.1days (Bell and Watters, 1982). The last instar larva constructs a pupal case from flour stuck together by a larval secretion, either within the grain or surrounding dust. Mean pupal period lasts 4.7 days (Bell and Watters, 1982). Under optimum conditions of 32 °C and 70-80 % r.h, average development from egg to adult takes 25.4 days on maize (Bell and Watters, 1982). The sex ratio for adults is reported to be 1:1 (Shires and McCarthy, 1976; Shires, 1979; Li, 1988; Scholz *et. al.,* 1997; Vowotor *et. al.*, 1998). This sex ratio is not significantly deviated by temperature or humidity changes (Shires, 1979). However, Howard (1983) reported that developing on maize grain at 25 °C and 70 % r.h., females emerged 2 days before males. When LGB is maintained on cassava at 70 % r.h, the females emerge one half days after the males, while at 50 % r.h., females emerged 1-2 days after males (Hodges *et. al.*, 1985).

Shires, (1980) reported mean life expectancy for adult males and females under optimum conditions and maintained on maize to be 44.7 and 61.1 days, respectively. Maximum longevity recorded for males and females are 107.8 and 112.5 days, respectively. Howard

(1983) suggested that different oviposition rates influence female longevity; females with much higher rates perhaps have shorter longevity.

2.3.5 Environmental Requirements

2.3.5.1 Humidity and temperature

Reports from several studies on the life cycle of *P. truncatus* over a wide range of temperatures (12-40 °C) and relative humidities (0-90 % r.h.) suggest that the optimum requirements for development on maize are 32 °C and 70-80 % r.h. (Shires, 1979; 1980; Bell and Watters, 1982). The lower and upper limits for the completion of its life cycle are 25 and 32 °C at 40 % r.h., 18 and 37 °C at 70 % r.h. and 20 and 30 °C at 90 % r.h. (Bell and Watters, 1982). The LGB is more adaptable to diverse environmental conditions than most other storage pests, as it can complete its life cycle over a broad range of humidities and temperatures. Developmental period has been reported by Shires (1979) to be markedly slower at relative humidities below 70 % r.h. and above 80 % r.h., at all temperatures. Likewise at temperatures below 22 °C and above 35 °C, development is extended. Mortality is also low between 27-32 °C and 70-80 % r.h.

Shires (1979) and Watters (1984) further reported that at relative humidities less than 40 %; the beetle substantially reduced its multiplication rates at temperatures less than 20 °C and incomplete development may result at temperatures between 20-25 °C. Observations by Nyakunga (1982) revealed that at 27 °C and 70 % r.h., LGB develops more rapidly on maize grains than on cassava, with developmental periods of 39.2 days and 43.1 days, respectively.

2.3.5.2 Moisture

Prostephanus truncatus has been reported to infest grains with moisture content as low as 9 - 10.6% (Hodges *et. al.,* 1983). The beetle benefits from the absence of any significant competition from other storage pests, having the ability to tolerate and develop under dry conditions better than other storage pests. According to Watters (1984), the moisture content for safe storage of commodities against the LGB should correspond to 30 % r.h. or less. This level of moisture content is, however, difficult to achieve and maintain in many tropical regions. Consequently, it is expected that *P. truncatus* would be a successful insect species in hot humid tropics and sub-tropical zones.

2.3.6 Grain Host and Infestation

2.3.6.1 Flight and infestation

Dispersal of *P. truncatus* is determined by a combination of physiological state, substrate quality and climatic conditions (Scholz, 1997) as well as possibly chemical cues from natural host plants. Climatic stimuli are yet to be clearly associated with flight initiation (Tigar *et. al.*, 1994; Borgemeister *et. al.*, 1997). However, it is known that environmental conditions modify dispersal behaviour to some extent. According to Scholz (1997), high mean temperature may increase the beetle's general activity and can change habitat suitability. Likewise, changes in humidity can reduce habitat suitability, thereby inducing dispersal. *Prostephanus truncatus* also reacts to crowding and to accompanying degradation of food sources through migration (Scholz, 1997). Temperature is thought to exert a significant effect on flight. The frequency of flight take-off increased with temperature over the range 20-30 °C but declined sharply at 35 °C. Flight activity increased with starvation up to a maximum at 2 days, after which it began to decline. The adult insect can fly distances of up to 2-4 km (NRI, 1996). Watters (1984) described *P. truncatus* as clumsy flyers, but are able to ascend heights of at least 3m at 25 °C with ease. Olfactometer studies by NRI (1996) indicate that *P. truncatus* reacts, at least at short range, to volatiles from starchy commodities (maize, wheat and cassava) and from some woody host plants (*Spondias purpurea* and *Commiphora africana*) but not to volatiles from a non-host plant such as cowpea.

The LGB has been reported to infest both stored maize grains (Lesne, 1897; Chittenden, 1911; Delgado and Luca, 1951; Genel, 1960) and the standing maize crop (Genel, 1960; Quintana *et. al.*, 1960). According to Giles (1975), attacks in the field might occur fairly early when drying maize on the cob has moisture content as high as 49-50 %. Mushi (1984) confirmed this by reporting that 5 % of maize cobs in the field were infested with *P. truncatus* at the time of harvest. Adult beetles have also been found in the stems of maize plants left standing in the field after harvest in southern Tanzania. Commodity residues in grain stores remain a major source of beetles for field infestation. Haubruge and Verstraeten (1987) observed that, on loose grain, *P. truncatus* preferentially attacked uninfested grains more than those previously infested by *Sitophilus zeamais*.

2.3.6.2 Boring process

Adult LGB usually initiates attack on the exposed maize core at the base of the maize cob with complete sheath cover. The maize core offers less resistance than the relatively hard sheath. Li (1988) suggested that the beetle probably has some acoustic mechanism for appraising its substrate, as they reject regions in a substrate that have insufficient depth when selecting a suitable location to bore. The beetles eventually gain access to the stabilized grains via the apex of the cob by walking between the grains and the sheath (Hodges and Meikle, 1984). However, it needs to brace itself against something that is fixed, relative to the boring target (Cowley *et. al.,* 1980); the spaces between grains on the cob give the beetle a place to insert its hooked spines at the end of the first pair of tibiae so that the body can be anchored and a hole chewed (Bell and Watters, 1982). With the aid of the pronotum as a lever, the beetle uses its mandibles to bite; exerting forces up to 1.5-2.7 g.mm^{-2}on the surface of grains (Robinson, 1979). According to Li (1988), it takes the beetle 85 minutes to bore an initial hole to a depth of 1.3 mm (which is the average length of the pronotum) and 55 minutes to bore 2.2 mm deeper. The LGB can also bore through very solid storage structures, including wood (Chittenden, 1911; Hodges *et. al.*, 1983) and plastic (35mm thick and more) (Li, 1988) to gain access to commodities in storage.

Loose grains are not stable, therefore forces pressed on them either by the mandibles or the pronotum can make the grains slip away. The beetle can hardly grip the surface of grains with its claws and the spur of the tibia. The beetle therefore often falls down from one grain to another, but in a sizeable grain store it will eventually lodge in a suitable position to support it to bore into the grains. The beetle sometimes uses the elytra to push against the grain(s) behind/above to force its mandibles into the grain in front when the gap between two grains is relatively large. Adults bore into maize grains and other crop produce, making neat round holes and, as they tunnel from grain to grain they generate large quantities of dust (Li, 1988). Cowley *et. al.*(1980) in a study recorded relatively lower damage levels suffered by shelled maize, as opposed to stabilized maize by *P. truncatus*. The beetle is essentially a boring insect, well adapted to feeding on large blocks of firm food, but rather poorly adapted to feeding on the small discontinuous bits of food such as shelled grain (Bell and Watters, 1982). However, in any large volume of shelled grain, most of the grains at the bottom would be held in fixed positions by the weight of the top layers and attack by *P. truncatus* may be high, but relatively lower than in grains on the cob.

It is assumed that the differences in developmental periods are related to the degree of packing of the development medium. Under optimum conditions, on whole grain or on flour, *P. truncatus* completes its life cycle in 24-25 days when grains are firmly packed (Bell and Watters, 1982). On the other hand, Shires (1979; 1980) reported that on loosely packed maize flour, developmental period lasted 35.4 days. Bell and Walters (1982) concluded that in firmly packed flour the larvae make narrow tunnels against which they could brace themselves and hence are able to force their mandibles into the forward end of the tunnel for effective chewing. In low density media, the tunnels are wider and larvae often twist back and forth without moving ahead.

2.3.6.3 Feeding and nutrition

The male beetles produce aggregation pheromones on a suitable food source (Smith *et. al.*, 1996), which attracts male and female conspecifics (Hodges *et. al.*, 1984; Obeng-Ofori and Coaker, 1990), primarily for locating food sources rather than as a sexual partner. It was suggested by Torreblanca *et. al.* (1983) that *P. truncatus* feeds selectively on the germ. This was, however, contradicted by Ramirez Martinez and Silva (1983), who have suggested that the beetle feeds indiscriminately within the grain. This was further supported by the findings of Howard (1983), that germ alone provides unsatisfactory diet, as few larvae reared on the germ flour survived to adult stage in the laboratory. Adem and Bourges (1981) and Torreblanca *et. al.* (1983) also argued that changes in maize composition due to LGB results only from direct infestation and not just selective feeding on one part of the grain. The adults and larvae of *P truncatus* have been shown to tunnel indiscriminately in all directions within the grain, causing indiscriminate damage to the germ and endosperm (Subramanyam *et. al.,* 1987; Ramirez Martinez, 1990). Demianyk and Sinha (1988) also reported that LGB larvae mostly burrow into the germ, but those larvae which burrow into the hard endosperm develop considerably slower than the average.

The nutritional quality of a substrate is an important factor for larval development (Diane, 1993), though *P. truncatus* can bore through non-nutritional substrates. Ramirez Martinez and Silva (1983) observed that grain genotypes with soft pericarp and a high lysine and tryptophan contents were most vulnerable to attack by this beetle. The LGB prefers media with high starch content and relatively low moisture content (optimum range of

9 – 12 %) (Diane, 1993). Nang'ayo *et. al.* (1993), however, reported that the breeding of this beetle is negligible at moisture content less than 10 %. Substrates with a high content of moisture, fat, protein or sugar are rejected by the LGB, as their nutritional composition do not provide this specialized pest a good basis for its survival. According to Li (1988), legumes and nuts with a high content of particularly proteins or oils might be toxic to *P. truncatus*, as the beetles were short lived on cowpea (5 days) and walnut (7 days) after boring and feeding on these.

2.3.6.4 Feeding and breeding substrates

Reports by various authors show that the following substrates support the feeding and development of *P. truncatus:* maize cobs, shelled maize grains and maize flour (considered the best breeding commodities) (Shires, 1977; Li, 1988; Diane, 1993; Poschko, 1994), oat and acorn from English oak (Li, 1988; Diane, 1993), dried whole-meal bread (without preservatives) (Diane, 1993), dried cassava chips and flour (Nyakunga, 1982; Magom, 1985; Marshed-Kharusy, 1990; Diane, 1993; Poschko, 1994; Chijindu, 2002), dried yam chips (NRI, 1996; Solomon 2002), soft wheat grains, wheat flour and biscuits made from the flour (Shires, 1977; Howard, 1983; Li, 1988; Diane, 1993; Poschko, 1994), chickpea (Howard, 1983; Diane, 1993), dried sweet potato and potato flour (Mushi, 1984; Li, 1988; Diane, 1993), soft and white sorghum grains (Verma and Lal, 1987; Dick, 1988; Li, 1988; Verma *et. al.* 1988; Poschko, 1994), dry wood from a range of trees (Detmers, 1988; Laborius, 1990) as well as the dried stems of maize and cassava (Boxall and Compton, 1996). Diane (1993) suggested the possibility of *P.*

truncatus developing on brown rice (husked), macaroni noodles, and dried, toasted bread with very low number of offspring.

Howard (1983) successfully reared adult beetles from eggs placed on artificial cereal grains consisting of gelatin capsules filled with finely ground sorghum, wheat, millet and maize. Development was, however, extended on barley, rice and oat. Hodges (1986) then concluded that most cereal grains are nutritionally adequate for the LGB. Furthermore, the beetle has the ability to bore into a range of non-nutritive substrates, causing damage with no evidence of breeding, for instance wood (Chittenden, 1911; Hodges *et. al*, 1983), cowpea (Giles, 1975; Shires, 1977; Li, 1988), cocoa beans (Shires, 1977), coffee beans (Shires, 1977), perspex and polythene (Howard, 1983; Ramirez Martinez and Silva, 1983), groundnut (Hodges *et. al*, 1983), plastic (Li, 1988), yellow split pea, scarlet oak acorn and walnut (Li, 1988).

2.3.7 Economic importance

Severe losses of stored commodities (especially maize and cassava) attributed to the LGB are well documented in Africa and Latin America. Losses as high as 34 % (dry weight) were recorded in Tanzania over a short storage period. Prior to LGB introduction, losses averaged about 9 % (Hodges *et. al.*, 1983). Extensive damage was recorded in Togo; 100 % of maize cobs were bored by *P. truncatus* after 9 months in stores (Krall, 1984). In Togo, Pantenius (1987 and 1988) reported that dry weight loss of maize after six months storage before the advent of the LGB averaged 7.1 %, but increased to 30.2 % and 44.8 % after eight months storage, rendering the grains unfit for human consumption. In

Honduras, heavy infestation by the beetle resulted in local loss of over 30 % on maize (Hoppe, 1986). Weight losses of maize averaging 5 % after six months and 13 % after 8 months were recorded in Costa Rica (Boeye, 1988). Severe losses reported on maize from Tanzania averaged 17.9 % after 6 months and 41.2 % after 8 months (Keil, 1988). The result of a store experiment in Honduras revealed loss on maize of about 8.5 % and 31.6 % after eight months storage in successive years (Novillo, 1991); over 14 % during 10 months storage in Mexico (Rios, 1991), and 15-20 % losses were recorded after 8 months storage in Ghana (Nicol, 1991). In Ghana, less than one year storage resulted in 20-25 % losses of kokonte (Entsie and Ofosu, 2001).

2.3.8 Control

2.3.8.1 Chemical control

The most technically efficient and potentially cost-effective means of controlling *P. truncatus*, is the admixture of produce and suitable contact insecticides where practicable and permissible (McFarlane, 1975). Reports have it that organophosphorous insecticides, such as pirimiphos-methyl, tetrachlorvinphos and malathion, do not control the LGB effectively. However, they control grain weevils (i.e. *Sitophilus spp.*) effectively, keeping grains protected for 8 months (McFarlane, 1975; Golob *et. al.*, 1985; Holloway, 1988). Pyrethroids like permethrin, deltametrin or fenvalerate plus fenitrothion in powder formulation of 0.5 % w/w, applied at 2.5 - 3.0 ppm on shelled maize or cobs, have been reported to give protection for 10 months' or more and do not present any residual problems for human consumption (Golob *et. al.* 1985; Makundi, 1986).

It was therefore recommended by Koudoha (1986) and von Berg and Biliwa (1985) that on mixed infestations by *P. truncatus* and *Sitophilus spp*, a combination of organophosphate and pyrethroid, such as pirimiphos-methyl and deltametrin, will give an excellent control of both pests. This combination has been applied extensively since this report.

Store fumigation, using phosphine under gas-proof sheets has also been useful in disinfecting both storage structures and stored commodities (Krall, 1984). The use of fumigation is however limited, especially in large stores or where airtight conditions cannot be met.

2.3.8.2 Biological control

The use of biological control agents has proven useful in controlling *P. truncatus*. Reports show that *Caliodis* spp, a predatory bug, reduces the number of eggs and larvae of *P. truncatus* (Boeye *et. al.*, 1988; Boye, 1998). The polyphagous predator, *Teretrius nigrescens* (Lewis) (Coleoptera: Histeridae), formerly known as *Teretriosoma nigrescens* is able to suppress the growth of *P. truncatus* population (Boeye, 1990; Leliveldt and Laborius, 1990). The imago of *T. nigrescens* eats the eggs or larvae of *P. truncatus*. Markham *et. al.* (1991) reported that *T. nigrescens,* which is attracted from a distance by the aggregation pheromone of the beetles and within bulks of grain, also responds to the frass of, or grain infested by *P. truncatus.* Rees (1987) estimated that the larvae of *T. nigrescens* on the average consumed 3.5 larvae of *P. truncatus* per day, possibly consuming some 60 prey individuals to complete their development.

2.4 Physical Grain Properties

2.4.1 Grain Hardness, Size and Texture

Grain hardness may be related to insect resistance (Baker *et. al.*, 1989). The extent of damage by insects to sorghum grains in storage has been reported to depend on the proportion of the endosperm layer of the seed (Doggett, 1957 and 1958). Doggett (1988) indicated that hard grains with largely corneous (flinty) endosperm usually succumb to insect attack slowly, where soft mealy grains succumb more rapidly. Dobie (1977) established a positive correlation between grain hardness and susceptibility to infestation by *S. zeamais* on maize grains. The ability of *P. truncatus* larvae to tunnel into and feed on grains is determined at least in part by the hardness of the grain (Dick, 1988). Previous reports also indicate that the amount of tunneling and the size of egg batches depend on the hardness of the substrate (Li, 1988). Relatively hard seeds had fewer egg deposits per period by the beetle during their peak oviposition period on maize grains and consequently fewer adults emerged (Li, 1988). Confirming this, Hodges (1986) recorded higher oviposition rates when *P. truncatus* was maintained on floury maize varieties. In contrast, Rios (1991) and Li (1988) have shown that tunneling is slow on relatively hard grains; females react to this by depositing larger groups of eggs which in turn increases larval competition and mortality; total lifetime fecundity therefore reduces. Grain hardness, therefore has a considerable influence on reproductive potential and consequent damage. According to Miekle *et. al.* (Unpublished) and Russell (1962) wrinkled grain surface, in addition to its hard grain texture also acts as a deterrent to pest infestation and probably results in low insect damage. It is also known that grain hardness influences water absorption, which in turn has an effect on diastatic enzyme activity.

Doggett (1957), Russell (1962) and Davey (1965) suggested that larger grains generally succumb easily to pest infestation compared to smaller ones. Hodges *et. al.* (1983) confirmed this; relatively small sized grains of local red sorghum varieties escaped infestation in Tanzania. Hodges (1986) observed that the dispersed nature of grains on stored sorghum heads and the small grain size makes it an unsuitable host for the LGB. Suitability of a commodity (grain size) for the breeding of *P. truncatus* is determined by oviposition site selection and the larval behavioural adaptation (Li, 1988). Komlaga *et. al.* (2001) established that the grain size of sorghum can affect some physico-chemcial properties, such as the amount of water it can absorb (smaller grains absorb more water) and other functional properties.

Prostephanus truncatus are more adapted to rough and coarse surfaces and find it difficult to scratch, walk or bore into the smooth, flat, and hard surfaces. The walking speed of the beetle on glass and tissue sheets are 5.83 cm/minute and 30.66 cm/minute, respectively (Li, 1988). *Prostephanus truncatus* failed to bore into oak acorn (scarlet oak) and yellow split pea because the surfaces are so hard, smooth and flat that their mandibles made no mark on the surfaces (Li, 1988).

2.4.2 Varietal Differences

Available information indicates that most local varieties of a grain are less susceptible to post-harvest insect infestation than some of the high yielding varieties (Ofosu, 1976, 1977; 1990). It is well documented that there are varietal differences in the susceptibility of maize and possibly other cereals to *P. truncatus* (Bell and Watters, 1982; Ramirez

Martinez and Silver, 1983; Howard, 1983; 1984). Records have shown higher oviposition rates when *P. truncatus* was maintained on floury maize varieties (Howard, 1983), while hard flint grains suffered less damage to LGB infestation, thus indicating varietal differences. The results of a laboratory study by Addo (1994) suggested that improved maize varieties on the cob generally have slightly higher damage than local varieties; however, all shelled maize varieties were equally susceptible to LGB infestation.

2.4.3 Loose and Stabilised Grains

Cowley *et. al.* (1980) suggested that *P. truncatus* develops better on stabilized grain, because it needs to brace itself against something that is fixed, relative to the boring target, so that the body can be anchored with the aid of its hooked spines placed in the spaces between grains on a cob. Once inside the grain, the pest establishes itself by extension of tunnels along the rows of tightly packed seeds. This boring behaviour will be difficult in a discontinuous medium as loosed grains. Golob *et. al.*, (1985) indicated that unless grain temperature is significantly favorable to the insect pest, shelled maize is somewhat less susceptible to *P. truncatus* damage than maize on the cob.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Site

This study was carried out at the Ministry of Food and Agriculture/Plant Protection and Regulatory Services Directorate (MOFA/PPRSD) at Pokuase, Ghana.

3.2 Grain

Two improved sorghum varieties (Naga-White and Framida) developed by the Savannah Agricultural Research Institute (SARI), Tamale, of the Council for Scientific and Industrial Research (CSIR), Ghana, and one other local sorghum variety (Mankaraga) were obtained from SARI. One maize variety (Obatanpa) was obtained from the Seed Testing Unit of the Ministry of Food and Agriculture, Pokuase.

Varietal characteristics:

1. Framida is an early to medium maturing variety of about 250 cm plant height, takes 110 days to mature, with a potential grain yield of about 4.0 t/ha.
2. Mankaraga, has a plant height of about 500 cm. It takes about 160 – 170 days to mature, and has a low yield potential of 2 t/ha.
3. Naga-White is an early maturing plant; it takes 95-110 days to mature. Has a plant height of about 190 – 280 cm and a potential grain yield of about 5.0 t/ha.
4. Obatanpa (white dent), is medium maturing (90 days). It grows to a height of 198 cm, yeilds over 4.2 t/ha, is high in protein quality and is slightly drought tolerant.

3.3 Insect Culture

A parent stock of adult *P. truncatus* (Plate 1) was obtained from the MOFA/PPRS laboratory at Kpeve, in the Volta Region. About 500 g of maize grains were frozen in a deep freezer at about -18 °C for two weeks (TDRI, 1984; Hodges and Dobsona, 1998). The grains were then defrosted thermally and thoroughly sterilized by heating at 45 °C for 4 hours in an air-oven in the laboratory (Santhoy and Rejesus, 1975; Solomon, 2002) against insects that may have survived the freezing temperatures. Glass jars used were also sterilized by heating as stated above.

Sterilized grains were conditioned for 21 days under the prevailing laboratory conditions of 32 °C ± 2 temperature and 74-87 % r.h. throughout the experiment. About 500 g of maize grains were poured into a series of 1-litre glass jars. Some 100 unsexed adult *P. truncatus* were counted from the parent stock and introduced into the medium. The glass jars were covered with wire mesh held in position by perforated screw tops to keep in the insects and also to facilitate ventilation. Six of such cultures were prepared and placed on inverted petri dishes in white oil on shallow trays, at least 3 cm apart, to keep out mites and other unwanted insects. The adult insects were sieved off after three weeks of oviposition. This was repeated daily for three days, to ensure thorough removal of all adult insects and also that offsprings of a synchronized age were obtained. The cultures were left undisturbed till adult emergence. Adult insects that emerged from the cultures within the first 7 days of emergence (0-7 days old) were used for this study. Reculturing of the insect was carried out at regular intervals to ensure availability of experimental insects (Plate 2).

Plate 1: Adult *P. truncatus* (mag. X 100)

Plate 2: Prepared insect cultures

3.4 Substrate Suitability

To determine the suitability of different substrates for insect development, 100 g samples were taken from each of the four grain varieties after sterilization, as stated above, and poured into 500 ml glass jars. Each variety was replicated five times. Twenty unsexed adults of *P truncatus*, 0-7 days old, were randomly collected and introduced into each experimental jar to oviposit for 21days; to provide the beetles sufficient time to get conditioned and oviposit on the grains; but removed before the emergence of their offspring. These experimental cultures were randomly arranged on a shelf in the laboratory in a completely randomized design and maintained under prevailing ambient conditions. At the end of the oviposition period, all adult insects were sieved out repeatedly for three days consecutively, using a set of USA standard sieve series (Nos. 10 to 35) (Newark Wire Cloth Company, New York). Adults remaining within the grains were removed by carefully dissecting the grains under a stereo microscope, using a pair of blunt-ended forceps to hold the grain firmly and a scalpel to cut the grain, after which all jars were left undisturbed until adult emergence of the F_1 generation. Emerged adults were subsequently removed on a daily basis and their numbers counted and recorded until all of the F_1 generation had emerged (Plate 3).

Developmental period (T) of *P. truncatus* was recorded as the time (days) taken from the mid-point of oviposition to the time of emergence of 50 percent of the F_1 generation. This method was used by Wheatley (1971) and Dobie (1974) on *S. zeamais* (Motsch.).

Plate 3: Experimental set up for
substrate suitability/susceptibility

3.4.1 Assessment of Substrate Suitability

Suitability of the different grain varieties to support the development of P. *truncatus* was assessed using the formula adopted by Dobie (1974) on *Sitophilus zeamais* (Motsch.):

$$S = \frac{\text{Log e } Y}{T} \times 100$$

Where; S = suitability index

Y = number of F_1 adults that emerged

T = mean development period (days)

This index combines the number of progeny produced on each grain variety and the developmental period of the progeny into a single parameter. Higher index values indicate greater suitability of the substrate to support the development of *P. truncatus*, due to higher suitability of the variety to the beetle. Lower index values on the other hand indicate poor suitability of the substrate.

3.4.2 Mean Insect Weight

To determine the effect of the grain varieties on the weight of *P. truncatus*, 10 adults were taken at random within 24 hours of emergence from each grain variety and weighed with an electronic microbalance (Adams Equipment, South Africa) to an accuracy of 0.01 milligramme (mg).

These experiments were arranged in a completely randomized design. Insect numbers (x) recorded for substrate suitability were transformed using square root of (x + 1). Data collected from the above parameters were analyzed using analysis of variance (ANOVA). The means were separated using Least Significant Difference (LSD).

3.5 Progeny Production, Damage and Loss Assessment

Two different sets of experiments were conducted; each set was sampled after one month (4 weeks), two (8 weeks) and three (12 weeks) months' storage. In the first set 250 g samples of each grain variety were put in 500 ml glass jars (18 cm x 31 cm) without compaction of grains (Plates 4). Each variety had four control jars prepared. In the second experiment, 250 g samples of each variety were put into 250 ml glass jars (13 cm x 18 cm) which produced some level of compaction on the loose grains (Plates 5).

Plate 4: Experimental set up for weight loss determination without much compaction

Plate 5: Experimental set up for weight loss determination with some level of compaction

Each treatment was replicated four times. About 20 unsexed adult insects were introduced into each experimental jar, with the exception of control jars for all of the grain varieties. Experimental jars were randomly arranged on shelves in the laboratory (in a completely randomized design) and left undisturbed for sampling until the desired sampling occasions. Samples disturbed after one and two months storage, were further sampled at the end of the three months experimental period. Experimental jars sampled after three months were sampled only once.

At each sampling occasion, the contents of each experimental jar were sieved using the set of USA standard sieve series (Nos. 10 to 35). Adult insects, frass or dust and grains were collected separately. After sieving, each grain sample was divided into sub-samples by the cone and quarter method. These sub-samples were used for the determination of moisture content, percentage damage and weight loss.

3.5.1 Progeny Production

To determine the effect of the grain varieties on LGB production, live and dead adult insects collected after sieving out each of the grain samples were then sorted by careful observation with a hand lens and their numbers counted. Likewise, adults remaining within the grains were removed by carefully dissecting the grains under the microscope, using a pair of blunt-ended forceps to hold the grain firmly and a scalpel to cut the grain.

3.5.2 Dust Production

The proportions of grain transformed to frass or dust were determined by weighing the quantities of dust produced (on each variety) with a Sortius electronic balance with an accuracy of 0.1 milligramme.

3.5.3 Moisture Content

The moisture content of all the grain samples was measured at each sampling occasion using a Digital Grainmaster (Protimeter) calibrated for testing sorghum and maize grains separately. The measurement of each grain sample was replicated five times.

3.5.4 Percentage Damage

Some 100 grains from each grain sample were taken at random from the sub-samples by the cone and quarter method. Bored grains were separated from whole grains and their numbers counted. Percentage damage was calculated using the formula described by Adams and Schulten (1978):

$$(\%)\ \text{Damaged grains} = \frac{\text{No. of bored grains}}{\text{Total no. of grains in sample}} \times 100$$

3.5.5 Weight Loss

3.5.5.1 Standard volume/weight method

3.5.5.1.1 Baseline curve

To obtain a baseline curve for the grains used in the investigations, 5 kg lots of each grain variety were weighed. Each lot was divided into 5 sub-samples. The moisture content of the grain lot was determined with a Digital Grainmaster (Protimeter) at the start of the storage periods. A range of moisture contents expected in the course of storage was determined, based on the initial storage moisture content which was closer to one of the values in the range selected (8, 10, 12, 14, and 14 %). Samples that needed a reduction in moisture content were spread in a shallow layer on aluminum trays and placed in a warm, dry air-oven at temperatures not exceeding 35 °C. Regularly, samples were removed and cooled before measuring the moisture content. For samples that required increased moisture content, water was added. The quantity of water added was calculated using the formula of Adams and Schulten (1978):

$$\text{Weight of water (g)} = \text{weight of grain (g)} \times \frac{\text{desired M.C} - \text{initial M.C.}}{100 - \text{desired M.C.}}$$

where; M.C. = moisture content

Water was added in milliliters (1g of water occupies 1ml) to the samples in sealed aluminum containers with sufficient headspace for mixing. Samples were left for two weeks to condition, vigorously shaken daily. Samples with moisture content above 16 % were kept in a refrigerator at 5 -10 °C to discourage mould growth, after which 5 sub-samples at different moisture contents for each variety were determined. The weight of each sub-sample that occupied the standard volume measure (a test weight chondrometer), filled and leveled up was recorded to the nearest 0.1 g on a Sortius electronic balance. This was repeated five times for each sub-sample and mean values taken. The mean wet weights were converted to dry weight, using the formula of Adams and Schulten (1978):

$$\text{Dry weight} = \text{Weight of grain (g)} \times \frac{100 - \text{Percentage M.C.}}{100}$$

where; M.C. = moisture content

A graph of the dry weights and moisture contents for each variety was drawn, from which a reference line was plotted. The graph was used to represent the dry weight of samples at any moisture content, as they should be when left undamaged in storage.

3.5.5.1.2 Loss determination

At each sampling period, the grains sieved out from the jars containing each variety were thoroughly mixed. Moisture content of the grain samples was determined with a Digital Grainmaster (Protimeter). The weight of grains occupying the standard volume cylinder was recorded. This was repeated five times and a mean taken. Mean wet weights were converted to dry weight. Weight loss (percentage dry weight loss which by definition excludes moisture content changes) was calculated using the formula described by Adams and Schulten (1978):

$$\text{Weight loss (\%)} = \frac{\text{dry weight from graph} - \text{dry weight of sample}}{\text{dry weight from graph}} \times 100$$

3.5.5.2 Count and weigh method

One hundred grains from the already infested grain samples were counted at random from the sieved out samples of all the varieties; from which damaged and undamaged grains were sorted. The number of damaged or undamaged grains were recorded and then weighed. Weight loss was calculated using the formula (Adams and Schulten, 1978);

$$\text{Weight loss (\%)} = \frac{(UNd) - (DNu)}{U(Nd + Nu)} \times 100$$

Where: U = weight of undamaged grains
D = weight of damaged grains
Nu = number of undamaged grains
Nd = number of damaged grains.

The weight loss data was transformed using arcsine and insect numbers using square root of (x + 1). Analysis of variance (ANOVA) was conducted to determine significant differences. The means were separated using least significant difference (LSD).

3.6 Physical Properties of Grain

3.6.1 Grain Colour

Differences in grain colour were observed by placing a few sample kernels on a sheet of white paper. With the aid of a hand lens, the colours of the pericarp (outer coat of the grain) were noted and recorded either as a single colour or a combination of several colours, according to the IBPGR and ICRISAT (1993) classification of kernel colour scheme.

3.6.2 Grain Size

A digimatic caliper (Baty) was used to measure the length (mm) of grains across the longest section of each grain, from the hilum (scar of separation of ovule from ovary) to the other end of the grain. Five replicates of 50-grain samples were counted at random from each variety and measured to get the representative mean size of each variety.

3.6.3 100-Kernel Weight

It is well known that variation exists in kernel weight within a variety. Therefore, to have an indication of the mean weight of 100-grains of each variety, about 100-grains were counted and weighed. Five replicates of 100-grains of each variety were counted and weighed and the results obtained were recorded.

3.6.4 Grain Density

Samples of fifty grains were taken from each grain variety, weighed and poured into a 250 ml graduated measuring cylinder filled with 100ml of 95 % ethanol. The amount of fluid displacement observed was recorded and used to calculate density using the formula provided by Meikle *et. al.* (Unpublished);

$$\text{Density} = \frac{\text{Weight of grain (g)}}{\text{Volume of ethanol displaced (ml)}}$$

3.6.5 Grain Hardness

Grains used for this test were equilibrated in a humidity chamber (Rumed :Type 3001-3601, Version E/30-35/12-96) using saturated aqueous sodium chloride (NaCl) salt solution to maintain 70 % r.h. at 30 °C. This was maintained for two weeks.

A grain hardness test was conducted to determine how hard or easily the respective varieties crack due to force or pressure applied. Grain hardness was determined by a method similar to that described by Pomeranz *et. al.* (1985) and Li (1988). This test was carried out in the tensile strength testing laboratory at Ghana Standard Board. A Hounsfield Tensile Strength Machine (Model H50KS) was used. Individual grains were placed between two flat surfaces (anvils) and a compression Force (Newton) was applied at a speed of 5 mm/min. The force at which the grain first cracked was recorded. Some 50 grain samples for all the grain varieties were tested.

Data collected was analyzed using analysis of variance (ANOVA). Their means were separated using Least Significant Difference (LSD).

3.6.6 Endosperm Texture

Grains used for this test were also equilibrated in a humidity chamber as described above (Section 3.6.5) for two weeks. A Grinding and Sieving Method, used by Davey (1965) and Dobie (1974) was adopted for this study which was carried out at Food and Nutrition Department, University of Ghana, Legon. About 250 g grain samples of each grain variety were weighed and ground at a constant setting in a Christy and Norris Laboratory

Hammer Mill. After grinding, five replicates of a 50 g sub-sample were taken from each grain variety. All replicates were sieved with a sieve of 500 µm mesh. The proportion of grains passing through and those retained by the sieve were weighed. Floury endosperm became finely crushed during grinding and mainly passed through the sieve, while the corneous endosperm tended to fragment and was mainly retained by the sieve. An estimate of the fractions of floury to corneous endosperm was calculated using the relation,

$$\%\ R\ retained = \frac{B}{(A+B)}\ x\ 100$$

Where: A=fraction of grains that pass through the sieve (g)

B=fraction of grains retained in the sieve (g)

Data collected for each of the grain properties was analyzed using analysis of variance (ANOVA). Their means were separated using Least Significant Difference (LSD).

Correlation was conducted to determine the associations between the various grain properties and susceptibility index, grain damage, weight loss, progeny production, insect weight, rate of development, as well as insect preference in each case.

3.7 Preference Test

Five replicates of 40 g samples of each variety were placed on a filter paper inside Petri dishes. The Petri dishes were arranged in a circular form, at least 10 cm apart in a transparent trough. Forty adults of *P. truncatus* were counted and placed in another Petri-dish placed at the centre of the trough. The set up was observed at four hours intervals for a total of 16 hours .The number of insects found on each variety were recorded. Each treatment was replicated five times.

Data collected were analyzed using Analysis of Variance and the means separated using LSD.

CHAPTER FOUR

4.0 RESULTS

4.1 Substrate Suitability

Significant differences ($P < 0.05$) were observed between the different grain varieties and the different forms of the same substrate with regards to the numbers of F_1 progeny, insect weight, developmental period of *P. truncatus* and susceptibility index as shown in Table 1.0. The highest mean values of F_1 progeny (166.4 ± 0.5), insect weight (4.9 ± 0.3), susceptibility index (19.1 ± 1.0) and the shortest developmental period (27 ± 1.1) were recorded on Obatanpa (maize). This was followed by Naga-White (sorghum) and Framida (sorghum). Least mean values were recorded on Mankaraga (sorghum); F_1 Progeny (1.8 ± 0.2), insect weight (2.5 ± 0.1), susceptibility index values (2.3 ± 0.6) and the longest developmental period (46.6 ± 1.2). In a similar manner, the highest mean values were recorded on Whole Grains, followed by Grain Flour with the least values on Coarsely Ground Grains.

Bivariate correlation coefficients for comparison at 5 % level were significant between F_1 progeny and susceptibility index ($r = 0.965$, $P=0.0035$), percentage damage ($r=0.990$, $P=0.010$) and weight losses by standard volume method ($r=0.978$, $P=0.022$). It was also significant between mean insect weight and percentage damage ($r=0.999$, $P<0.001$), weight losses by standard volume method ($r=0.997$, $P=0.003$), count and weigh method ($r=0.997$, $P=0.003$) and dust production ($r=0.999$, $P<0.001$).

Table 1.0. Means (± S.E) of F_1 Progeny produced, Insect Weight, Developmental Period and Susceptibility Index of three sorghum and one maize varieties grown in Ghana following infestation by *P. truncatus*.

SUBSTRATE	VARIETY	NUMBERS OF F_1 PROGENY	MEAN INSECT WEIGHT (mg)	MEAN DEVELOPMENT PERIOD (DAYS)	INDEX OF SUSCEPTIBILITY (S I)
WHOLE GRAIN	1. Mankaraga (sorghum)	2.40 ± 0.23a	2.49 ± 0.13a	46.60 ± 1.16a	2.28 ± 0.61a
	2. Naga-White (sorghum)	11.0 ± 0.29b	3.02 ± 0.27a	36.00 ± 3.43b	7.06 ± 0.93b
	3. Framida (sorghum)	13.6 ± 0.28b	2.98 ± 0.31a	37.40 ± 1.88b	7.14 ± 0.58b
	4. Obatanpa (maize)	166.40 ± 0.45c	4.91 ± 0.29b	27.00 ± 1.14c	19.09 ± 1.03c
GRAIN FLOUR	1. Mankaraga (sorghum)	1.51 ± 0.16a	1.70 ± 0.13a	60.60 ± 1.16a	1.27 ± 0.37a
	2. Naga-White (sorghum)	2.33 ± 0.20b	2.22 ± 0.27 a	50.00 ± 3.43b	3.33 ± 0.34b
	3. Framida (sorghum)	2.17 ± 0.15b	2.18 ± 0.31a	51.40 ± 1.88b	3.02 ± 0.35b
	4. Obatanpa (maize)	4.86 ± 0.14c	4.11 ± 0.29b	41.00 ± 1.14c	7.72 ± 0.18c
COARSELY GROUND GRAIN	1. Mankaraga (sorghum)	1.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
	2. Naga-White (sorghum)	1.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
	3. Framida (sorghum)	1.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
	4. Obatanpa (maize)	1.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a

Means followed by different letters in each column, for each substrate form, are significantly different at $P<0.05$ level (LSD) (Insect numbers were transformed using square root $(x + 1)$).

4.2 Damage and Weight loss

4.2.1 Damage

The levels of grain damage were significantly different (P<0.05) between the grain varieties (Plates 6, 7, 8 and 9) (Figure 1). The mean percentage damage values increased gradually with time (in months') as the storage period increased. The least mean percentage damage value observed after three months' storage was 18.3 ± 1.65 on Mankaraga, while the highest mean value recorded was 69 ± 2.1 on Obatanpa.

Results also indicated significant (P<0.05) differences between the mean percentage damage values when stored with or without compaction (Figure 1). Grains stored with compaction had higher mean percentage damage value of 69 ± 2.1 compared to 64 ±2.0 on Obatanpa grains stored without compaction. Mankaraga had the least mean percentage damage values of 19.0 ± 1.5 for grains stored with compaction compared to 18.3 ± 1.7 for grains stored without compaction.

The means of percentage damage observed at the end of the three months' storage period were significantly (P<0.05) different, on the different grain varieties (Figure 2). Grains left undisturbed for the entire three months' storage period had the highest mean percentage damage of 69.0 ± 2.1 for Obatanpa and the least 18.3 ± 1.7 for Mankaraga. This was followed by grains disturbed after one month of storage (67.0 ± 0.4) for maize and 18.1 ± 1.7 Mankaraga. The least mean values were recorded on grains disturbed after two months of storage, i.e. 64.0 ± 1.1 for Obatanpa and 18.0 ± 1.6 for Mankaraga.

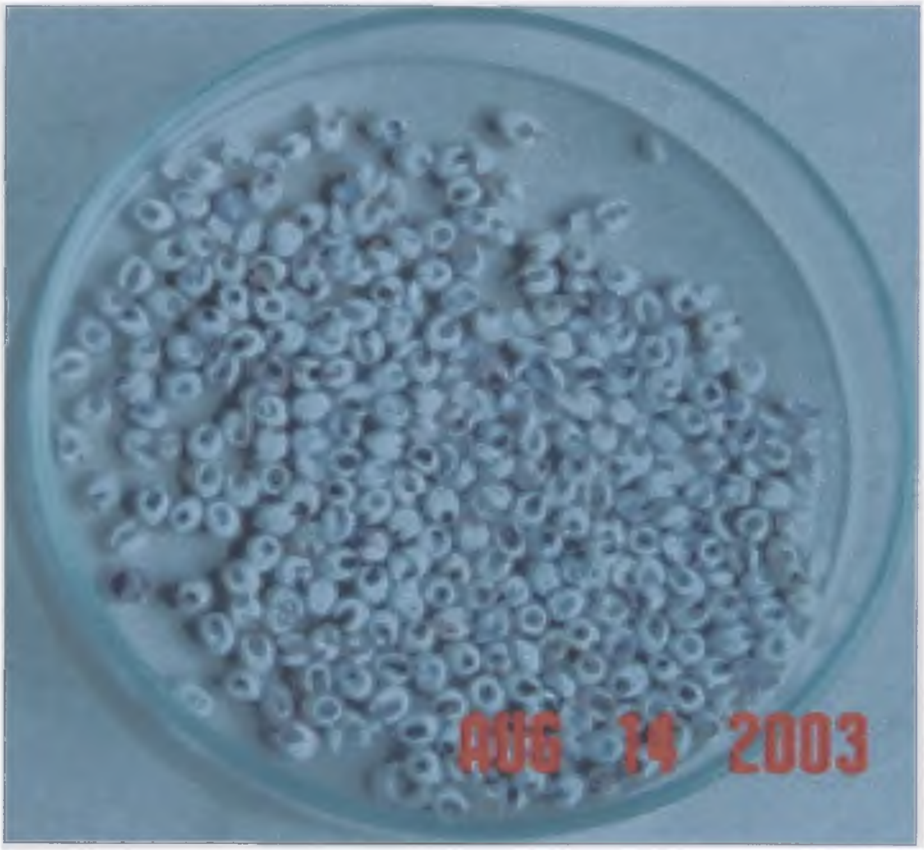


Plate 6: Mankaraga (sorghum) grains damaged by *P. truncatus*

Plate 7: Framida (sorghum) grains damaged by *P. truncatus*

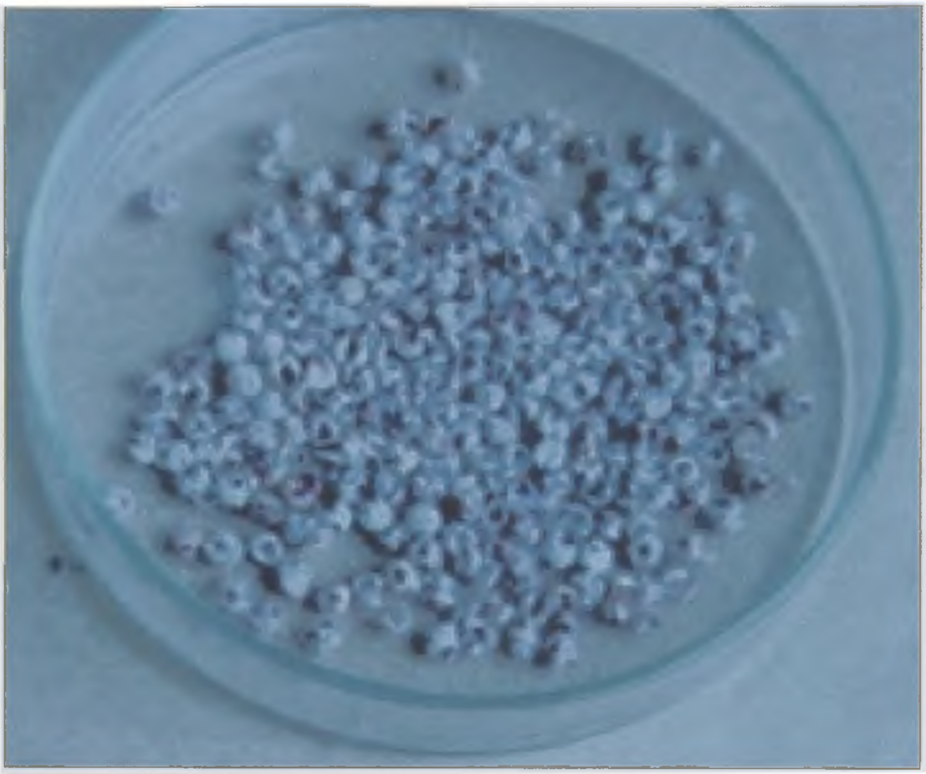


Plate 8: Naga-White (sorghum) grains damaged by *P. truncatus*

Plate 9: Obatanpa (maize) grains damaged by *P. truncatus*

Figure 1. Mean percentage damage after 1, 2 and 3 months of storage of three sorghum and one maize varieties with or without-compaction

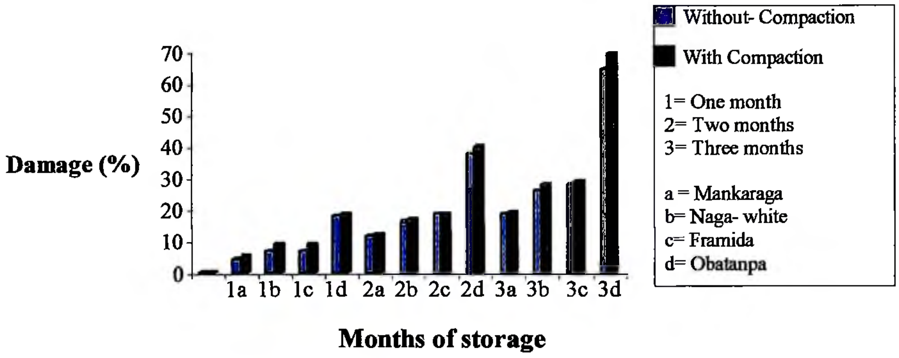
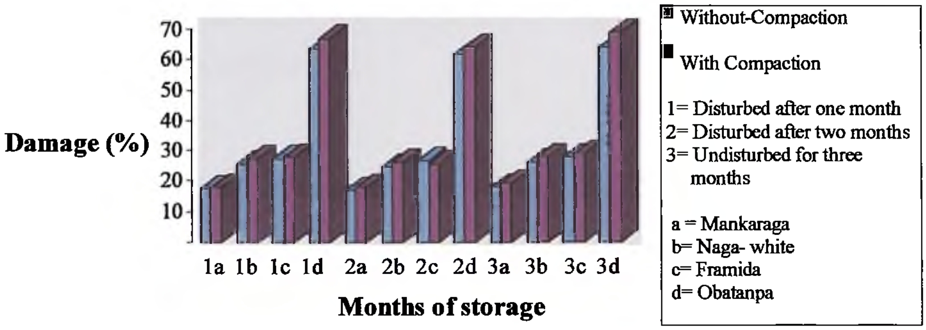


Figure 2. Mean percentage damage on stored grains at the end of three months with or without-compaction, when left disturbed or undisturbed.



Interaction between disturbed storage, compaction and variety was significant ($P<0.001$). However, interaction between compaction, month of storage and variety ($P=0.125$), as well as the interaction between disturbed storage, month and variety ($P=0.368$) and the interaction between compaction, disturbed storage, month and variety ($P=0.477$) were not significant.

4.2.2 Weight loss

Weight losses were significantly different ($P<0.05$) between the grain varieties. The mean values of weight loss calculated by the Standard Volume/Weigh Method (dry weight basis) (Figure 3) and by the Count and Weigh Method (wet weight basis) (Figure 5) gradually increased with time as the storage period increased. The least mean weight loss obtained by Standard Volume/Weigh Method after three months storage was 5.1 ± 0.3 % on Mankaraga, while the highest mean value recorded was 18.4 ± 0.4 % on Obatanpa. The least mean weight loss obtained by Count and Weigh Method after three months' storage was 6.3 ± 0.8 % on Mankaraga, while the highest mean value recorded was 20.3 ± 0.7 % on Obatanpa.

The results also indicated significant ($P<0.05$) differences between the mean values of weight loss when stored with or without compaction. Grains stored with compaction determined by the Standard Volume/Weight Method (Figure 3), had the highest mean percentage weight loss of 18.4 ± 0.4 compared to 17.3 ± 0.4 % for grains stored without compaction for Obatanpa variety. Mankaraga had the least mean weight loss values of

5.1 ± 0.3 % on grains stored with compaction compared to 4.89 ± 0.3 % on those stored without compaction.

When determined by the Count and Weigh Method (Figure 5), grains stored with compaction had the highest percentage mean weight loss of 20.3 ± 0.7, compared to 19.9 ± 0.5 % for grains stored without compaction on Obatanpa variety. Mankaraga had the least mean weight loss values of 6.3 ± 0.8 % for grains stored with compaction compared to 5.7 ± 0.3 % for those stored without compaction.

The mean weight losses observed at the end of the three months' storage period were significantly (P<0.05) different on the different grain varieties (Figure 4). Grains left undisturbed for the entire three months' storage period; determined by the Standard Volume/Weight Method showed the highest mean weight loss value of 18.4 ± 0.4 % on Obatanpa. Mankaraga had the least mean weight loss of 5.1 ± 0.3 %. This was followed by grains disturbed after one month of storage, with the means weight loss values of 18.4 ± 0.2 % on Obatanpa and 5.0 ± 0.2 % on Mankaraga The least mean weight loss values were recorded on grains disturbed after two months' of storage, i.e. 18.1 ± 0.3 % for Obatanpa and 4.6 ± 0.2 % for Mankaraga.

The mean weight losses observed at the end of the three months storage period were significantly (P<0.05) different on the different grain varieties when determined by count and weigh method (Figure 6). Grains left undisturbed for the entire three months storage period, when determined by the Count and Weigh Method had the highest mean weight loss of 20.3 ± 0.7 % on Obatanpa and the least mean values of 6.3 ± 0.8 % on

Mankaraga. This was followed by grains disturbed after one month of storage, with the mean weight loss values of 19.7 ± 0.6 % on Obatanpa and 6.2 ± 1.9 % on Mankaraga. The least mean weight loss values were recorded on grains disturbed after two months of storage, 19.5 ± 0.8 % on Obatanpa and 6.0 ± 1.3 % on Mankaraga.

There were significant interactions between compaction, grain disturbance and variety ($P<0.001$); compaction, month and variety ($P<0.001$); grain disturbance, month and variety ($P<0.001$) and compaction, grain disturbance, month and variety ($P=0.027$) when percentage weight losses were determined by Standard Volume/Weight Method.

Again, there were significant interactions between compaction, grain disturbance and variety ($P=0.015$) and grain disturbance, month and variety ($P<0.001$), when percentage weight losses determined by Count and Weigh Method. There was, however, no significant interaction between compaction, month and variety ($P=0.818$) as well as compaction, grain disturbance, month and variety ($P=0.462$) when percentage weight loss were determined by the Count and Weigh.

Figure 3. Mean weight losses (%) by standard volume/weight method after 1, 2 and 3 months of storage with or without-compaction

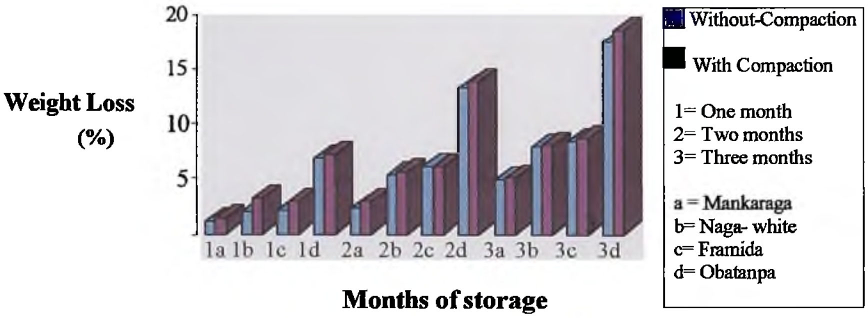


Figure 4. Mean weight losses (%) by standard weight/volume method at the end of three months storage with or without-compaction, left disturbed or undisturbed

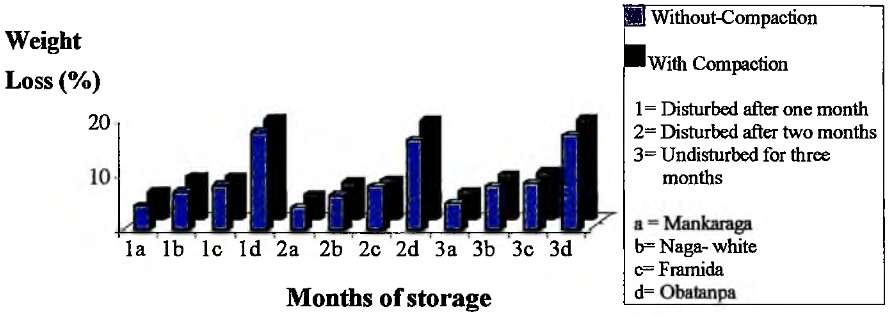


Figure 5. Mean weight losses (%) by count & weight method after 1, 2 and 3 months storage with or without-compaction

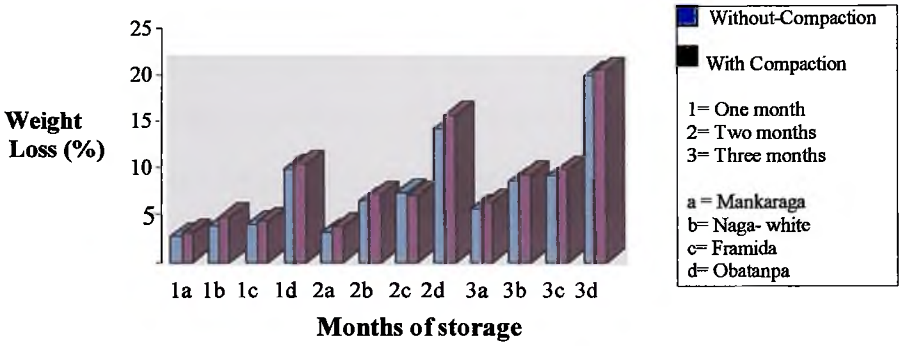
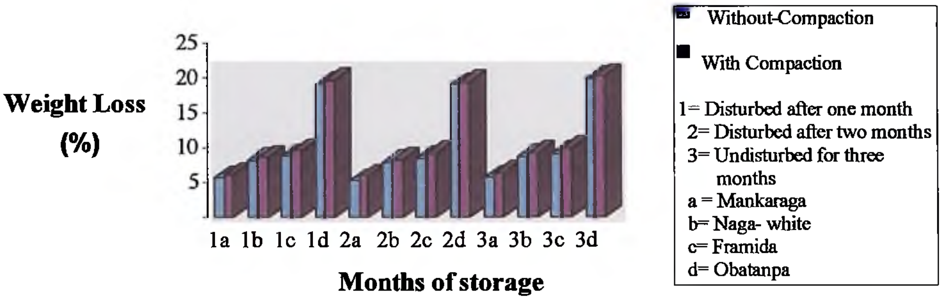


Figure 6. Mean weight losses (%) by count & weight method at the end of three months storage, with or without-compaction, when left disturbed or undisturbed



4.2.3 Frass or Dust Production and Number of Live Insects

Frass or dust production and the number of live insects were significantly different ($P<0.05$) between the various grain varieties used. The mean dust production (weight) and the number of live insects also increased gradually with time, as the storage period increased. The least mean weight of dust produced after three months storage was observed on Mankaraga, which was 3.2 ± 0.3 g, while the highest mean value recorded was 51.1 ± 0.4 g on Obatanpa (Figure 7). The least mean number of live insects (zero) after three months' storage was observed on Mankaraga, while the highest mean value recorded was 231.3 ± 0.4 g on Obatanpa (Figure 9).

The results also showed significant ($P<0.05$) differences between the mean weight of dust produced when stored with or without compaction (Figure 7). Grains stored with compaction, had the highest mean weight of dust produced, 51.1 ± 0.4 g, as compared to 49.8 ± 0.4 g for grains stored without compaction on Obatanpa variety. Mankaraga had the least mean weight of dust produced, 3.2 ± 0.8 g for grains stored with compaction as compared to 3.0 ± 0.7 g for those stored without compaction.

Bivariate correlation coefficients for comparison at 5 % level were significant between dust produced and grain weight ($r=0.975$, $P=0.025$), susceptibility index ($r = 0.994$, $P=0.006$), the number of live insects ($r=0.995$, $P=0.005$), percentage damage ($r=1.000$, $P<0.001$), weight losses by standard volume method ($r=1.000$, $P<0.001$) and by count and weight method ($r=0.999$, $P<0.001$).

The results also indicated significant ($P<0.05$) differences between the mean number of live insects when stored with or without compaction (Figure 9). Grains stored with compaction, had the highest mean number of live insects of 231.3 ± 0.9, as compared to 227.8 ± 0.4 for grains stored without compaction on Obatanpa variety. However, Mankaraga, recorded the least mean number of live insects for grains stored with compaction, as well as those stored without compaction.

Bivariate correlation coefficients for comparison at 5 % level were significant between the number of live insects and susceptibility index ($r = 0.978$, $P=0.022$), percentage damage ($r=0.996$, $P=0.004$), weight losses by standard volume method ($r=0.987$, $P=0.010$) and by count and weight method ($r=0.990$, $P=0.010$).

The mean dust production (weight) observed at the end of the three months' storage period were significantly ($P<0.05$) different on the different grain varieties (Figure 8). Grains left undisturbed during the entire three months' storage period had the highest mean dust production of.51.1 ± 0.4 g on Obatanpa and the least mean dust production of 3.2 ± 0.8 g was recorded on Mankaraga. This was followed by grains disturbed after one month of storage with the means of 49.8 ± 0.9 on Obatanpa and 2.90 ± 0.6 on Mankaraga. The least mean values were recorded on grains disturbed after two months of storage, having the means of 49.3 ± 2.1 on Obatanpa and 2.5 ± 0.3 on Mankaraga.

The mean numbers of live insects observed at the end of the three months' of storage were significantly ($P<0.05$) different on the different grain varieties (Figure 10). Grains left undisturbed for the entire three months' storage period, had the highest mean numbers (such as 231.3 ± 1.0) on Obatanpa. The least mean insect number was recorded on Mankaraga (0.00 ± 0.1). This was followed by grains disturbed after one month of storage with the mean insect numbers of 230.5 ± 0.4 on Obatanpa and 0.00 ± 0.2 on Mankaraga. The least mean insect numbers were recorded on grains disturbed after two months' of storage, such as 228.6 ± 1.1 on Obatanpa and 0.00 ± 0.3 on Mankaraga.

The interaction between grain disturbance, month and variety was significant ($P<0.001$). However, the interaction between compaction, month and variety ($P= 0.276$), as well as the interaction between compaction, grain disturbance and variety ($P= 0.266$) were not significant. Similarly, the interaction between compaction, grain disturbance, month and variety ($P= 0.310$) was also not significant for dust produced.

There were significant ($P<0.001$) interactions between compaction, grain disturbance and variety, and grain disturbance, month and variety on the number of live insects. However, the interaction between compaction, month and variety ($P=0.764$), and the interaction between compaction, grain disturbance, month and variety ($P= 0.153$) were all not significant for the number of live insects.

Figure 7. Mean quantity (g) of dust produced on the grains after 1, 2 and 3 months storage with or without-compaction.

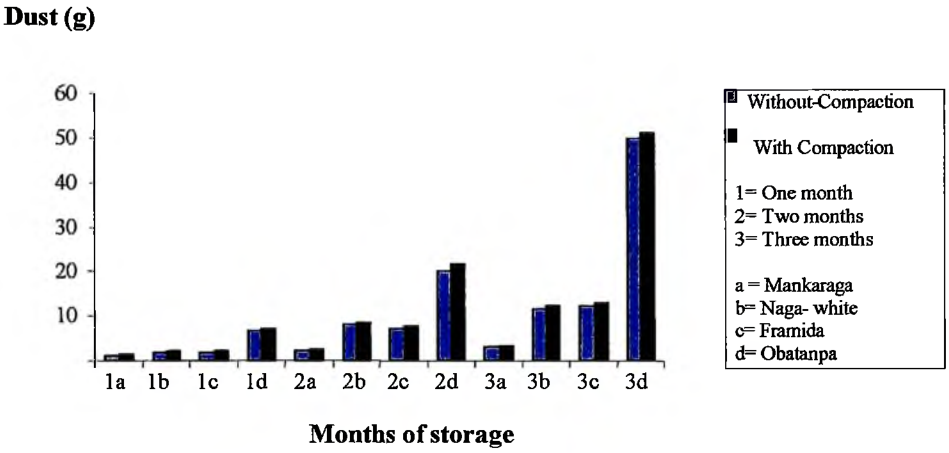


Figure 8 Mean quantity (g) of dust produced at the end of three months' storage with or without-compaction, left disturbed or undisturbed

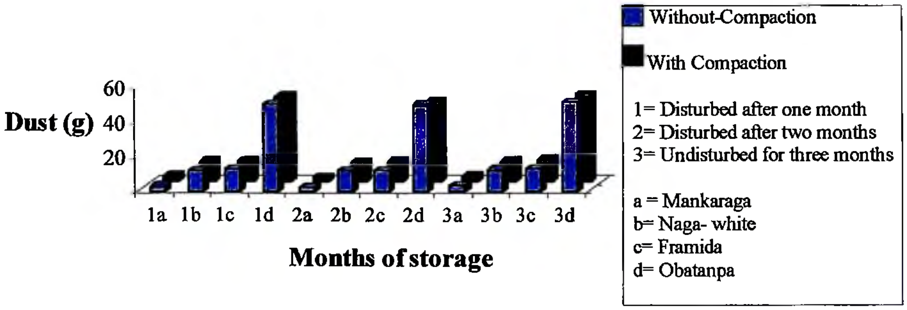


Figure 9. Mean numbers of live insects surviving after 1, 2 and 3 months' storage with or without-compaction

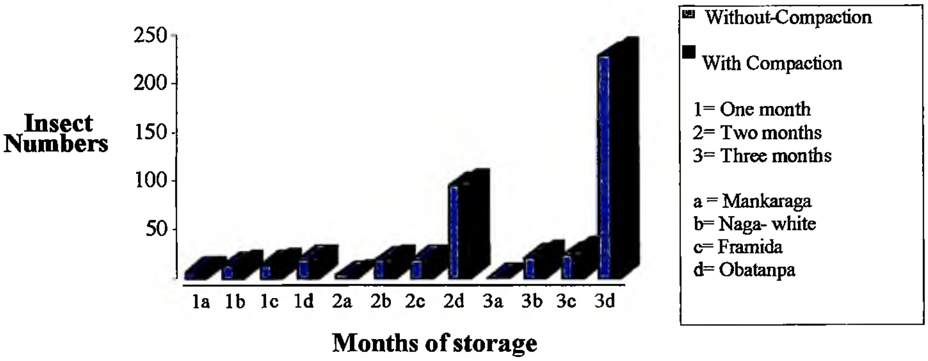
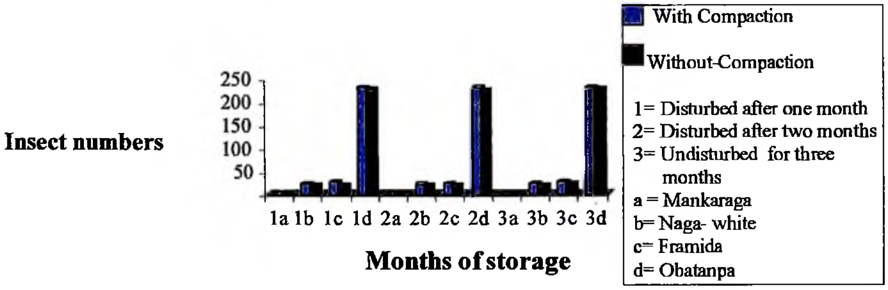


Figure 10. Mean numbers of live insects on the grains at the end of three months' storage with or without-compaction, left disturbed or undisturbed



4.3 Physical Properties of Grain

Most of the physical grain properties observed on the different grain varieties were significantly ($P<0.05$) different (Table 2.0). Amongst these were colour, size, 100–grain weight, endosperm texture and grain hardness. Grain density was however not statistically significant ($P>0.05$).

Obatanpa variety had higher mean values of length (10.8 ± 0.2 mm) and breadth (8.8 ± 0.1 mm) which were significantly different ($P< 0.05$) from the length and breadth of Framida, Mankaraga and Naga-White sorghum varieties (Table 2). There were, however, no significant differences ($P>0.05$) between the sorghum varieties with regards to the length of the grain. Bivariate correlation coefficients at 5 % level were significant in a comparison between grain length and F_1 progeny ($r=0.995$, $P=0.005$), mean insect weight ($r=0.966$, $P=0.034$), number of live insects ($r=0.988$, $P=0.012$), percentage damage ($r=0.971$, $P=0.029$), weight losses by standard volume-weight method ($r=0.952$, $P=0.048$), count and weigh method ($r=0.957$, $P=0.043$) as well as the weight of dust produced ($r=0.969$, $P=0.031$). Again, bivariate correlation coefficients at 5 % level were significant for comparisons between grain breadth and F_1 progeny ($r=1.000$, $P<0.001$), mean insect weight ($r=0.988$, $P=0.012$), susceptibility index ($r = 0.968$, $P=0.032$), number of live insects ($r=0.999$, $P=0.012$), percentage damage ($r=0.991$, $P=0.009$), weight losses by standard volume-weight method ($r=0.986$, $P=0.020$) and by count and weigh method ($r=0.983$, $P=0.017$), as well as dust production ($r=0.990$, $P<0.001$).

The 100-grain weight of Obatanpa variety (i.e. 25.70 ± 0.24 g) was significantly higher ($P<0.05$) than those of Framida, Mankaraga and Naga-White varieties. However, between these sorghum varieties; there were no significant differences ($P>0.05$) (Table 2.0). Bivariate correlation coefficients at 5 % level were significant in comparisons between 100-grain weight and F_1 progeny produced ($r=0.982$, $P=0.018$), mean insect weight ($r=0.974$, $P=0.026$), percentage damage ($r=0.978$, $P=0.022$), weight loss by standard volume-weight method ($r=0.961$, $P=0.039$) and by count and weigh method ($r=0.966$, $P=0.034$), as well as the dust produced ($r=0.975$, $P=0.025$).

The endosperm textures of the various grain types were significantly different ($P<0.05$) from each other. Mankaraga and Obatanpa varieties had the hardest endosperm texture of 72.2 ± 1.1 % tailing. This was followed by Naga-White with a mean of 56 ± 1.1 %. Framida had the softest endosperm texture with the least percentage tailing of 47.9 ± 1.6 %. Bivariate correlation coefficients for comparison (among sorghum grains) at 5 % level were significant between endosperm texture and grain hardness ($r=1.000$, $P=0.019$).

The grain hardness was also significantly different ($P<0.05$) between the grain varieties. Obatanpa variety was the hardest grain requiring the highest mean force of 298.6 ± 8.5 % (N) to crack. This was followed by Mankaraga, Naga-White and Framida, in that order (Table 2.0). The bivariate correlation coefficients for comparison (among sorghum grains) at 5 % level were not significant but showed strong associations between grain hardness and insect preference ($r=-0.975$, $P=0.143$), grain density ($r=-0.979$, $P=0.132$) and the number of live insects ($r=-0.989$, $P=0.093$).

4.4 Preference Test

Preference test conducted showed statistical significances ($P<0.05$). Mankaraga had the least mean number of insects (6.4 ± 0.2) recorded, while the highest mean number of 14.8 ± 0.1 was recorded on Obatanpa (Table 2.0). Bivariate correlation coefficients at 5 % level were significant between insect preference and grain varieties ($r = 0.970$, $P=0.030$), as well as with susceptibility index ($r = 0.974$, $P=0.029$).

Table 2.0. Means ± S.E. of Physical grain properties and grain preference

VARIETIES **GRAIN PROPERTIES**		**MANKARAGA** (sorghum)	**NAGA-WHITE** (sorghum)	**FRAMIDA** (sorghum)	**OBATANPA** (maize)
1. **COLOR**		White	White with reddish spots	Red	Creamy white
2. **GRAIN SURFACE**		Smooth	Smooth	Smooth	Smooth
3. **SIZE**	**Length (mm)**	4.57 ± 0.13a	4.22 ± 0.10a	4.35 ± 0.11a	10.77 ± 0.18b
	Breadth (mm)	3.54 ± 0.11a	3.87 ± 0.11ab	3.95 ± 0.13b	8.78 ± 0.12c
4. **DENSITY (g/cm^3)**		1.05 ± 0.31a	0.92 ± 0.12a	0.84 ± 0.12a	1.24 ± 0.14a
5. **100-GRAIN WEIGHT(g)**		2.67 ± 0.14a	2.43 ± 0.11a	2.50 ± 0.14a	25.70 ± 0.24b
6. **ENDOSPERM TEXTURE**		72.20 ± 1.12a	56.12 ± 1.07b	47.88 ± 1.59c	72.20 ± 1.12a
7. **GRAIN HARDNESS (NEWTON FORCE)**		82.38 ± 3.15a	59.18 ± 2.60b	45.84 ± 1.99c	298.59 ± 8.48d
8. **PREFERENCE (INSECT NOS)**		6.40 ± 0.15a	7.80 ± 0.14b	9.80 ± 0.15b	14.80 ± 0.10c

Means followed by different letters in each row are significantly different at $P<0.05$ level (LSD)

CHAPTER FIVE

5.0 DISCUSSION

5.1 Substrate Suitability and Susceptibility

The study revealed that *P. truncatus* can both feed and breed on sorghum grains. This agrees with the findings of Verma and Lal, (1987), Dick (1988), Li (1988), Verma *et. al.* (1988) and Poschko (1994). The results of this study further confirm the reports of various authors that maize is the suitable substrate for the feeding and breeding of *P. truncatus* (Shires, 1977, Li, 1988, Diane, 1993; Poschko, 1994).

High-yielding sorghum varieties (Framida and Naga-White) had susceptibility indices of between 7.06-7.14 on whole grains and 3.02-3.33 on grain flour. The local low-yielding sorghum variety (Mankaraga) had the least susceptibility index of 2.28 on whole grains and 1.27 on grain flour. Maize grains on the other hand had the highest susceptibility index of 19.09 on whole grains and 7.72 on grain flour. This suggests that the high-yielding sorghum varieties (Framida and Naga-White) were suitable in supporting the completion of the life cycle of *P. truncatus*; within 36-37 days on whole grains and 50-51 days on grain flour. The low susceptibility of the local low yielding variety (Mankaraga) probably explains the long developmental periods recorded on it; 46 days on whole grains and 60 days on grain flour. It is due to this high susceptibility of maize that the beetle could develop fast, 21 days on whole grains and 41 days on grain flour.

The weight of offsprings obtained further showed differences in susceptibility. The reasonably high mean weights of 2.98-3.02 mg on whole grain and 2.18-2.22 mg on grain flour obtained from the two high-yielding sorghum varieties (Framida and Naga-White) confirm their higher susceptibility compared to the lower weights obtained from offsprings that developed on the local low-yielding variety (Mankaraga); 2.49 mg on whole grain and 1.70 mg on grain flour. Maize grain showed the highest susceptibility, with a higher mean weight of 4.91mg on whole grains and 4.11mg on grain flour.

From the results of this investigation, it is safe to report that high-yielding sorghum varieties are a more suitable substrate than the local low yielding sorghum variety. This supports the findings of several workers (Schulten 1971; Dobie 1974; Wheatley 1971; Giles and Ashman 1971; and Ofosu 1976; 1977; 1986) that, high-yielding varieties of grain are generally more susceptible to storage insect pest infestation and damage than the local low-yielding varieties.

The results of correlation also support the above statements, indicating that LGB developed faster on varieties with higher susceptibility. It is, therefore, safe to conclude that the higher the index of susceptibility, the greater the percentage damage, weight loss, quantity of dust production and consequent number of live insects.

5.2 Damage, Weight losses, Compaction and Grain Disturbance

Grain damage includes scarification of the pericarp and of the periphery of the endosperm, eating out of the germ, eating out and partial or complete consumption (hollowing out) of the kernel. Damage and weight losses caused by the tunneling and feeding activities of adults were observed to have increased gradually as the storage period increased. Damage and weight losses recorded were greater when grains were stored with higher compaction, compared to those stored with much less compaction. Grains stored undisturbed experienced greater damage and weight losses than those disturbed in the course of storage. Grains disturbed earlier in storage, when the beetles were not too well established were not so affected. Insects in them would probably recover and get established when stored further undisturbed. However, when disturbed at a later stage in storage, their life cycle was probably disturbed, evident by the low levels of weight loss after three months storage. After a three months storage period, the local low-yielding sorghum variety (Mankaraga) suffered the least percentage damage and weight losses, while the maize variety suffered the highest percentage damage and weight losses. This was expected, as maize is well known as a suitable grain substrate for LGB. The high-yielding sorghum varieties (Framida and Naga-White) suffered greater damage and weight losses than the local low-yielding variety. Grains of high-yielding sorghum varieties (Framida and Naga-White) had soft pericarp and endosperm texture which was easy to bore through the peicarp (offering less resistance to boring) and to tunnel, respectively. This is because, the results obtained indicate that both high-yielding varieties had their pericarp cracked at the application of the least force and also because they had the softest endosperm texture, respectively. Correlation between endosperm texture and damage also indicated that grain types with soft endosperm suffered more damage as a result of tunneling and therefore produced large quantities of dust.

This investigation indicated that storage with some level of compaction makes the storage environment more favourable for *P. truncatus* to cause serious destruction. Reports by

Cowley *et. al.* (1980) indicate that these beetles need to brace themselves against something that is fixed, relative to the boring target (i.e. maize grains on the cob). In the case of loose grains, different levels of compaction are obtained based on the level of stacking in the storage medium. For instance, it is well known that grains tightly sealed in a bag are more likely to be held in fixed positions (especially those at the bottom) by the weight of the top layers. Different levels of compaction may be observed from different shapes and sizes of the storage medium. Without much compaction in storage, forces pressed on loose grains by the mandibles or by the pronotum make the grains slip away. The beetles can hardly grasp the smooth grain surfaces with its claws and the spur of the tibia. The beetle sometimes uses the elytra to push against the grains behind or above it to force its mandibles into the target grain. Therefore, the less compaction observed in a storage medium, the less favourable the medium is for *P. truncatus* infestation. This may be due to the fact that the beetles develop and perform better when grains are firmly packed (more stabilized). The beetles can brace themselves and force their mandibles to effectively tunnel (Bell and Watters, 1982). Tunnels bored by the adult beetles in media with low compaction are usually wider and the larvae often twist back and forth without moving forward resulting in their death.

5.3 Dust Production

The quantity of dust produced by the feeding of LGB increased as the months progressed on all the varieties. The results of correlation indicated that the quantity of dust produced increased with increase in grain weight.

Larger quantities of dust were produced on the high-yielding sorghum varieties (Framida and Naga-White) than on the local low yielding variety (Mankaraga). Generally, the quantity of dust produced from maize grain was far greater than those produced from sorghum grains. The high-yielding sorghum varieties (Framida and Naga-White) also produced more dust, probably due to the fact that they were relatively soft to bore. Ramirez Martinez and Silva (1983) reported that grain genotypes with soft pericarp are most vulnerable to LGB attack. These varieties also have soft endosperm which the beetles can tunnel through with ease. On small grains like sorghum, it is thought that the beetles lay their eggs in the dust produced, where they hatch and develop (Li, 1988). This may explain the presence of a greater number of live insects observed at the end of three months storage on the high-yielding varieties compared to local low-yielding variety (Mankaraga).

5.4 Grain Hardness

Grain hardness is believed to influence the amount of boring and tunneling activities, the feeding rates and the rate of egg production (reproductive potential) of the beetle. Boring and tunneling was probably slow on the local low-yielding sorghum variety (a relatively hard grain among sorghum varieties). This confirms the findings of Rios (1991) and Li (1988). It is also possible that the extent of tunneling and the size of egg batches laid in the dust produced was determined by grain hardness. According to Li (1988), females react by depositing larger egg clutches on relatively hard grains, which in turn increases larval competition and mortality, consequently reducing survival. Among the sorghum varieties, the local low-yielding sorghum variety with hard testa possibly had fewer eggs deposited in the dust produced, as suggested by Hodges (1986).

Correlation between grain hardness and insect preference (among sorghum grains) indicates that grains with hard pericarp were less attractive to the LGB. Grain hardness coupled with the smooth surface of sorghum grains may serve as a deterrent to LGB infestation and probably reduce insect damage. The larger grain borer are more adapted to rough and coarse surfaces (Li, 1988) and find it difficult to scratch, walk or bore into the smooth, flat or hard surfaces Li (1988).

5.5 Grain Size

It is thought that most grains are nutritionally adequate for the LGB. Grains with large sizes can support more insects to survive to emergence and produce heavier insects (Parker and Courtney, 1984; Li, 1988). On small grains, the female beetles lay less egg subclutches (carrying capacity) (Li, 1988). Maize grains can accommodate at least two average adult beetles (3 - 4.5 mm long) (Haines, 1991) at a time. Because the life of the beetle is based on tunneling, maize grains provide the beetle with enough space for tunneling and for oviposition. It is possible also that the offspring suffer less mortality due to less competition within the grains. Sorghum grains can probably accommodate only one average sized adult at a time. This makes it difficult for the beetle to tunnel comfortably and oviposit. This is in agreement with the reports of Doggett (1957), Russell (1962) and Davey (1965) that smaller grains generally escape infestation much better than larger ones, which easily succumb to infestation. The results of various correlations indicate that the larger the grain length and/or breadth, the greater the number of offspring produced, mean insect weight, the number of live insects, percentage damage, dust produced, weight loss and index of susceptibility. It is therefore safe to suggest that small grains are less susceptible and do not support infestation by the LGB.

The implication of this study is that, sorghum grains, especially soft-textured high-yielding varieties such as Framida and Naga-White can serve as an alternative host for P. *truncatus*, where the beetle can subsist on for a substantial period in the absence of a more preferred grain host, which is maize. This may likely serve as a reservoir host for infestation by the beetle. The infestation is also likely to be more serious on whole grains, than on ground grain flour. This fact implies that the control of *P. truncatus* on stored products in sorghum growing areas could become more complicated. Therefore, it is necessary to apply control measures to keep the LGB in check from spreading to other sorghum growing regions and to control those already on the stored grains. It is also advisable not to keep ground grain flour for too long (not more than two months), where the beetles can also hide and breed.

It is advisable that compaction of commodities in storage should be avoided.

Grains disturbed earlier in storage, when the beetles are not too well established may not affect their life cycle. They will probably recover and get established when further stored undisturbed. However, when disturbed at a later stage in storage, their life cycle was probably disturbed and this observation is evident by the low levels of weight loss that occurred after three months' storage.

Inspite of the small size of sorghum grains, high-yielding sorghum varieties suffered the most damage and loss, supporting the survival and reproduction of *P. truncatus* better than the local low-yielding sorghum variety. It is therefore, recommended for sorghum breeders to incorporate hard pericarp and hard endosperm texture in high-yielding sorghum varieties to reduce post-harvest losses during storage.

CHAPTER SIX

6.0 CONCLUSIONS AND RECCOMMENDATION

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

1. The beetle can feed and breed on sorghum grains fairly, especially on high-yielding varieties (Framida and Naga-White). Maize remains the most suitable grain substrate for *P. truncatus* infestation.
2. The high-yielding sorghum varieties (Framida and Naga-White) showed higher susceptibility indices than the local low- yielding variety (Mankaraga).
3. High-yielding sorghum varieties (Framida and Naga-White) suffered more damage and weight loss than the local low-yielding variety (Mankaraga). Maize grains suffered the most damage and weight loss observed.
4. Frass production and the number of live insects observed were higher on the high-yielding sorghum varieties (Framida and Naga-White) than on the local low-yielding variety (Mankaraga). Maize grains generally produced the most frass and the highest number of live insects.
5. *Prostephanus truncatus* thrives well on grains (substrates) with soft pericarp, soft endosperm texture and rigid or fixed mass.
6. Compactions of grains in a storage medium make conditions favourable for *P. truncatus* to feed and reproduce, consequently resulting in higher damage and loss.
7. Grains left absolutely undisturbed for three months suffered the most damage and losses. When disturbed at a later stage in storage, less damage and weight loss were observed.

8. Correlations were strongly positive between grain size (length and breadth) and damage, weight losses, frass/dust produced and progeny production.
9. *Prostephanus truncatus* showed preference for sorghum grains with soft pericarp. Hard grains with smooth surfaces probably are less susceptible to infestation beetle.

Finally, investigations of the effect of grain nutrient content on the biology of *P truncatus* may shed more light on the performance of LGB on sorghum varieties which are grown in Ghana.

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Appendix 1

ANOVA FOR SUBSTRATE SUITABILITY

1. ANOVA FOR SUCEPTIBILITY INDEX ON WHOLE GRAIN

	Sum o Square	df	Mea Squar		Sig
Between Group	771.37	3	257.12	76.97	.00
Within Groups	53.44	16	3.34		
Tota	824.82	19			

2. ANOVA FOR MEAN DEVELOPMENTAL PERIOD ON WHOLE GARIN

	Sum o Square	df	Mea Squar		Sig
Between Group	965.35	3	321.78	14.28	.00
Within Groups	360.40	16	22.52		
Tota	1325.75	19			

3. ANOVA FOR FI PROGENY ON WHOLE GRAIN

	Sum o Square	df	Mea Squar		Sig
Between Group	379.86	3	126.62	236.72	.00
Within Groups	8.55	16	.53		
Tota	388.42	19			

4. ANOVA FOR MEAN INSECT WEIGHT ON WHOLE GRAIN

	Sum o Square	df	Mea Squar		Sig
Between Group	34.19	3	11.39	16.31	.00
Within Groups	25.15	36	.69		
Tota	59.34	39			

5. ANOVA FOR MEAN INSECT WEIGHT ON GRAIN FLOUR

	Sum o Square	df	Mea Squar		Sig
Between Group	34.01	3	11.34	16.32	.00
Within Groups	25.00	36	.69		
Tota	59.02	39			

6. ANOVA FOR MEAN DEVELOPMENTAL PERIOD ON GRAIN FLOUR

	Sum o Square	df	Mea Squar		Sig
Between Group	965.35	3	321.78	14.28	.00
Within Groups	360.40	16	22.52		
Tota	1325.75	19			

7. ANOVA FOR F1 PROGENY ON GRAIN FLOUR

	Sum o Square	df	Mea Squar		Sig
Between Group	32.67	3	10.89	76.47	.00
Within Groups	2.27	16	.14		
Tota	34.95	19			

8. ANOVA FOR SUSCEPTIBILITY INDEX ON COARSELY GROUND GRAIN

	Sum o Square	df	Mea Squar		Sig
Between Group	.00	3	.00		
Within Groups	.00	16	.00		
Tota	.00	19			

9. ANOVA FOR MEAN DEVELOPMENTAL PERIOD ON COARSELY GROUND GRAIN

	Sum o Square	df	Mea Squar		Sig
Between Group	.00	3	.00		
Within Groups	.00	16	.00		
Tota	.00	19			

10. ANOVA FOR FI PROGENY ON COARSELY GROUND GRAIN

	Sum o Square	df	Mea Squar		Sig
Between Group	.00	3	.00		
Within Groups	.00	16	.00		
Tota	.00	19			

Appendix 2

Univariate Analysis of Variance for Weight loss By Standard Volume/Weight Method

Dependent Variable

Sourc	Type III Sum of Square	d	Mean Squar	F	Sig
Corrected Mode	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Intercep	65310.50		65310.50	671542.	.00
COMPACTION	42.94		42.94	441.55	.00
DISTURBANCE	6432.56		6432.56	66141.55	.00
MONTH	5617.03		2808.51	28878.01	.00
VARIETY	29056.33		9685.44	99588.67	.00
COMP * DIST	.12		.12	1.31	.25
COMP * MONTH	4.10		2.05	21.12	.00
DIST * MONTH	821.28		821.28	8444.74	.00
COMP * DIST * MONTH	4.04		4.04	41.59	.00
COMP * VARIETY	10.48		3.49	35.95	.00
DIST * VARIET	2893.78		964.59	9918.25	.00
COMP * DIST * VARIETY	11.00		3.66	37.71	.00
MONTH * VARIETY	2488.29		414.71	4264.23	.00
COMP * MONTH * VARIETY	11.33		1.88	19.42	.00
DIST * MONTH * VARIETY	474.73		158.24	1627.13	.00
COMP * DIST * MONTH * VARIETY	.91		.30	3.14	.02
Erro	15.56	16	9.725E-0		
Tota	98294.03	20			
Corrected Total	40054.94	19			

a. R Squared = 1.000 (Adjusted R Squared = 1.000)

Univariate Analysis of Variance for Weight loss By Count and Weigh Method

Tests of Between-Subjects Effects

Dependent Variable

Sourc	Type III Sum of Square	df	Mea Squar		Sig
Corrected Mode	38302.51 [a]	43	890.75	266.31	.00
Intercep	66827.86	1	66827.86	19980.05	.00
COMPACTION	37.38	1	37.38	11.17	.00
DISTURBANCE	2628.11	1	2628.11	785.74	.00
MONTH	3586.68	3	1195.56	357.44	.00
VARIETY	27894.77	3	9298.25	2779.97	.00
COMP * DIST	3.07	1	3.07	.91	.33
COMP * MONTH	.25	2	.13	.03	.96
DIST * MONTH	1216.74	2	608.37	181.88	.00
COMP * DIST * MONTH	.10	1	.10	.03	.86
COMP * VARIETY	28.39	3	9.46	2.83	.04
DIST * VARIET	3086.22	3	1028.74	307.57	.00
COMP * DIST * VARIETY	36.00	3	12.00	3.58	.01
MONTH * VARIETY	2791.16	7	398.73	119.21	.00
COMP * MONTH * VARIETY	9.74	6	1.62	.48	.81
DIST * MONTH * VARIETY	519.22	4	129.80	38.80	.00
COMP * DIST * MONTH * VARIETY	8.65	3	2.88	.86	.46
Erro	521.77	15	3.34		
Tota	116975.	20			
Corrected Total	38824.29	19			

a. R Squared = .987 (Adjusted R Squared = .983)

Univariate Analysis of Variance for Percentage Damage

Tests of Between-Subjects Effects

Dependent Variable

Sourc	Type III Sum of Square	df	Mea Squar		Sig
Corrected Mode	66204.25 [a]	43	1539.63	81.08	.00
Intercep	169457.	1	169457.	8923.98	.00
COMPACTION	70.80	1	70.80	3.72	.05
DISTURBANCE	7057.36	1	7057.36	371.65	.00
MONTH	15032.65	3	5010.88	263.88	.00
VARIETY	41051.36	3	13683.78	720.61	.00
COMP * DIST	1.80	1	1.80	.09	.75
COMP * MONTH	38.09	2	19.04	1.00	.36
DIST * MONTH	708.97	2	354.48	18.66	.00
COMP * DIST * MONTH	99.95	1	99.95	5.26	.02
COMP * VARIETY	158.42	3	52.80	2.78	.04
DIST * VARIET	6879.78	3	2293.26	120.76	.00
COMP * DIST * VARIETY	748.83	3	249.61	13.14	.00
MONTH * VARIETY	2516.96	7	359.56	18.93	.00
COMP * MONTH * VARIETY	193.48	6	32.24	1.69	.12
DIST * MONTH * VARIETY	82.02	4	20.50	1.08	.36
COMP * DIST * MONTH * VARIETY	47.49	3	15.83	.83	.47
Erro	2962.27	15	18.98		
Tota	239692.	20			
Corrected Total	69166.53	19			

a. R Squared = .957 (Adjusted R Squared = .945)

Univariate Analysis of Variance for Dust Produced

Tests of Between-Subjects Effects

Dependent Variable

Sourc	Type III Sum of Square	df	Mea Squar		Sig
Corrected Mode	50335.67 [a]	43	1170.59	59.13	.00
Intercep	59076.48	1	59076.48	2984.35	.00
COMPACTION	.32	1	.32	.01	.89
DISTURBANCE	5986.87	1	5986.87	302.43	.00
MONTH	7858.19	3	2619.39	132.32	.00
VARIETY	29838.83	3	9946.27	502.45	.00
COMP * DIST	25.82	1	25.82	1.30	.25
COMP * MONTH	117.08	2	58.54	2.95	.05
DIST * MONTH	794.29	2	397.14	20.06	.00
COMP * DIST * MONTH	5.52	1	5.52	.27	.59
COMP * VARIETY	145.59	3	48.53	2.45	.06
DIST * VARIET	5687.00	3	1895.66	95.76	.00
COMP * DIST * VARIETY	79.06	3	26.35	1.33	.26
MONTH * VARIETY	4510.47	7	644.35	32.55	.00
COMP * MONTH * VARIETY	150.45	6	25.07	1.26	.27
DIST * MONTH * VARIETY	545.61	4	136.40	6.89	.00
COMP * DIST * MONTH * VARIETY	71.60	3	23.87	1.20	.31
Erro	3088.08	15	19.79		
Tota	119591.	20			
Corrected Total	53423.75	19			

a. R Squared = .942 (Adjusted R Squared = .926)

Univariate Analysis of Variance for the Number of Live Insects

Tests of Between-Subjects Effects

Dependent Variable

Sourc	Type III Sum of Square	df	Mea Squar		Sig
Corrected Mode	21826.52 [a]	43	507.59	89.38	.00
Intercep	28406.17	1	28406.17	5002.42	.00
COMPACTION	59.18	1	59.18	10.42	.00
DISTURBANCE	1748.57	1	1748.57	307.93	.00
MONTH	11598.47	3	3866.15	680.84	.00
VARIETY	5240.33	3	1746.77	307.61	.00
COMP * DIST	14.59	1	14.59	2.57	.11
COMP * MONTH	55.10	2	27.55	4.85	.00
DIST * MONTH	224.94	2	112.47	19.80	.00
COMP * DIST * MONTH	12.54	1	12.54	2.21	.13
COMP * VARIETY	54.75	3	18.25	3.21	.02
DIST * VARIET	768.76	3	256.25	45.12	.00
COMP * DIST * VARIETY	139.85	3	46.62	8.21	.00
MONTH * VARIETY	831.37	7	118.76	20.91	.00
COMP * MONTH * VARIETY	18.98	6	3.16	.55	.76
DIST * MONTH * VARIETY	173.73	4	43.43	7.64	.00
COMP * DIST * MONTH * VARIETY	30.35	3	10.11	1.78	.15
Erro	885.84	15	5.67		
Tota	46162.56	20			
Corrected Total	22712.36	19			

a. R Squared = .961 (Adjusted R Squared = .950)