CONTROL OF *PROSTEPHANUS TRUNCATUS* (Horn) (COLEOPTERA: BOSTRICHIDAE) THROUGH THE TREATMENT OF WOOD USED FOR THE CONSTRUCTION OF MAIZE STORAGE BARNS

BY

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DEDICATION

TO

DANIEL KUDJOE AVEMEGAH

MAY HE REST IN PERFECT PEACE.

DECLARATION

I hereby declare that, except for references to other peoples' work which have been duly cited, this work is the result of my own original research and that this thesis has neither in whole nor in part been presented for any degree elsewhere.

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SEPTEMBE, 1998

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ABSTRACT

The ability of the Larger Grain Borer (LGB), *Prostephanus truncatus* (Horn), to bore and survive for several weeks in various wood materials led many pest control specialists to conclude that the quick and early build up of the pest in stores results from residual populations from previous infestation that survived in the wooden store structure.

The relative susceptibility to *P. truncatus* infestation of five wood species: stems of borassus/fan palm (*Borassus aethiopium* (Warb.)), bambo (*Bambusa vulgaris* (Schrad)), neem (*Azadirachta indica* (A. Juss.)) and fronds of raphia palm (*Raphia hookerii* (A. Chev.) and oil palm (*Elaesis guineensis* (A. Chev.)), which are most commonly used for store construction in the Volta Region of Ghana, was investigated.

The efficacy of lindane, dursban, solignum, spent motor (engine) oil and water treatment for the protection of the above woods as store structure against LGB was also investigated.

Results obtained showed marked differences among the different woods in terms of their susceptibility to LGB. Borassus stem was the most susceptible while bamboo stem and oil palm frond were the least susceptible. Lindane applied at 0.2% concentration to the surface of woods gave complete protection to all woods and killed all insects in the infested woods in laboratory trials. Dursban, though effective at 1% concentration in laboratory trials, failed to protect the same woods in a store platform in the field. Spent motor oil and solignum did not prevent infestation completely in any wood in the laboratory trial, but were effective when applied to laboratory infested woods.

Results from field trials, however, indicated that only lindane solution applied as 0.4% solution to the surface of store platforms protected all the woods tested from LGB infestation. Dursban applied as 1% solution was also effective but did not protect any of the woods completely from borer infestation. Though motor oil was not effective in laboratory trials, no LGB infestation was recorded on any motor-oil-treated bamboo platform during the eight month storage period.

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1.0 INTRODUCTION

1.1 Maize production and importance of storage in the Ghanaian rural economy

Maize is an important crop in the domestic economy of the Ghanaian. The production of maize cuts across all the ecological zones of the country, although the intensity of cultivation and production systems differ in these ecological zones. Two crops a year ('major'- and 'minor'- season maize) are produced in the southern sector of Ghana. However, in the northern sector there is only one season, which may be variously attributed to the unimodal rainfall pattern, incidence of stem borers or farmers getting involved in other lucrative ventures. With supplemental irrigation, however, it is possible to produce three crops per year (NARP, 1993) although this is scarcely done.

Maize is not only a major staple but also an important source of protein in Ghana, ranking only after fish and legume in terms of annual protein production (Twumasi-Afriyie *et al.*, 1992). The bulk is grown in Brong-Ahafo, Ashanti and Eastern Regions. More than 13% of total land in cultivation in Ghana is put to maize cultivation (Dixon and Ocansey, 1988). In spite of many problems such as inconsistent rainfall and incidence of stem borers that tend to reduce the success of the crop, production of maize continues to grow nation-wide. Average annual production increased from 141,000 metric tonnes in 1983 to 533,000 metric tonnes in 1993 (PPMED, 1993) and is currently estimated to be 1,000,000 tonnes.

As maize can be stored for longer periods than root crops, it is a very important crop during the lean season. Nyanteng and Apeldoorn (1971) reviewed the factors that influence the storage of maize in Ghana and concluded that maize price was one of the most important factors. In areas where maize price increases throughout the year, farmers tend to hold back substantial quantities of their grain in order to take advantage of price rises (Southwood *et al.*, 1980). In maize deficit areas in Ghana, this trend in price hikes is observed. Here, maize prices can increase by over 200-300% from the main harvest to the lean season. A Policy Planing, Monitoring and Evaluation Division of the Ministry of Food and Agriculture analysis on average maize prices for Volta Region of Ghana show seasonal price variation from 73% to 293% between 1986 and 1991 (Magrath, 1994). These price increases are significant even when one takes into account the rate of inflation which was usually 13-40% per annum over the same period (Magrath, 1994). A market survey from September, 1993 to July, 1994 also showed seasonal price spreads from 210% to as high as 320% with an average of 236% for some markets in the Volta Region (Magrath and Compton, 1994).

A study by Magrath (1993) in the Volta Region revealed that most farmers usually plan to store major season maize for almost nine months (August to May) to serve as food reserve during the lean period of February to June. Others with substantial surplus store for this period so as to fetch higher market prices for the commodity. The revenue from storage is very vital since it helps in the preparation of new maize fields, pay fees for dependents and as savings to meet other family and social commitments. In some communities in the Volta Region, very large barns standing in the compound are a source of pride and portrays the wealth status of the farmer, and in some cases determines his potential to marry a new spouse where polygamy is prevalent (Addo, pers. comm.).

1.2 The *P. truncatus* problem

P. truncatus (Horn.) (Coleoptera: Bostrichidae) commonly called the larger grain borer (LGB) is a serious pest of farm stored maize and dried cassava in East and West Africa. It is a small dark brown beetle, which until recently, was known as primary pest of minor importance in Mexico and central America (Markham *et al*., 1991; Chittenden, 1911). Since its accidental introduction into East and West Africa in the late and early eighties respectively (Dunsta & Magazini, 1981; Harnisch & Krall, 1948), the beetle has spread, to date, to a total of 12 African countries (Hodges, 1994; Adda *et al*:, 1996). How the pest entered the continent is not clear but it is speculated that it arrived through cereal shipment as food aid. In Ghana, LGB was first recorded in pheromone traps in the eastern part of the Volta Region in January 1989 (Dick *et al.*). The adult is able to fly and so is capable of distributing itself. However, the main means of distribution is thought to be through grain movement in trade.

Severe losses of farm stored maize and dried cassava chips due to LGB have been well documented following the major outbreaks in Africa (Hodges, 1986; Keil, 1988). Adults bore into maize and dried cassava, converting them to dust and losses are far greater than are experienced from other storage pests. Losses as high as 34% and 30.2% (dry weight) were recorded in Tanzania and Togo respectively over a short storage period (Hodges *et al*., 1983; Pantenius, 1988). Loss studies in Ghana revealed high damage levels in the forest zones where cobs are stored for extended periods (MOFA/ODA (UK) Ghana LGB Project, 1994). LGB is capable of developing large damaging populations under wide range of conditions. Pheromone trap catches indicate the presence of LGB in all the ten regions of Ghana since 1994 (MOFA/ODA (UK) Ghana LGB Project, 1994). In Kenya, it is known from the humid lowlands, dry Savannah and cooler highlands up to 2000 m above sea level.

The pest is not restricted to stores: it also occurs widely in the natural environment (Dendy *et al.*, 1989b; Rees, *et al.*, 1990; Novillo Rameix, 1991; Nang'ayo *et al.*, 1993 and IITA unpublished). Although no preferred breeding sites have yet been discovered, laboratory tests show that it is able to breed successfully on dried wood from a range of trees, as well as the dried stems of maize and cassava (Nang'ayo *et al.*, 1993; Addo, 1994). Thus, apart from being a serious threat to the food security of the region, LGB also destroys the wooden storage structures of maize. Results from carry-over populations in Benin revealed that wooden storage structures harbouring residual LGB results in a rapid population build up of the pest in the second season of storage.

In the Volta Region of Ghana, maize is stored in many different ways. These include, in the main, stacking the crop in barns constructed with wood obtained from different plant species. In a survey, Addo (1994) observed that all the common wood species that are used as components of maize stores in the Volta Region can support adult LGB for several weeks thus confirming reports that the quick and early build-up of the pest in stores in the region might be the result of carry-over populations from previous infestation. The problem of carry over infestation can simply be solved by dismantling an infested barn and burning the wood. However, wood is becoming scarce hence the need to protect the wood so that the barn could be used for more than one season. It is therefore necessary to investigate if some combinations of wood species and wood treatments could protect the wooden fabric against the pest and reduce the carry-over infestation with the concomitant severe losses that result from such infestation.

1.3 Objectives

The main objective of this study was to determine the most suitable combination of wood and treatment methods that least support carry-over populations of LGB into new produce to reduce the general incidence of LGB in stores.

The following specific questions were addressed:

1. Which wood species among those most commonly used for store construction in the Volta Region is most resistant to LGB?
2. What is the efficacy of dursban, lindane, solignum, spent engine oil and water treatments against the larger grain borer under laboratory and field conditions?
3. What is the persistency of dursban, lindane, solignum and spent engine oil on wood against the larger grain borer under laboratory conditions?

2.0 LITERATURE REVIEW

2.1 Recognition and identification of *P. truncatus*

Prostephanus truncatus (Horn) was first described by Horn (1878) as *Dinoderus truncatus* (Horn). The genus *Prostephanus* was later erected by Lesne (1939). Elaborate identification keys of adult *P. truncatus* and other Bostrichids are provided by Horn (1878), Fisher (1950), Kingsolver (1971) and Hodges (1982). Spilman (1984) gives detail descriptions of larvae and pupae but unfortunately there are no identification keys for these stages.

The species of the beetle family Bostrichidae are principally wood borers but some will breed in stored products and are important as pests. The basic form of adult Bostrichidae is rather uniform and typical of boring beetles. The body is cylindrical and the head ventral to the prothorax so that it is not visible from above. Characteristically, the pronotum has rasp-like teeth, hooks or horns. The antennae are straight, i.e. not elbowed, and have a loose 3- or 4-segmented club. At the posterior end of the beetle, the elytra slopes ventrally more or less steeply (this sloping region is called the declivity) and are generally somewhat flattened. The elytra declivity may be marked or decorated with ridges, tubercles or hooks, all of which are useful recognition features. The tarsi are all five-segmented.

Adults *P. truncatus* may be sexed using clypeal tubercles (Shires and MaCarthy, 1976) and pupae according to the size and shape of the genital papillae (Bell & Watters, 1984). Haines (1991) used the following features to distinguish adult *P. truncatus*.

-typical bostrichid shape, body cylindrical and dark brown in colour

-head ventral to the prothorax

-rows of teeth on anterior part of pronotum

-antennae 10-segmented with a loose three-segmented club

-a slender funicle clothed with long hairs

-posteriorly flattened and steeply inclined elytra

-five segmented tarsi

2.2 World-wide distribution of *P. truncatus*

The distribution of *P. truncatus* is considered very phenomenal, at least compared to some major storage pests, in that it is very discrete and delimited (Markham *et al.*, 1991). Historically, *P. truncatus* has been found only in (or in materials from) the Americas. Although, the insect was originally described from specimen collected in California, it appears to be indigenous to Mexico and parts of Central America where it sporadically achieves a primary pest status of local importance on maize (Markham *et al.*, 1991). *Prostephanus truncatus* was first reported from Mexico by Chittenden in 1895 (Wright, 1984). He recorded specimens sent to him from Oaxaca and Chihuahua in 1902 (Chittenden, 1911). Ramirez *et al.*, (1958) published a distribution map of *P. truncatus* in Mexico. The beetle was found from Baja, Sonora, Chihuahua, Coahuila, Nuevo Leone, and Tamaulipas on the southern border with Guatemala.

The distribution in Central America includes Panama, Honduras, El Salvadore (McGuire & Crandall, 1967), Nicaragua, and Costa Rica (Fisher, 1950). Guatemala was the earliest reported Central American country to harbour *P. truncatus*. Two specimens dated 1884 were mentioned by Chittenden (1911). In South America, *P. truncatus* was first recorded in Brazil in 1937 (Cotton & Good, 1937). Posada *et al.* (1976) officially recorded the presence of this beetle in Colombia. Peru apparently has *P. truncatus* among its storage pests (personal correspondence cited in Wright, 1984). Other correspondence from stored product entomologists cited in Wright (1984) indicated that *P. truncatus* is not found in Chile, Bolivia, Ecuador, Venezuela, Guyana, Uruguay, Paraguay or Jamaica.

Outside the Americas, the beetle has been found only on rare occasions as an imported pest. In 1961 maize seed imported by Israel was infested (Calderon & Donahaye, 1962 cited in Wright, 1984) but apparently *P. truncatus* did not establish itself. Iraq also received infested maize in 1969 (Al-Souse *et al.*, 1970 cited in Wright, 1984). Thailand has a published record of *P. truncatus* (Sukprakarn, 1976 cited in Wright, 1984). Other recently recorded cases of *P. truncatus* cited in Markham *et al.* (1991) are Hong Kong (Zimmerman, 1990) and India (Verma *et al.*, 1988).

In Africa the outbreak of the pest apparently resulted from separate introductions; first in Tanzania (Dustan & Magazini, 1981) then Togo (Krall, 1984) and again into Guinea (Kalivogui & Muck, 1991). From Tanzania the insect has spread to the nearby countries of Kenya (Kega & Wurui, 1983), Burundi (Gilman, 1984), Malawi and Rwanda (GTZ, unpublished). The Togo introduction has apparently spread to Benin (Krall & Favi, 1986), Ghana (Dick *et al.*, 1989) and Nigeria (Pike *et al.*, 1992).

2.3 Life history of *P. truncatus*

The life cycle of *P. truncatus* can be completed within a fairly wide range of temperature and relative humidity (r. h.) conditions. Though 32 °C and 70-80% r. h. are widely reported to be the optimum conditions for development on maize diet (Shires, 1979, 1980; Bell & Watters, 1982; Hodges & Meik, 1984), the developmental period under these conditions varies with the form in which the substrate is presented (Dick, 1988). Under the above conditions *P. truncatus* takes 24-25 days to complete its life cycle on tightly packed ground maize or whole grains (Bell & Watters, 1982) and 35.4 days on loosely packed ground maize (Shires, 1979, 1980).

The reason for this apparent discrepancy is that in firmly packed flour the larva is able to make narrow tunnels against which they could brace themselves and hence force their mandibles into the forward end of the tunnel for effective chewing (Bell & Watters, 1982). In less dense media, the tunnels are wider and larvae often twist back and forth without moving their heads resulting in unnecessary expenditure of energy which probably retards their growth. Subramanyam and Hagstrum (1991), however, suggested differences in strains used by these researchers as the main cause of the observed discrepancy.

Oviposition in *P. truncatus* has been reviewed by many authorities including Hodges (1982), Howard (1983) and Markham *et al.* (1991). *P. truncatus* is relatively long-lived as an adult and does not lay eggs as rampantly or haphazardly as shorter-lived stored product insects. Adult females lay fertilized eggs within the grain, in blind-end chambers bored at right angles to the main tunnel (Hodges, 1982; Howard, 1983). Oviposition rate of *P. truncatus* is influenced by grain stability (Howard, 1983; Cowley *et al.*, 1980) and quantity of food provided (Nyakunga, 1982). According to Cowley *et al.* (1980), oviposition on stabilized grain and maize cob is more productive than on loose grain because oviposition period on loose grain is longer. In a detailed study with adult pairs confined to damaged grains embedded in maize flour maintained at 25 °C and 70% r. h., Howard (1983) observed an average pre-oviposition period of five days, with 14 days oviposition period and a mean life-time fecund period of 114 days. Under optimum conditions, eggs hatch after 4.1 days and the three larval stages (Bell & Watters, 1982; Subramanyam *et al.*, 1985) complete within an average of 16.1 days (Bell & Watters, 1982). The mean pupal period of *P. truncatus* is 4.7 days. Nyakunga (1982) observed that the mean developmental period on yellow 'America No.3' maize and blocks of dried cassava kept at 27 °C and 70% r. h. were respectively 39.2 days and 43.1 days. This suggests that maize is more suitable for development of *P. truncatus* than cassava.

Sexual differences has also been observed in the development and life span of *P. truncatus*. On dried cassava at 32 °C and 70% r. h., Hodges *et al.* (1985) observed that on the average females emerged one and a half day after the males. The difference became more substantial, with females emerging on the average one-two days after the males when the r. h. was reduced to 50%. Shires (1980) found that on maize flour at 32 °C and 80% r. h., females generally out-lived males, the mean life expectancies being 61.6 days and 44.7 days respectively. In contrast, at 25 °C and 70% r. h. on maize flour and grains, males were found to out-live the females (Howard, 1983). These differences in female longevity may be due to different oviposition rates; the females in Howard's studies having much higher rates, hence a shorter longevity.

2.4 Pest status and losses due to *P. truncatus*

The pest status of LGB in the Neotropics has been a subject of considerable debate because of serious discrepancies in loss reports (Hoppe, 1986; Boeye, 1988). However, many researchers believe that losses are generally higher in Africa than in the Neotropics (Markham *et al.*, 1991). Infestation of cobs generally commences shortly before harvest and during storage, and quickly spreads to adjoining stores during the season. In Tanzania, up to 20% of farmers' stores were infested immediately after storage, rising to 80% of stores within a storage period of five months (Hodges, 1984). The average weight losses in stores for maize and cassava are shown in Table 1.

By contrast, losses to maize cobs in traditional storage systems by the more common storage pests such as *Sitophilus zeamais* (Motsch.), *S. oryzea* (L) and *S. cereallela* (Olivier) in many parts of Africa stand at 2-6% (Adams, 1977; De Lima, 1979; Golob, 1981) The most obvious cause of loss in LGB attack is the conversion of maize into flour by adult boring rather than consumption by the larvae during development (De Lima, 1979). Consequently, large quantities of dust are associated with infested maize cobs (Hodges *et al.*, 1983). LGB is less efficient at utilization of its food than *S. zeamais* (Motsch.) (Demianyk & Sinha, 1987) and its production of dust and frass is much higher than with *S. zeamais* (Motsch.) (Compton, pers. comm.). This may explain the higher weight losses associated with LGB infestation.

Table 1: Recorded weight losses in stored maize and cassava due to LGB

Produce	Storage period (months)	% wt loss	Country	Reference
cob-maize	6	40	Nicaragua	Giles & Leon, 1874
"	3-6	30	Honduras	Hoppe, 1986
"	3-6	34	Tanzania	Hodges *et al.*, 1983
"	6	17.9	"	Keil, 1988,
"	8	41.2	"	"
"	8	44.8	Toga	Pantenius & Schulz, 1986
"	6	14-20	Ghana	Golob *et al.*, Unpublished
Dried cassava tubers	4	70	Tanzania	Hodges *et al.*, 1985
"	3	9.7	Togo	Wright *et al.*, 1993
"	7	19.5	"	"

LGB damage to maize and cassava, as is the case for many pests, is highly reflected in economic loss. In a study of the relationship between maize retail price in four markets in the Volta Region of Ghana and the degree of LGB infestation, Compton (1993, 1994) observed that the percent number of damaged grains by LGB has a consistent relationship with retail price. The relationship appears almost linear, with about a 0.75% drop in retail price for every 1% increase in damaged grains. Total economic loss of grains is also common. Farmers in Ghana and Togo (Compton, 1991) and even chicken (personal observation) reject for consumption the large amounts of flour produced by LGB.

2.5 *P. truncatus* as a wood borer

The presence of *P. trucatus* in habitats without maize or cassava indicates the pest's ability to survive and breed as wood, stem and root borer. Work on the survival and reproduction of LGB in wood were undertaken in Mexico, Honduras, Kenya, Togo and Benin (Helbig *et al.*, 1990; Rios Ibarra, 1991; Ramirez-Matinez *et al.*, 1992; Kossou *et al.*, 1992; Nang'ayo *et al.*, 1993 Wright & Novillo, unpublished). The pest has been found in a wide variety of different habitats, including forests (Rees *et al.*, 1990; Rios Ibarra, 1991; Ramirez-Matinez *et al.*, 1994). Markham *et al.*(1991) suggest that *P. truncatus* is more of a forest inhabiting insect that sometimes attacks stored maize or cassava than the reverse. This proposition is supported by recent laboratory experiment which showed that while some wood species only allow for survival of the adults, others actually support reproduction (Nang'ayo *et al.*, 1993). Rees *et al.* (1990) thus suggested that the high loss of maize and cassava to LGB in Africa may have resulted from selection pressure that produced strains of LGB that breed especially well on these produce. It is however not yet conclusive if the stock of LGB in Africa is significantly different from those in Central America to be regarded as different species.

As a recently introduced exotic species, LGB may have less opportunity to live outside maize and cassava production systems. Apart from crop plant hosts, the flora of dissimilar climatic zones in Africa may contain predominantly different species which LGB has had little time to locate and adapt to. Potentially suitable niches too may have already been occupied by different species. Commenting on the failure of some stock of LGB to breed on some species of wood contrary to the report of other workers, Detmers (1988) speculated that the laboratory stock of *P. truncatus* he used in his study, which had been bred exclusively on maize for a number of generations, might have lost their ability to reproduce in wood due to loss of appropriate intestinal fauna.

Recent studies using pheromone traps show that LGB is widespread in natural vegetation in Tsavo National Park, Kenya. Giles *et al.* (1995) concluded that the close association of flight activity of the pest in Kenya with the minor rainy season is probably more related to the availability of natural host plants than a straight forward relationship of dispersion with meteorological factors. Table 2 is a summary of work done so far on the survival of LGB in woods.

The breeding success of LGB in wood depends on the age and moisture content of the wood (Nang'ayo & Hill, 1994). Results of breeding experiments in woods under different constant humidity regimes confirm that breeding occurs within a relatively narrow range of wood moisture content, with an optimal at around 10-12% (Nang'ayo & Hill, 1994). The failure of the pest to breed in the test woods used by some earlier workers may be because the woods were too dry to support the pre-adult stages. Nang'ayo and Hill (1994) observed that the proportion of adults and immature stages varies in populations of LGB bred on different susceptible wood species. This suggests that LGB has different growth characteristics on different host plants. In both Central America and Africa, *P. truncatus* has been observed to tunnel in, and damage , the wood of traditional maize stores.

According to Addo (1994), nineteen wood/plant species are used for store construction in the Volta Region. The choice of wood is largely influenced by the agro-ecological zone or store type. The raised platform store can be constructed with a variety of materials but the most commonly used woods are Bamboo (*Bambusa vulgaris* (Schrad.)) or Raphia (*Ruphia hookeri* (A. Chev.)) fronds as platforms supported by stems of fan palm (*Borassus aethiopium* (Warb.)) or other stronger woods.

The inverted cone is normally built with neem (*Azadirachta indica* (A. Juss.)), fan palm (*Borassus aethiopium* (Warb).) or 'toti' (*Baphia nitida*) while the Katchalla, typical of the far north (woodland Savannah), is constructed from Zana grass (*Andropogon gayanus*) matting with a hardwood base, often from Acacia spp. Farmers' adoption of the Global 2000 designed narrow ventilated crib in the region has been very slow. High cost of construction appears to be the main draw back, as the quantity of maize harvested by most farmers does not justify the cost of building such a structure.

A built platform can be used for 2-4 years if durable woods are used as supports. The current cost of constructing a platform barn varies from ¢14,000 to ¢17,000, depending on availability of materials (Personal observation).

2.7 Susceptibility of *P. truncatus* to insecticides

Because *P truncatus* has generally been regarded as a pest of lower economic significance in its native home, where there has been only a limited investigation to identify specific insecticides with which to control it (Golob *et al.*, 1985). According to Ayertey (1995), the Central Americans themselves began to investigate this pest only in the 70s. Following the recent introduction and establishment of the LGB into many parts of Africa.

many field trials were undertaken to evaluate the effectiveness of locally available dilute insecticide dusts against it. Giles and Leon (1974) found that 12.5 ppm of malathion or pirimiphos-methyl applied as 2% dust protected maize cobs without husk for 16 weeks but by the 24th week, the damage had increased to more than 50%. Field trials undertaken in the Tabora Region of Tanzania, however, indicated that pirimiphos-methyl could provide adequate protection of loose maize grain for periods longer than six months (Golob *et al.*, 1983).

In a rapid screening test to compare the effectiveness of malathion and pirimiphos-methyl against *P. truncatus* and six other species of stored product insects by exposing them for 5 hours to treated filter papers, Watters (1984) observed that malathion was less effective than pirimiphos-methyl against *P. truncatus* and *Tribolium castaneum* (Herbst.). In a related experiment in which the toxicity of various insecticides to *P. truncatus* was compared by exposing the young adult beetles to filter papers treated with 0.5 ml dilution of the insecticides for 24 hours at 27 °C and 70% r. h., Golob *et al.* (1985) found lindane (an organochlorine) to be the most effective among the other three groups of insecticides tested in the trial i.e. five organophosphorus insecticides (matacrifos, chlorpyrifos-methyl, pirimiphos-methyl, malathion, and fenitrothion), two pyrethroids (permethrin and phenothrin) and one carbamate (carbaryl). With topical application at the same conditions stated above, the order of toxicity changed. Pyrethroids became the most effective followed by lindane and carbaryl before the organophosphorus compounds. Genel (1960) obtained a satisfactory control of the pest with a high dose of lindane (25 ppm) on maize grain but Giles and Leon (1974) obtained a poor protection with lindane in Nicaragua.

surface. According to Mallis (1964), insecticides applied to the surface of wood do not penetrate much more than 3 mm below the surface, but a considerable amount concentrates at the surface and top 1 mm which diminishes gradually within three months. He observed that the loss of insecticides at the surface is aided by temperature and air movement across the wood surface. Morgan and Purslow (1973) reported that temperatures below 21 °C did not influence the loss of lindane from wood but after 3 months at 74 °C there was a 75% loss of the original amount. Loss of activity from the surface of treated wood is thus expected to be high in the tropics where average ambient temperatures are higher. The penetration and persistence of chlorpyrifos in structural timber have been studied by Dodson and Robinson (1988), and Robinson and Powell (1989). These researchers reported that 1% chlorpyrifos applied to the surface of seasoned pine penetrated to approximately 2 mm. Though the concentration of chlorpyrifos at the surface diminished after three months, the concentration at 2 mm depth remained stable for two years. Dodson and Robinson (1988) reported that a range of 7-15% in the moisture content of seasoned pine wood did not influence the penetration of chlorpyrifos.

Morgan and Purslow (1973) and Osler and Stone (1982) reported on the penetration and persistence of lindane on structural wood. They reported that lindane penetrates approximately 3 mm and though the lindane at the surface dissipates, the concentration below the surface remains stable for five years or longer. In a study on the loss of lindane by volatilization from pine and spruce wood, Morgan and Purslow (1973) observed that the penetration of lindane into spruce was considerably less than it is for pine and fir. Smith (1956) and Spiller (1949) reported on the use of oil and pentachlorophenol for the control of lyctid and knobbed powder post beetles. Brady *et al.*(1980) and Bush *et al.* (1987) reported chlorpyrifos to be more persistent in wood than lindane. Baker and Berry (1980) tested permethrin and cypermethrin, plus two other pyrethroids, decamethrin and fenvalerate, for the control of wood-infesting beetles. Their result indicated that persistence in wood was superior to that of lindane for all of the compounds except fenvalerate. Lorenz *et al.*(1985) reported high stability and long term retention of cypermethrin and fenvalerate on wood.

Testing over 20 insecticides in the laboratory in Southern England as alternatives to lindane and dieldrin for the control of wood boring insects, Baker & Berry (1980) observed that only permerthrin and penthoate had sufficient toxicity (though lower persistence than the organochlorines) after aging to afford satisfactory control as remedial wood preservatives. In common with most synthetic pyrethroids, permethrin is at present far more expensive than gamma-HCH and phenthoate has an unacceptable odour that persists for many months (Baker & Berry, 1980). These characteristics make both insecticides unsuitable for use as wood preservatives. Comparing the effectiveness of lindane, permethrin and deltamethrin against Ambrosia wood borers, Mercer *et al.* (1986) observed that the insecticides were more effective if diluted in dieselene than in water.

2.9 Non-chemical control of wood infesting beetles

Heat sterilization of wood to kill old house borers (*Hylotrupes bajulus* (L.))and lyctid powder post beetle larvae (*Lyctuc* sp.)has been used in central and northern Europe as well as Russia (Reickhardt *et al.*, 1930; Snyder, 1923; Jensen-Storch & Hendricksen, 1932). Ebeling (1963) observed that temperature at or near 49 °C killed dry wood termites. Temperatures maintained above 88 °C for several hours will kill old house borer larvae (Durr, 1954). Vongkaluang (1978) reported on the effectiveness of extremely low temperatures, achieved by the application of dry ice to the surface of infested wood, in controlling *H. bajulus* (L.) larvae. Addo (1994) observed that smoking of LGB-infested bamboo was a very effective way of disinfecting infested platforms of maize barns. He observed that smoking for long periods (7-12 hours/day) with an oil palm mat screen around the fire placed under maize barns kills all LGB within a week. Removal of infested wood has been used as a control measure in Europe and the United States. Work done by Jensen-Storch (cited in Mallis 1964) showed that by removing 71% of the infested wood, 69% of the larvae were eliminated. Agents for biologically controlling larval stages of wood infesting Coleoptera include other beetles (Cleridae) and parasitic wasps (Braconidae and Ichneumonidae). Mallis (1964) reviewed the effectiveness of these predators and parasitoids.

The development of *Xylectinus peltata* (Harris) larvae, and the spread of infestation are influenced by the temperature and moisture content of infested wood. When the temperature of the wood is below 4.5 °C or above 32 °C larvae do not feed. Adverse temperature affects the development and survival of young larvae (Williams, 1977). Although egg hatching was not reduced by low wood moisture, wood moisture levels below 12% significantly decreased larval feeding and survival (Williams, 1983; Moore, 1968). Manipulating the temperature of infested wood may be difficult, but there are ways in which wood moisture can be manipulated. Mallis (1964) suggested the use of plastic (polyethylene) sheets to cover the soil around wood to reduce movement of moisture from the soil to exposed wood to reduce the wood moisture content. This method, however, would be ineffective for control in areas where surface water drainage into wood soil spaces and high relative humidity often occur (Williams, 1983).

Another factor that influences the choice of host of wood-infesting insects is the carbohydrate content of the wood material. By reducing the soluble sugar in wood, it is possible to reduce its suitability to most wood-boring insects. Mallis (1964) reported that when the amount of starch in sapwood is insufficient, the life cycle of *lyctus* spp. is extended far above the normal period. Ismanto (1990) reported that powder post beetle attack on rattan can be prevented by decreasing the amylose content of rattan through soaking the wood in water for some periods, as practised by a rattan growing community in Indonesia.

3.0 MATERIALS AND METHODS

3.1 Store woods

Five storage woods were chosen for the laboratory experiment. These were:

1. Stems of borassus/fan palm (*Borassus aethiopium* (Warb.))
2. Bamboo (*Bambusa vulgaris* (Schrad.))
3. Neem (*Azadirachta indica* (A. Juss.))
4. Fronds of raphia palm (*Raphia hookeri* (A. Chev.))
5. Fronds of Oil palm (*Elaeis guineensis* (A. Chev.))

The major reason for choosing the above wood species for the study is that they are the commonly used wood materials for store construction across most parts of the Volta Region. Also, most of them have been reported to support higher than average carry-over populations of LGB in the field (Addo, 1994). In order that the results from the experiment would relate to the situation in the field, the wood materials tested in all the laboratory trials were used in the same state in which they are normally employed in the field. Borassus stem was cut into an average size of 5 x 4 x 3 cm^3 prisms leaving the outer skin on one side. Bamboo stem was split into two equal halves and cut to 5 cm lengths. Neem, Raphia and Oil palm fronds were also cut to 5 cm lengths. The average diametre of neem stems used was 1.5 cm. A photograph of all wood pieces used in the laboratory experiment is shown in Plate 1.

Plate 1: A photograph of wood materials used in laboratory work

3.2 Chemicals (wood protectants)

The wood protectants tested in this study were:

1. Lindane (Gamma-HCH) 4EC
2. Dursban (Chlorpyrifos) 480EC
3. Solignum
4. Spent engine oil
5. Water

3.3 Preparation of wood pieces for laboratory work

Several quantities of the 5 cm long piece of each wood material were sterilized by heating in the oven at 70 °C for 3 hours. The reason for sterilization was to kill disease pathogens and insects that may be carried by the wood from the field. The sterilized wood pieces were transferred to Kilner jars covered with fine wire mesh and kept in the laboratory to equilibrate under ambient conditions of 22-28 °C and 65-70% r. h. for three weeks. From among the equilibrated wood pieces, samples of five of each wood were dried to constant weight and percentage moisture content determined by the oven method. The average percentage moisture content of the wood species are recorded in Table 3.

3.4 Culturing of experimental insects

All insects used in the studies were reared on sterilized shelled maize in Kilner jars of 1 litre sizes, covered with fine metallic mesh under ambient laboratory conditions of 22-28 °C and 65-70% r. h. at the Ministry of Food and Agriculture laboratory, Ho. The parent stock of the beetles were obtained from infested maize from villages in and around Ho. All equipment (glassware, scalpels, forceps) used in handling insects were dry-heat sterilized at 100 °C for 1 hour. The maize used for rearing was sterilized at 80 °C for 3 hours, to prevent diseases or cross-infestation of the cultures. Kilner jars were placed on Petri dishes surrounded by engine oil to prevent unwanted insects and mites from crawling into them. New cultures were started weekly so that young adults were always available for the experiments.

Table 3: Moisture content of wood materials used in laboratory work.

Wood species	*Percent moisture content (±S.E.)
Bamboo	10.0 ± 0.34
Borassus	14.4 ± 0.52
Neem	15.2 ± 0.48
Oil palm	14.7. 0 ±51
	12.5 ± 0.77

*Mean of five replicates

3.5 Laboratory studies

3.5.1 Relative susceptibility of wood types to *P. truncatus*

This preliminary laboratory work was aimed at determining the preference of LGB for the various wood species under free choice condition. The wood pieces described in section 3.3 above were exposed to infested maize in metal containers (15 cm diameter by 17 cm height) for a period of four weeks.

Four containers were each filled to one-quarter depth with infested maize approximately 4 kg each. Five wood pieces were put on top of the infested maize in each container such that each container had all the five wood materials. The containers were immediately covered with 850 μm wire mesh to allow for ventilation and placed on a shelf in the laboratory away from bright light. In order that the initial infestation level of maize in all the four containers may be equal, the infested maize was thoroughly mixed in a larger container before it was distributed in all the smaller containers. The set up described above formed one block. Two other blocks were set up at intervals of two weeks. For each block the wood pieces were removed after 4 weeks (30 days), dissected and the numbers of live and dead beetles in each wood piece recorded. Observation was also made of any immature stages in the wood pieces. The daily ambient temperature and r. h. during the experimental period averaged 27 °C and 70% respectively

3.5.2 Mortality of adult *P. truncatus* exposed to treated woods

The main objective of this laboratory test was to screen the wood protectants mentioned in section 3.2. The effectiveness of these protectants in preventing LGB infestation were compared so that only those that were significantly effective compared to the untreated controls were selected for testing in the field. For dursban and lindane treatments, 1% and 0.2% were respectively applied to several pieces of each wood material by surface brushing with a horse hair brush till the surface was wet. Solignum and spent engine oil were also similarly applied to the surface of the wood pieces. In the case of water treatment. The wood pieces were soaked for 14 days.

After four days' drying under an open shade, followed by a further one week conditioning at 27 °C and 70% r. h. in the laboratory, the treated wood pieces were transferred into separate paper cartons and kept in the laboratory for use as and when required. Each replicate consisted of two pieces of similar wood material in a Kilner jar covered with fine wire mesh (850μm).

Plate 2: A replicate of lindane treated borassus

Preliminary observation revealed that the beetles were unable to bore into wood pieces placed individually in jars. This was probably due to lack of small spaces within which the beetles could brace themselves to bore entrance holes. Consequently, in this experiment, the two wood pieces in each jar were tied together with a string to simulate the situation in stores where wood joints create such spaces which makes boring possible. Also, a filter paper was placed at the bottom of each jar as preliminary observation revealed that beetles could not easily move on the glass surface. Fifty young (1-5 day old) unsexed LGB adults were introduced into each jar and covered with 850 μm wire mesh to allow for ventilation.

Four replicates were prepared at intervals of two weeks in a randomized complete block design. in which each fortnight represents a block. The Kilner jars were kept on shelves in the laboratory with a diurnally-fluctuating ambient temperature and r.h. which averaged about 27 °C and 65% respectively. Kilner jars were opened three days after introduction of LGB, and the number of beetles which had not entered the wood was counted, taking into account both live and dead adults after which the bottles were tightly closed again. A second and third counts were made on the 7th and the 12th day respectively. Wood pieces were dissected immediately after the last count and a record made of both live and dead adult beetles as well as any other stages of beetles found within the wood. When data on the first block was being taken it was realized that the mortality in the controls were very high due to the low relative humidity at that period (Harmattan). The r. h. in the bottles was therefore increased for the remaining three blocks by suspending a cotton wool soaked in water in each bottle and this reduced the control mortalities. The first block was therefore discarded during analysis of the results.

3.5.3 Persistence of wood treatments

Following the success of lindane and dursban to give complete protection to all the wood types used against LGB attack in the laboratory, it was decided to determine how long it would take for their residual effect to break down. New sets of wood pieces were treated with lindane and dursban as described in section 3.5.2 and stored in paper cartons. At the beginning of each month, 50 adult LGB were introduced to each of the wood pieces in Kilner jars and similar data as described in section 3.5.2 were collected for a period of 10 months.

3.5.4 Treatment of infested woods

The main objective of this work was to find out the effect of surface treatment of LGB-infested wood on the beetles within the wood. Results from this experiment would determine the possibility of controlling LGB in infested stores by treating the store structure. The wood pieces used for this experiment were infested in the laboratory by exposing them to LGB infested maize in large metal containers until LGB entrance holes were visible on them. The infested wood pieces were then treated with lindane, dursban, solignum and spent motor oil as described in section 3.5.2, and placed on filter papers in ventilated Kilner jars. The Kilner jars were arranged in a completely randomized design on a shelf in the laboratory under ambient conditions of 27 °C and 70% r. h. There were four replications. After a period of 3 weeks (21 days), all treated wood pieces were removed from the Kilner jars, dissected and the numbers of live and dead adult beetles were recorded. Observation were made also of any immature stages that may be present within the wood.

3.6 Field Studies

3.6.1 Study site

The field work was carried out from February to September 1995 at the Ministry of Food and Agriculture (MOFA) Research Station, Kpeve, Volta Region, Ghana, within the research activities of the MOFA/ODA (UK) Ghana Larger Grain Borer Project.

Kpeve is located on 8 17N, 0 29E. The area receives a mean annual rainfall of 1000-1500mm which begins from March and ends in November with two peaks at July and September. The average day maximum and minimum temperature are 33°C and 22°C and the annual rainfall during the year of study was 1088.6 mm.

3.6.2 Treatments

Three wood protectants were tested in the field. These were lindane, dursban and spent motor oil applied to the surface of the wood. Although solignum and spent motor oil achieved similar controls in the laboratory trials, solignum could not be tried in the field due to insufficient funds. The number of wood species were also reduced from five to two for the same reason. Thus only borassus and bamboo were tested in the field trial. Bamboo was selected because of its wide use in all the ecological zones of the region while borassus was selected because results from the laboratory screening indicated that it was the most susceptible among the five. The wood materials were used to construct the platforms of the barns. Each platform, consisting of one wood type only, was treated with one chemical (Appendix 6). The wood protectants were applied by surface application of solutions of the materials to the platforms with a painter's bush. Approximately 0.4% lindane and 1% dursban solutions were applied to the woods till the surfaces were wet. A 1% concentration of dursban was the manufacturer's recommendation.

3.6.3 Description of experimental stores

The maize store structure used in this experiment was the raised platform version of the traditional 'Ewe barn'. The barn used in the present trials consisted of a 1 m^2 platform supported at the corners by four wooden poles (legs). The platforms were 1 m above the ground with a rodent guard fixed unto each of the legs, about 0.6 m from the ground, to protect the maize from rodent attack. Platforms were constructed by nailing fourteen to sixteen 1.2 m long pieces of the wood materials on two horizontal cross beams. On the platforms, maize was stacked with the husk-on in a circular fashion to mimic a typical traditional 'Ewe barn'. Large cobs were carefully stacked in the exterior with the remaining filling the inside column into a compact cylinder. Each cylinder of cobs was about 0.8 m in diameter and approximately 0.4 m in height. A thatch roof grass (*Imparata cylindrica* (L. Beauv.)) covered the maize against sun and rain.

3.6.4 Experimental design and field layout

A total of 24 stores were used in the field experiment. These were arranged in rectangular matrix of 6 rows by 4 columns. A randomized complete block design was used. A block consisted of two adjacent rows of eight barns. The distance between barns in a block was 3 m and 3.5 m between blocks. There were three blocks and eight treatments were randomly assigned to each of the barns in a block (Appendix 6).

3.6.5 Sampling of wood in platforms for dissection

The sampling procedure used for the selection of wood pieces for dissection was stratified random sampling. The platform of each store was divided into four parallel areas namely, A, B, C, and D. Each division contains four-five wood pieces. A similar pattern of division was done for all platforms such that the position of areas A, B, C and D were consistent in terms of direction of wind, sun and an adjacent forest. These steps were followed so that all areas of the store platform would be sampled and also made it possible to determine any influence of the above factors on the distribution of LGB infestation in store platforms. From each of the demarcated areas, a single wood piece was randomly selected. and two sub-pieces of length 14-17 cm were cut from the end and middle sections for dissection (Plate 3).

Plate 3: Sampled wood pieces from store platforms

The following data were taken from each sampled wood piece:

1. Length, breadth and the thickness
2. Number of LGB entrance/exit holes
3. Number of live and dead LGB within
4. Number of any other insects within

3.6.6 Data analysis

The main statistical package used in the analysis of the result is Statgraf. version 4.2. All the data were transformed to meet the assumptions of normality and homogeneity of variances for Analysis of Variance (ANOVA). Percent mortalities calculated based on equal number of insects were transformed to Arcsin values. Other percentage mortalities, actual numbers and numbers of insects expressed on per unit area basis were transformed to logarithm values $[X \rightarrow \log_{10}(X+1)]$.

Analyses of variance were performed on transformed data and treatment means compared using Duncan's Multiple Range Test (DMRT). Means in the presented tables are, however, on actual insect numbers or percentages.

4.0 RESULTS

4.1 Laboratory studies

4.1.1 Relative susceptibility of wood types to *P. truncatus*

Analysis of the data from this experiment showed a high significant difference in the susceptibility of the different wood types to the beetle ($F_{4,8}$=20.6; P=0.0003) (Appendix 1). The result of Duncan's multiple range test (DMRT) on treatment means is shown in Table 4.

Table 4: Mean numbers of LGB recorded in wood pieces

Wood	*Mean number of LGB
Borassus	131.8±8.4a
Raphia	31.8±3.9b
Neem	25.9±1.8b
Oil palm	9.0±0.8c
Bamboo	7.3±0.6c

Mean ± S.E followed by the same letter are not significantly different (P< 0.01, DMRT)
*Means of 3 replicates.

Borassus stem recorded the highest number of live beetles and was thus the most susceptible of the five woods tested. It is therefore expected to carry the heaviest infestation under field conditions. Raphia and neem have the same level of susceptibility which is significantly lower than that of borassus. The least susceptible wood was bamboo. The susceptibility of oil palm falls in the same range as bamboo.

4.1.2 Mortality of adult *P. truncatus* exposed to treated woods

Analysis of the data shows a high significant difference in chemical treatments ($F_{5,58}$=117.831, P<0.0001) but not in type of wood (Appendix 2). There was also no significant interaction between wood and chemical treatments. This shows that effectiveness of a chemical treatment does not depend on the type of wood.

Table 5: Percent mortalities of adult LGB exposed to treated wood

Chemical	*Mean percent mortality of LGB per treated wood				
	Bamboo	Neem	Borassus	Raphia	Chemical mean
Lindane	100.00	100.00	100.00	100.00	100.00±0.0a
Dursban	100.00	100.00	100.00	100.00	100.00±0.0a
Solignum	38.67	42.67	35.33	38.00	38.00±2.5b
M. oil	40.00	32.67	48.00	33.33	37.60±2.3b
Water	25.33	10.67	5.33	12.67	16.00±3.7c
Control	22.67	20.00	6.67	7.33	15.20±3.1c
Wood Mean	54.11±8.2	51.00±8.1	49.22±9.5	48.56±7.7	

Mean ±S.E followed by same latter are not significantly different (DMRT, P=0.005)
*Each value is a mean of 3 replicates

Table 5 gives the mean percent mortality of fifty adult beetles exposed to each treated woods. The mean percent mortality of beetles on lindane, dursban, spent motor oil, and solignum treated woods are significantly higher than that of the untreated controls (DMRT, P=0.05). However only lindane and dursban recorded 100% mortality of beetles in all the five woods tested. Spent motor oil and solignum, though with mean percent mortalities significantly higher than the untreated controls, did not give complete protection to any of the woods. The percent mortality of water treated woods was not significantly different from that of the untreated control.

4.1.3 Persistence of wood treatments

Table 6 gives the percent mortality of 50 batches of beetle introduced to treated wood pieces at monthly intervals from the fourth to the tenth month after treatment. The corresponding graphs of percent mortality against time (in months) for treated wood species is presented in pages 42 and 43. Lindane recorded 100% mortality on all the wood consistently until the seven month when its toxic effect begum to decline. For both chemicals, toxic effect begun to decline on all five wood species simultaneously, remaining quite stable afterwards except for lindane treated bamboo and dursban treated neem where mortalities fell to very low levels at the 8^{th} and 7^{th} months respectively before rising back to the average level.

Table 6: Mean mortality of LGB exposed to treated woods at monthly intervals

Months	Mean percent mortality														
After	Untreated control					Dursban					Lindane				
Treatment	Bor	Bam	Rap	Nem	O. p	Bor	Bam	Rap	Nem	O. p	Bor	Bam	Rap	Nem	O. p
4	8	14	16	18	12	100	100	100	100	100	100	100	100	100	100
5	10	14	20	16	14	84	78	78	86	90	100	100	100	100	100
6	12	16	20	14	22	80	82	78	90	100	100	100	100	100	100
7	4	14	12	20	14	76	90	82	10	88	100	100	100	100	100
8	8	18	22	16	12	58	72	80	100	70	70	26	60	54	68
9	6	16	14	14	14	60	70	64	80	60	70	86	60	54	80
10	12	14	10	16	8	60	70	64	80	60	70	80	60	54	80

The experiments in this trial were not replicated

Chart 2 Graph of percent mortality of 50 batches of adult P truncatus exposed to treated neem and oil palm frond pieces at monthly interval

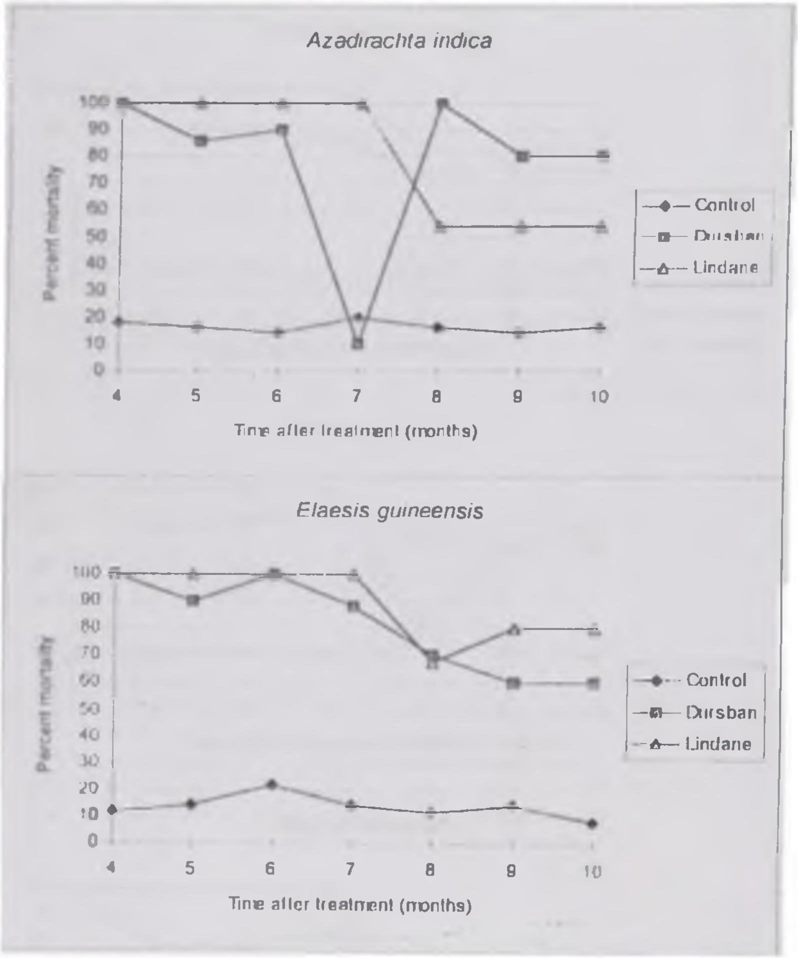
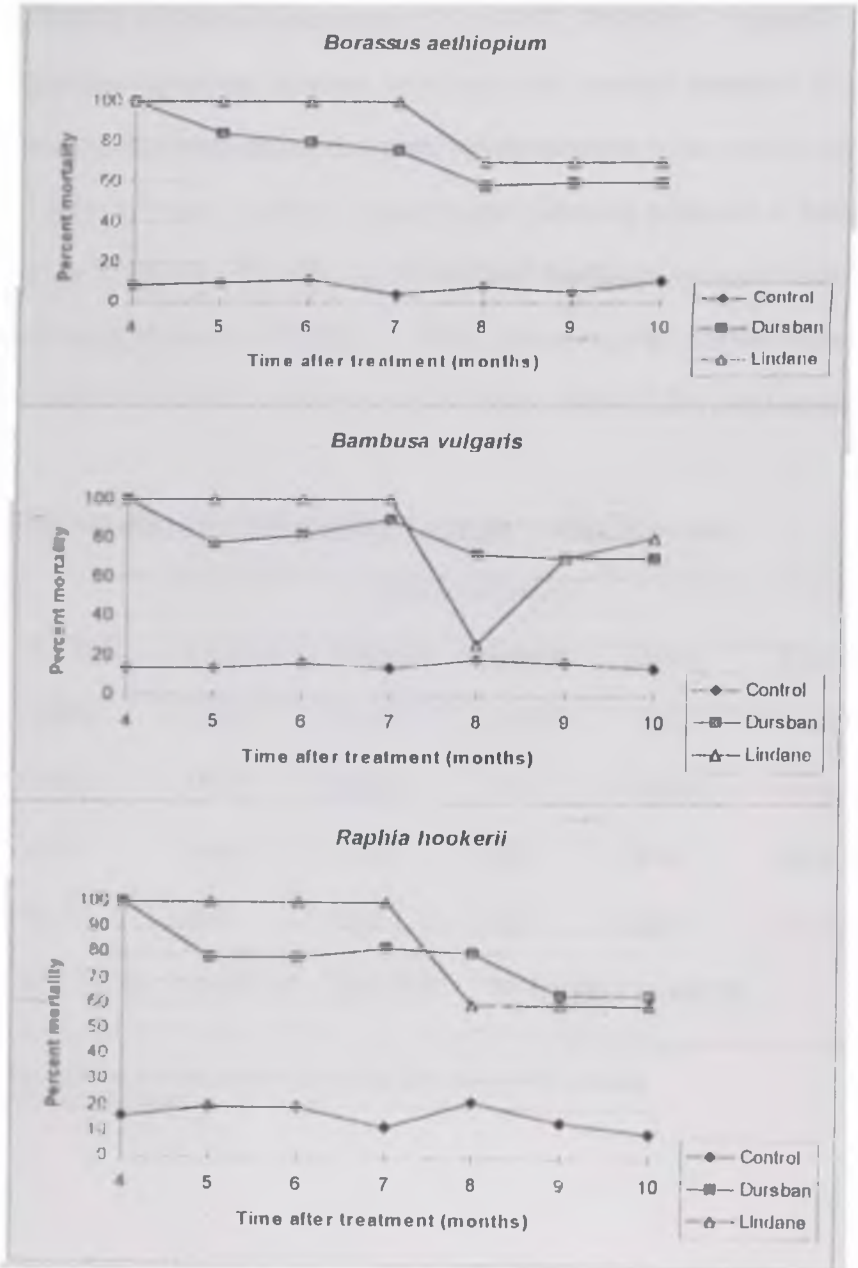


Chart 1: Graph of percent mortality of 50 batches of adult *P. truncatus* exposed to treated borassus, bamboo and raphia fronds pieces at monthly intervals



4.1.4 Treatment of infested woods

Analysis of variance on the data showed high significant difference in both wood type ($F_{4,40}$=5.95, P=0.0007) and chemical treatments ($F_{3,40}$=163.73, P=0.0001) (Appendix 3). There was also a significant interaction between wood type and chemical treatment ($F_{12,40}$=4.45, P=0.0002). Therefore differences among chemicals varied depending on the type of wood.

Table 7 gives the mean mortality of adult beetles following treatment of infested wood pieces with various chemicals. The mean of all chemical treatments are significantly different from that of the untreated controls (DMRT, P = 0.01). However, only dursban treatments gave 100% mortality and thus archived complete control of beetles within all five wood species.

Table 7: Percent mortality of LGB following treatment of infested woods

Chemical	Percent mortality					
	Bamboo	Oil palm	Borassus	Raphia	Neem	Chem. Mean
Dursban	100.0	100.0	100.0	100.0	100.0	100.0±0.0a
Lindane	100.0	100.0	100.0	99.4	100.0	99.9±1.2a
Motor. Oil	100.0	100.0	100.0	96.8	84.4	98.2±3.2a
Control	46.9	54.8	24.2	22.1	22.1	32.2±5.8b
Wood mean	86.73±7.2a	86.45±7.1a	81.0±9.9b	79.3±9.8b	76.6±9.7b	

Means ± S. E. followed by same latter are not significantly different (DMRT, P=0.05)
Each value is a mean of three replicates

There are also significant differences among the mean percent mortalities of beetles recorded from the woods. The mean percent mortality recorded from bamboo and oil palm are significantly higher than that from borassus, raphia and neem. This shows raphia and neem are more difficult to treat when infested. Lindane, for instance killed all LGB infestation in all the woods except raphia. Similarly, motor oil was very effective on all the woods except on raphia and neem.

4.2 Field Studies

4.2.1 Infestation of treated store platforms

Analysis of data showed a high significant difference in both wood ($F_{1,14}$=18.9, P=0.0007) and chemical treatments ($F_{3,14}$ =20.06, P = 0.0001) (Appendix 4). There was also a significant interaction between wood and chemical treatments ($F_{3,14}$=11.44, P=0.0005) indicating that difference among chemicals vary according to the type of wood. Tables 8 shows the mean number of live beetles recorded in a unit area of the treated store platforms. The mean number of live adult beetles recorded from treated stores were significantly higher than that of the untreated controls (DMRT, P=0.05) The mean number of live LGB recorded in a unit area of borassus platform was also significantly higher than for bamboo. This agrees with the results of the laboratory experiment that borassus is more difficult to treat than bamboo.

Table 8: Mean numbers of live LGB per unit area of treated store platform

Chemical	Mean number of LGB/m^2		
	Bamboo	Borassus	Chemical mean
Lindane	0.0	0.0	0.0±0a
Dursban	16.2	5.6	10.85±5.5b
Motor oil	0.0	58.8	29.40±18.3b
Control	11.0	116.9	63.99±25.4c
Wood mean	6.8±3.4a	45.3±16.0b	

Means ± S. E. followed by same latter are not significantly different (DMRT, P=0.05)
* Means of 3 replicates

Table 9 however shows that only motor oil treated borassus, lindane treated borassus and bamboo have significantly lower number of live beetles than the untreated controls. There was actually no live beetles in any of the above mentioned treatments. The number of live beetles recorded from dursban treated bamboo and motor oil treated borassus are however not significantly different from any of the untreated controls (DMRT, P = 0.05). Though no live beetles was recorded from motor oil treated bamboo, the number recorded on motor oil treated borassus was high and not significantly different from any of the untreated control.

Table 9: Mean separation of numbers of live LGB per unit area of store platform

Treatment	*Mean number of LGB/m^{2}
Lindane treated Bamboo	0.0±.0.0a
Lindane treated Borassus	0.0±0.0a
M. oil treated Bamboo	0.0±0.0a
Dursban treated Borassus	5.6±3.3ab
Untreated Bamboo	11.0±7.0abc
Dursban treated Bamboo	16.2±10.5abc
M. oil treated Borassus	58.8±28.4bc
Untreated Borassus	116.9±19.1c

Means±S. E. followed by same latter are not significantly different (DMRT, P=0.05)
* Mean of 3 replicates

4.2.2 Distribution of *P. truncatus* in store platforms

The number of live beetles recorded from the various location across all store platforms is shown in Table 10. There was no significant difference in LGB numbers recorded from the different locations (Appendix 5).

Table 10: Mean numbers of LGB from different locations of store platform.

Location	*Mean number of LGB per unit area of store platform
A	7.8±0.31
B	13.4±3.4
C	10.6±3.8
D	13.2±6.1

Means±S.E. followed by same latter are not significantly different (DMRT. P=0.05).
* Means of 24 platforms.

5.0 DISCUSSION

5.1 Relative Susceptibility of wood types to *P. truncatus*

The mean number of live beetles recorded on each wood gave an indication of the preference or the suitability of the woods relative to each other, and hence its susceptibility to the pest. The susceptibility of the five store woods tested follow the following descending order: stems of *Borassus aethiopium*, fronds of *Raphia hookeri*, stem of *Azadirachta indica*, fronds of *Elaeis guineensis* and stems of *Bambusa vulgaris*. Borassus stem was thus the most susceptible of the five woods tested and expected to carry the heaviest infestation under field conditions. Raphia and neem have the same level of susceptibility which is significantly lower than that of borassus. The least susceptible woods were bamboo and oil palm. Borassus, though not mostly used as platform, forms a very important component of store structure. It's use as support legs and cross beans supporting the store platform (Addo, 1995) makes it not only the most common component of stores in the region but also the most commonly retained component when parts of the store structure are being changed. This is because it is more durable and more resistant to termites relative the other woods. That LGB did infest all the woods tested confirmed work done by Addo (1995) who reported that LGB could infest different types of wood species including those tested in the present study.

Among the factors which determine the suitability or other wise of wood for wood boring insects are: (1) the food value measured by the soluble carbohydrate content (Helbig *et al.*, 1990), (2) the moisture content (Boeye, 1988; Detmers, 1988; Williams, 1977; Williams, 1983; Helbig *et al.* 1990), (3) age (Detmers *et al*, 1988) and (4) the surface features of the wood (William and Mauldin, 1974; William *et al*, 1979). One or any combination of the above factors may be responsible for the differences in the susceptibility of these woods to the LGB. There is a controversy in the literature as to whether wood has any nutritional significance for LGB. In a study on the biological importance of wood for LGB, Detmers (1988) could not establish utilization of cellulose or any other component of wood by the LGB and concluded that wood has no nutritional or physiological significance for LGB. Since enough food was also available at the time when the beetles infested the woods, the food value of wood is unlikely to be a factor responsible for the differences in susceptibility observed here. Due to lack of facilities, the soluble carbohydrate content of woods tested in this study could not be determined, but all of them were obtained from mature plants. More LGB were observed in the younger section of the woods, especially for bamboo and raphia.

Differences in moisture content, density and the surface properties of the wood could also determine the suitability of woods to the pest. Detmers and other workers quote a moisture range of 12-15% to be the optimum for the LGB (Addo, 1995; Detmers, 1988). Except for bamboo, the moisture content of all woods used in the trials fall within this range. The average moisture content for bamboo used in this trial was 10.2. This may explain the very low values observed on this wood. It is also possible that the differences in susceptibility observed in this trial was due to the differences in texture and some surface properties of the wood. The ease with which entrance holes are made may greatly influence the ability of LGB to bore into a particular wood. Addo (1995) reported that LGB bored easily into wood when its surface was rough than when smooth. Borassus, though a hard wood, has it's fibres or wood elements arranged such that the cut surface sections, especially those made parallel to the long axis of the plant are rough. This makes it easy for LGB to make entrance holes. Most LGB that infested borassus entered the wood through parallel holes made in between the loose fibres in the wood. Detmers (1988) reported a relationship between the surface structure of wood and number of *P. truncatus* that bored their way into wood. He reported that LGB showed particular preference for boring into rougher surfaces, points where branches started, soft spots and areas of wood where there was a gap.

The wood of raphia frond, though softer than borassus was covered by a thick compact and smooth bark, the phloem. This smooth bark, which is very difficult to penetrate, forms a barrier that leaves only the cut cross section available for boring. This equally applies to oil palm and bamboo. As expected, no entrance hole was observed on the smooth surfaces of raphia and oil palm fronds. The surface area available for boring is thus very much reduced in the case of these two wood species. In the case of oil palm, the inner spongy tissue shrunk up during drying resulting in large gaps at the cut ends. On initial observation, large numbers of the beetles were found entering the wood through these gaps. The final low numbers recorded suggests that the beetles that went in came out, maybe due to their inability to bore holes in the loose spongy fibre. On neem stem, most of the entrance holes were made at points where branches started, the junctions between the phloem and the heartwood and the pith when available. Similarly, no entrance hole was seen in the cut sections of bamboo. Most of the entrance holes were located at the nodes with very few on the inner concave side of the split bamboo.

5.2 Mortality of adult *P. truncatus* exposed to treated woods

Results from this experiment show that store woods can be protected from *P. truncatus* infestation through surface application of wood protectants. However, only lindane and dursban applied at 0.2% and 1% concentration respectively by surface brushing gave complete protection to all five woods tested by killing all *P. truncatus* adults exposed to the treated surface of the wood pieces. Spent motor oil and solignum, though with mean values significantly different from the untreated controls, did not give complete protection to any of the woods species. The inability of motor oil and solignum to give complete protection to any wood showed they are not very toxic to the beetle.

Though the interaction between wood and chemical was not significant, the performance of some treatments varied from wood to wood. Thus, apart from lindane and dursban, which recorded 100% mortalities on all woods, the mean percent mortality for all other chemicals varied considerably. The practical implication of this observation is that, a chemical may work well on one wood species but fail on another. Motor oil for example, worked better (next to lindane) on borassus but least on neem, while the reverse is true for solignum. This observation agrees with Mallis (1964) who observed that the effectiveness of different insecticides on woods vary from wood to wood. This may be due to differences in surface properties of the woods which determine the amount of insecticide absorbed or retained during application. The amount of chemicals retained on the surface of the various woods was not determined in this work. However, it is likely that the variation in the effectiveness of the wood protectants to control LGB attack on the different wood species was due to differences in the amount of chemical absorbed.

Water-treated-woods did not perform any better than the respective untreated controls. Water treated borassus, and neem did actually give lower mean percent mortality values than their respective untreated controls. This shows that water treatment employed in this study rather made these woods easier to attack. This may be because water treatment made the wood softer and easy to penetrate. Also, the soaking period (14 days) might be too short that it only dissolved the sugar in the wood, and thus made it rather more available to the beetles, instead of washing it out.

5.3 Persistence of wood treatments

Results from this experiment indicated that lindane applied at 0.2% concentration was more persistent on wood than dursban at 1%. Both chemicals consistently gave 100% mortality values on all woods during the first four months following treatment. By the end of the 5th month however, no dursban treated wood could give 100% mortality of fifty adult beetles exposed to it. Lindane continued to give 100% mortality for all wood species until the end of the seventh month when its toxic effect started to decline. Contrary to expectation, the toxic effect of both chemicals broke down simultaneously on all wood species. This observation may be because enough insecticide was not applied to the woods for the differences in their surface retention properties to manifest. The result from this study, however, agrees with Dodson and Robinson (1988) and Powell and Robinson (1989). Reporting on the penetration and permanence of chlorpyrifos (dursban) in structural timber, the above mentioned authours stated that 1% solution of the pesticide applied to the surface of seasoned pine penetrated approximately 2 mm; and that the material at the surface diminishes after three months but the concentration at 2 mm depth remained stable for two years. Both authors, however, did not mention the concentration of active ingredients on the wood surface. Morgan and Purslow (1973) and Osler and Stone (1982) also reported that lindane penetrates approximately 3 mm into wood, and though dissipates at the surface within three years, remains stable at below the surface for five years or longer. Brady *et al.* (1980) and Bush *et al.* (1987) reported chlorpyrifos (dursban) to be more persistent in wood than lindane. The result obtained in this work does not agree with their observation. This may also be due to low concentration of lindane on the wood surface either due to insufficient application or low retention of the wood species used in this study.

5.4 Treatment of infested woods

The results of this experiment show that treatment of LGB infested wood is possible. Though the mean percent mortality of all chemicals significantly differed from those of the untreated controls, only dursban, applied at 1% gave 100% mortality and thus achieved complete control of all LGB infestations within all the woods. Lindane achieved complete control on all woods except raphia where only one beetle survived out of the fifty-four that infested the wood in one replicate. This single insect may have bored deep and hid itself under the impermeable bark of the raphia frond.

Motor oil achieved complete control of beetles only on bamboo, borassus and oil palm. Surviving beetles were found in most replicates of motor oil treated neem and raphia. The success achieved by motor oil on some of the woods gave an indication that it maybe a cheap alternative treatment material for the rural poor farmer.

5.5 Infestation of treated tore platforms

The results obtained from the field experiment confirms the preliminary laboratory trials that *P. truncatus* infestation of wooden store platforms can be controlled by surface treatment of wood. Though analysis of data shows that lindane (0.4% conc) and dursban (2% conc) treatments gave significantly lower number of beetles recorded in a unit area of platform, only lindane completely protected all store platforms from beetle infestation. Dursban treatment did not prevent LGB infestation completely in any of the woods. This was not expected, especially when the application of a lower concentration in the laboratory was effective. This may be due to a quicker breakdown of the material under the field condition as against the laboratory conditions. Superiority of dursban to lindane in terms of penetration and persistence in wood is widely reported (Baker and Berry, 1980; Brady *et al*., 1980; and Bush *et al*. 1987). On the other hand, low concentration of active ingredients on wood surface, either due to low application dose or low retention, could be the reason for the above discrepancy. There was an interaction effect between chemical and wood. Though the average number of beetles in a unit area for all motor oil treated platforms put together was higher than that for dursban, no live beetles was recorded in any motor oil treated bamboo platform. This shows that motor oil is more effective on bamboo and less so on borassus. The likely explanation for this observation could be that the motor oil makes the already smooth and slippery surfaces of bamboo very difficult for the pest to grip and make entrance holes.

5.6 Distribution of *P. truncatus* in store platform

There was no evidence of any factor influencing distribution of the pest in the store platform. There was no difference in the numbers of beetles recorded from different locations of the store platform. Observation of the raw data did not reveal any consistent pattern of distribution of infestation. The beetle appears to infest the platform randomly from any side or angle of the store. This suggests that all wood pieces in a store platform have equal chance of habouring the pest. There is therefore no need for any elaborate sampling techniques when selecting wood for dissection in future trials.

5.7 Other observations

During sampling of wood for dissection, it was observed that some platforms were infested with termites. To assess the nature of infestation in relation to the treatments, some data on termite infestation was collected. Though the data (Appendix 7) do not satisfy the criteria for any statistical analysis, a visual assessment reveals that the treatments protected the store woods from termite attack as well. Most platforms treated with lindane, dursban and motor oil did not record termite infestation. Where infestation occurred, it was very low. There seems to be a positive correlation between degree of termites and LGB infestation; very heavy termite-infested platforms, especially borassus recorded high LGB numbers. It seems the treatments equally protected the store woods against termites and other wood borers. The newly introduced predator of LGB, *Terretriosoma nigresens* (Lewis), was also found in some of the LGB holes. Other unidentified borers were also observed in some platforms notably, untreated bamboo.

CONCLUSION AND RECOMMENDATIONS

The relative susceptibility to *P. trucatus* infestation of five important wood species used for maize store construction in the Volta Region of Ghana was studied. The efficacy of lindane, dursban, spent motor oil, solignum, and water treatment for protection against *P. truncatus* of the above woods as store structure was also investigated. The following are the summary of results from the study.

1. There was a marked difference in susceptibility among the different wood species to LGB. Wood of borassus palm was the most susceptible or preferred by the pest while bamboo and oil palm fronds were the least susceptible. Susceptibility appears to be related to ability of the beetle to bore entrance holes which was easy on woods with rough surfaces.
2. It is possible to protect store woods against *P. truncatus* infestation through surface treatment of wood with remedial insecticides.
3. A 0.4 % concentration of lindane (Gamma-HCH) application on surface of woods protected all store platforms from *P. truncatus* infestation during a storage period of eight months.
4. Application of 2% dursban (chlorpyrifos) solution to wood surface did not completely prevent *P. truncatus* infestation of store wood during the same storage period though infestation was markedly reduced compared to untreated controls.
5. Water treatment (i.e. soaking wood in water for two weeks) did not reduce the susceptibility of woods to *P. truncatus*.
6. Efficacy of some treatments vary from wood to wood. Spent motor oil , for example was very effective on bamboo platform but not so on borassus.
7. The distribution of LGB infestation in store platforms was random.

For future research, it is recommended that the field work of this study be repeated to include solignum and all the other woods which could not be tested in the field in this study. Also, more work needs be done to compare the effectiveness of oil based formulations of the insecticides tested in these trials

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Appendix 1

ANOVA on Log-transformed numbers of LGB recorded from wood pieces

Sources of Variation	df	Sum of Square	Mean Square	F-Ratio	Sig Level
Total	14	3.7770			
Block	2	0.0527	0.0263	0.640	0.5524
Wood	4	3.3950	0.8486	20.607	0.0003
Error	8	0.3295	0.0412		

Appendix 2

ANOVA on Arcsin-transformed percent mortality values of LGB exposed to wood pieces.

Sources of Variation	**df**	**Sum of Square**	**Mean sum**	**F-ratio**	**sig Level**
Total	89	47198.154			
Block	2	383.713	191.857	4.099	0.0419
Chemical	5	42501.516	8500.303	117.831	0.0000
Wood	4	472.180	118.045	2.469	0.1280
Chemical X Wood	20	1171.304	58.565	1.225	0.2400
Error	58	2714.441	47.800		

Appendix 3

ANOVA on Log-transformed percent mortality values of LGB from treated infested wood piece

Source of Variation	**df**	**Sum of Square**	**Mean Sum**	**F-ratio**	**Sig level**
Total	59	3.473			
A: Chemical	3	2.295	0.7646	163.726	0.0001
B: Wood	4	0.111	0.0278	5.953	0.0007
A X B	12	0.250	0.0208	4.454	0.0002
Error	40	0.187	0.00467		

Appendix 4

ANOVA on Log-transformed number of live LGB per unit area of store platform.

Sources of Variation	df	Sum of Square	Mean Sum	F-ratio	Sig level
Total	23	14.4319			
Block	2	0.0097	0.0049	0.043	0.958
A: Chemical	3	6.1841	2.2714	20.061	0.0001
B: Woo	1	2.1376	2.1376	18.879	0.0007
AXB	3	3.8855	1.2952	11.439	0.0005
Error	14	1.5851			

Appendix 5

ANOVA on Log-transformed numbers of LGB per unit area (location) of store platform.

Source of Variation	df	Sum of Square	Mean Square	F-ratio	Sig level
Total	11	0.5040			
Block	2	0.0703	0.3157	0.383	0.6023
Location	3	0.5160	0.0172	0.552	0.8450
Error	6	0.3824	0.0637	0.270	

Appendix 6: FIELD PLAN