TOLERANCE OF DIFFERENT MAIZE VARIETIES AND WOOD SPECIES USED IN MAIZE STORAGE STRUCTURES IN THE VOLTA REGION, GHANA TO THE LARGER GRAIN BORER, *PROSTEPHANUS TRUNCATUS* (HORN) (COLEOPTERA: BOSTRICHIDAE)

BY

SAMUEL ADDO

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BY

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BSc.(Hons) Zoology, Dip. Ed.

SUBMITTED TO THE FACULTY OF SCIENCE IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN ZOOLOGY

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ABSTRACT

Prostephanus truncatus (Horn) (Coleoptera: Bostrichidae), the Larger Grain Borer (LGB) has become a serious pest of stored maize and dried cassava chips since it was first seen in Ghana in 1989. Studies on the tolerance of maize varieties and wood species used in the construction of maize storage structures in the Volta Region of Ghana to *P. truncatus* were made under laboratory and field conditions.

Varietal resistance of maize to insects could be of great help to farmers, especially those who have not got money for chemical treatment. In field studies of farmers' barns, maize cobs with longer, tighter and stronger husks had much lower levels of LGB damage than others in the same barn. Selected cobs from farmers barn also showed that good husk is important in resisting penetration of LGB.

In no-choice laboratory trials, weight losses for local and improved maize varieties due to LGB were determined. The most susceptible improved variety had 6 times the weight loss (19% in 40 days) of the most resistant local variety Hardness (that is seed coat) of grain showed no obvious relationship to resistance in dehusked cobs. Husk cover was significantly related to resistance (p= 0.005) in a laboratory trial on degree of husk penetration by LGB. This is likely due to physical

qualities rather than biochemical factors as ground-up husks sent to the Natural Resources Institute (NRI), Chatham, England, showed no evidence of antifeedant properties.

A survey of maize storage facilities used in the Volta Region, showed that the platform, inverted cone and kitchen stores were the most widely used (51%, 18% and 12% respectively of total stores surveyed). Other store types were the katchalla (grass mat store), room store and basket.

The survey identified 19 wood species used as components of these stores with bamboo (*Bambusa vulgaris* L.) and oilpalm (*Elaeis guineensis* Jacq.) fronds being the most widely used in all the agro-ecological zones. The six most important woods (*Bambusa vulgaris*, *Elaeis guineensis*, *Borassus aethiopium*, *Raphia hokerri*, *Azadirachta indica* A. Juss., *Chlorophora excelsa* and *Triplochiton sclerexylon* K. Schum.) were chosen for further testing. None of these supported breeding of LGB in laboratory trials. However, adult LGB survived in all woods for 7 weeks. Farmers with LGB in their storage platforms may not be able to replace the wood before stacking the new maize. Two possible alternative strategies were explored: (a) leaving the platform long enough for the adult LGB to die or (b) smoking the empty platform to disinfest it. Adult LGB survived in infested platform left in the open air for 3 months after removal of maize.

Smoking of LGB-infested bamboo platforms resulted in disinfestation of woods within 3 days with intense smoking and within a week when smoking was done to simulate farmer's cooking time of 7 hours a day alongside an oilpalm mat screened fireplace. However, without screen, smoking was ineffective: some live LGB were recorded even after 7 weeks.

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S. Addo

December 30 1994

DECLARATION

I declare that the work involved in this thesis for the degree of Master of Philosophy (Zoology) represents my original work and has not been previously submitted for any degree. All helps have been duly acknowledged.

. . . .
Samuel Addo

CERTIFICATION

I certify that this work was carried out by Mr Samuel Addo in the Department of Zoology, University of Ghana, Legon and the Ghana Larger Grain Borer Project, Volta Region, Ghana.

Supervisor

Professor W. Z. Coker

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

CHAPTER ONE

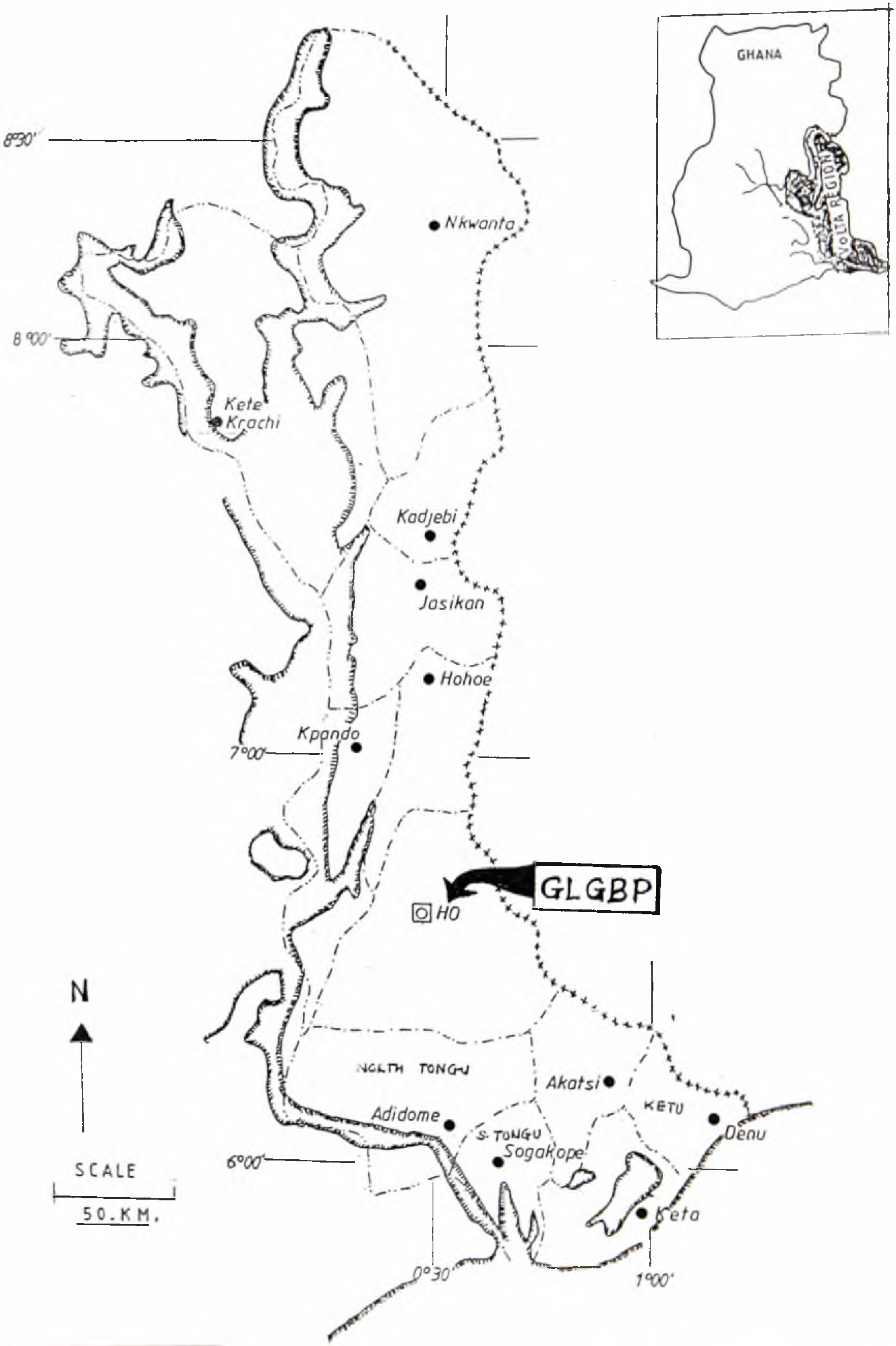
GENERAL INTRODUCTION

Prostephanus truncatus (Horn) (Coleoptera: Bostrichidae) commonly called the larger grain borer (LGB) is a new and very serious pest of stored maize and dried cassava chips in Ghana. It originates from Central America and was first introduced into Africa in the early 1980s. LGB was first noticed in the Tabora region of Tanzania (Dunstan and Magazini, 1981; Golob and Hodges, 1982) and in West Africa, the outbreak of the pest was first recorded in 1984 (Krall, 1984; Harnisch and Krall, 1984) It is probable that LGB was introduced into Africa through cereal shipments.

In Ghana, LGB was first recorded in eastern Volta Region using pheromone traps in January 1989 (Ofosu, *pers. comm.*) LGB is carried to uninfested areas via maize and dried cassava chips ("kokonte") bought at rural and urban markets, and via sacks which have previously carried these commodities. LGB may spread from one country to another by a similar process, especially on the Ghana-Togo border where there is much local movement of small amounts of grains across the border as head-loads. Passengers travelling long distances by buses or lorries also carry small quantities of maize and cassava chips for gifts or personal consumption; and these commodities may sometimes be infested. LGB may have entered Ghana from Togo either through trade or by flight.

The LGB problem has assumed a very serious dimension in Ghana. In 1992 the Ministry of Food and Agriculture (MoFA), in collaboration with the U.K. Overseas Development Administration (ODA) set up a project known as the Ghana Larger Grain Borer Project (hereafter referred to as GLGBP) to research into the LGB problem in Ghana and come out with appropriate recommendations. The GLGBP research group is based in the Volta region, Eastern Ghana (Figure 1) where the work in this thesis was carried out.

Figure 1: Map of Volta Region showing the location of Ghana Larger Grain Borer Project (GLGBP) and district boundaries.



Ghanaian farmers (especially those in the Volta Region) see LGB as a real threat to stored maize which is the backbone of the economy of the small scale farmer. In many areas, infestation in farmers' stores is getting worse, with the resultant change in farmers' attitude towards the production and storage of maize. Many farmers who previously cultivated maize as a cash crop before suffering serious LGB infestation declare that they will switch to other crops (Farmers meetings in the Volta region, *pers. comm.*).

The subject matter presented in this thesis includes:

(i) Maize storage in the rural economy

The importance of maize production and consumption in Ghana with particular reference to farmers in the Volta region. Maize in the economic and social set-up of farmers in the northern, central and southern sectors of the Volta region and the forms in which it is stored have been treated in this section.

(ii) Insect pests and their importance in maize storage

A brief account of pests of maize before and after storage have been documented. Other pests of maize including stem borers in West Africa are also looked at.

(iii) LGB in Ghana

The records of the incidence of LGB in Ghana and data showing trap catches and infestation in the Volta region. Farmer group assessments of LGB and of possible solutions to the LGB problem have been discussed.

(iv) Objectives of research

The objectives of this research have been discussed as; wider or long-term, short-term and specific objectives to meet the expectations of various groups which will benefit from the research findings.

Chapter 2: Literature review

(i) Classification, recognition and identification of LGB

This section summarizes the evolutionary tree of LGB, characteristics and features used in the recognition and identification of LGB.

(ii) Biology and ecology of LGB

The distribution of LGB in various countries, development and losses due to LGB have been reviewed with current observations by GLGBP.

(iii) LGB as a wood borer

The role of LGB in infesting wood is reviewed.

(iv) Maize varietal tolerance to post-harvest pests

In this section, maize varieties and their selection, varietal tolerance to LGB and *Sitophilus zeamais* Motschulsky (Col: Curculionidae) have been tackled.

Chapters 3 (Methods) and 4 (Results) form the main body of the thesis. These are sub-divided as follows:

(a) Laboratory studies

(i) Laboratory studies of maize varietal tolerance to LGB

This part of the work looked at the laboratory tests involving local and high-yielding varieties. Tests were done on their susceptibility to LGB both in dehusked and undehusked form over 40-day period. Penetration of different varieties of maize by LGB over a 5-day period were also investigated.

(ii) Development of LGB on common woods

Some woods used in the construction of stores in the Volta Region were infested with LGB under laboratory conditions to determine their potential as hosts for survival and development.

Laboratory studies to determine the survival and development of LGB in some selected woods.

(b) Field studies

(i) Survey of materials used in traditional storage structures

Various types of storage structures for maize in the Volta Region of Ghana were documented. In each of the districts covered, wood species used in the construction of the stores were recorded.

(ii) Maize storage studies

Ewe raised platform type stores were investigated by looking at the pattern of infestation by LGB under free-choice condition and the influence of husk and grain type on damage levels.

(iii) LGB in storage platforms

The survival of LGB in empty infested maize storage platforms was recorded over a period of time to assess the period of survival in platforms. Materials and methods used in smoking of LGB-infested platforms under different experimental conditions as a way of disinfesting the storage woods were reported in this section.

Chapter 5

This deals with the discussion of results, recommendations from work done and suggestions for future work.

1.1. Maize storage in the rural economy

1.1.1 Maize production in Ghana

Maize is an important crop in the domestic economy of the Ghanaian. The production of maize cuts across all the regions of Ghana. Two crops a year ("major" and "minor" season maize) are produced in most areas, but in some areas there is only one season which may be variously attributed to a unimodal rainfall pattern, incidence of stem borers or farmers involved in other lucrative crops. Maize and cassava are the major staples of Ghana and are grown almost everywhere in the country, but the bulk of the maize is grown in Brong Ahafo, Ashanti and Eastern Regions. Of the total area of 3 million hectares under cultivation, maize covers 400,000 ha. and accounts for 50-60% of total production of cereals. The average annual yield estimate for the period 1986-90 is 605,000t. Root and tubers (cassava, yams, sweet potato, cocoyam, etc.) are cultivated over an area of about 60% of the total area under cultivation (Dixon and Ocansey, 1988)

Maize production figures in 1993 have increased by six times since 1990 according to the estimates of the Policy Planning Monitoring and Evaluation Department (PPMED) of the Ministry of Food and Agriculture. National maize production figures are shown in Table 1.

Table 1. Production of maize in Ghana

Year	Production figures ('000 metric tonnes)
1983	141
1984	575
1985	411
1986	559
1987	553
1988	600
1989	715
1990	553
1993	961

Source: PPMED (MoFA), 1993.

In the Volta region production of maize is high compared to national output. Figures of maize production in the Volta region between 1986 and 1991 and the proportion to national production levels are given in Table 2.

Table 2: Production of maize in the Volta region

Year	Total production ('000 metric t.)	% Share in terms of national production
1986	54.0	10
1987	53.4	9
1988	42.0	7
1989	80.4	11
1990	91.5	17
1991	116.3	13

Source: PPMED (MoFA), 1991.

Maize is very important in the diet of the Ghanaian especially in the southern part of the Volta region where foods such as 'akple' (thick maize porridge), and kenkey (steamed, fermented maize dough) are taken every day As maize can be stored longer than root crops, it is important during the lean season.

1.1.2 Maize storage and its importance

Nyanteng and van Apeldoorn (1971) have identified some factors which influence the storage of maize in Ghana. These factors come under two main categories; positive and negative. On the positive side the reasons given are:

(i) storing for consumption by the farmer and his family;
(ii) storing as seed for the next planting season;
(iii) storing to await higher prices; and
(iv) storing as a means of saving.

The negative factors include:

(i) infrequent visits by buyers, or no buyers at all;
(ii) infrequent marketing opportunities elsewhere;
(iii) lack of transport or poor roads;
(iv) credit arrangements which in some cases force farmers to store.

In areas where prices increase throughout the year, farmers tend to hold back substantial quantity of their grain in order to take advantage of price rises (Southworth *et al.*, 1980). This trend in price hikes is seen in some maize markets in Ghana especially maize deficit areas where maize prices can increase by over 200-300% from the main harvest to the lean season.

1.1.3. Maize storage in the Volta region

A rapid survey of representative villages in the Volta Region (Ghana Larger Grain Borer Project (GLGBP) 1993a) showed that maize is the most important cash crop for many farmers, especially in the former cocoa-growing areas of the Jasikan, Kadjebi and Hohoe districts. The cocoa and coffee trees have become overgrown and financial returns from cocoa farms are very low, trees had been cut down and replaced with maize as a cash crop. In some areas of the region, maize is a major staple and is depended on throughout the year.

A crop budget for the production of maize under the traditional and partially mechanised technologies showed that it is profitable to produce maize and Volta region ranks first in terms of profitability of cereals including maize (FAO, 1986).

Average retail prices (in cedis) for a unit bowl (2.5 kg.) of maize in the Volta region are given in Table 3.

Table 3: Average prices for maize in the Volta region (1986-1991)

Year	Average price (cedis/2.5 kg bowl)
1986	82
1987	124
1988	175
1989	146
1990	260
1991	298

Source: Kartey, 1992

Maize storage by farmers in the Volta region is becoming more lucrative every year. PPMED analysis on average maize prices for Volta region show seasonal price spreads ranging from 73% to 293% for the period 1986-1991. 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 GLGBP survey of four markets: Ho, Kpeve, Brewaniase and Dodo Amanfrom from September 1993 to July 1994, also showed seasonal price spreads from 210% to as high as 320% with an average of 236% for the four markets (Magrath and Compton, 1994)

In the northern parts of the Volta Region, which include the Kete Krachi and Nkwanta districts (see Figure 1), the major staple is yam fufu, consumption of maize is low and small quantities are mixed with kokonte. Maize however plays an important role since it is one of the main cash crops of farmers in this area. In certain parts of the Kete Krachi district, around Dormabin, maize is a second staple and a major cash crop.

In the Kpando and Ho districts (see Figure 1) maize is harvested twice a year, so most farmers dispose of major season maize early when they expect the minor season maize to be good. The major season crop is harvested between July-September and the minor season harvest occurs from December to January Most farmers store maize up to 10 months in order to get higher market prices during the lean season. Although cassava fufu is the main staple of the people in this area, maize is gradually becoming more important in the diet in the southern part of Ho district.

The southernmost part of the Volta Region takes into account the coastal savannah zone (see Appendix 7). This includes Ketu, Akatsi, and North and South Tongu districts (see Figure 1) where maize is the major staple (except for those along the Volta lake who eat a lot of kokonte). The greater part of this zone is a maize deficit area.

Maize is stored in different traditional ways. In Northern Ghana, maize is stored in mud silos and in Ashanti and Brong Ahafo regions most of the maize is stored in bags (Ofosu, 1987). In much of the northern part of the Volta Region, maize is stored as dehusked cobs in a 'katchalla', which is a large basket made from 'zana grass' (*Andropogon gayanus*) (see Appendix 5). In central and southern Volta region, maize in the husk is stored in the "Ewe barn" (raised platform or inverted cone) type (see Appendix 5). In the forest zones of the Volta region where the rainfall is quite heavy during the harvest time kitchen stores where maize is packed in the loft above the fireplace are very common. The idea is that the fire lit beneath the platform should accelerate the drying process.

Most farmers aim to store major season maize for almost 9 months (August to May) to serve as a food reserve during the lean period of February to June. Farmers with substantial surplus also store for this long period so as to fetch higher market price for the commodity (Magrath, 1993).

The revenue from storage is very vital since it helps in the preparation of new maize fields, pay fees of dependants and as a savings to meet other family and social commitments. In some areas very large barns standing in the compound is a source of pride and portrays the wealth status of the farmer, and in some cases it determines the potential of a farmer to get a new spouse (personal communication with maize farmers in Hohoe, Ketu and Kpando districts).

1.2. Insect pests and their importance in maize storage

Food commodities in tropical Africa are usually infested with insect pests either from the field before harvest or through poor post-harvest storage systems. The activities of these pests which the peasant farmer has to cope with, lead to substantial losses of food commodities especially in the sub-Saharan regions of Africa (Hall, 1970; Adams, 1977, Allotey, 1991, 1993). Insect pests in stored food commodities belong to two major groups; the Coleoptera and Lepidoptera, with the beetles being the dominant group. These insects are the most important agents of storage losses in the tropics where they play a dominant role in the biodeterioration of stored grains. The storage environment in the tropics is often highly favourable for insect growth and development all the year round (Semple, 1982). Maize storage insect pests, earworms and other stem borers in tropical Africa are shown in Table 4.

Table 4: Most important field and storage insect pests of maize in West Africa

Insect species	Order	Family
Pre-harvest pests		
Sitophilus zeamais Motschulsky	Coleoptera	Curculionidae
Sitophilus oryzae (Linnaeus)	Coleoptera	Curculionidae
Sitotroga cerealella (Ol.)	Lepidoptera	Gelechiidae
Sesamia calamistis Hampson	Lepidoptera	Noctuidae
Eldana saccharina (Wlk.)	Lepidoptera	Pyralidae
Mussidia nigrivenella Rag.	Lepidoptera	Pyralidae
Cryptophlebia leucotreta (M.)	Lepidoptera	Tortricidae
Tribolium castaneum (Herbst)	Coleoptera	Tenebrionidae
Ephestia cautella (Wlk.)	Lepidoptera	Phycitidae
Post-harvest primary pests		
Rhizopertha dominica (Fab.)	Coleoptera	Bostrichidae
Dinoderus minutus (Fabricius)	Coleoptera	Bostrichidae
Prostephanus truncatus (Horn)	Coleoptera	Bostrichidae
Sitophilus zeamais Motschulsky	Coleoptera	Curculionidae
Secondary post-harvest pests		
Oryzaephilus spp.	Coleoptera	Silvanidae
Carpophilus spp.	Coleoptera	Nitidulidae
Cryptolestes ferrugineus (S.)	Coleoptera	Cucujidae
Cathartus quadricollis G-Men.	Coleoptera	Silvanidae

Ref: Mould, 1973; Hodges, 1984; Allotey, 1991; Schultess *et al.*, 1991; Gounou *et al.*, 1994;

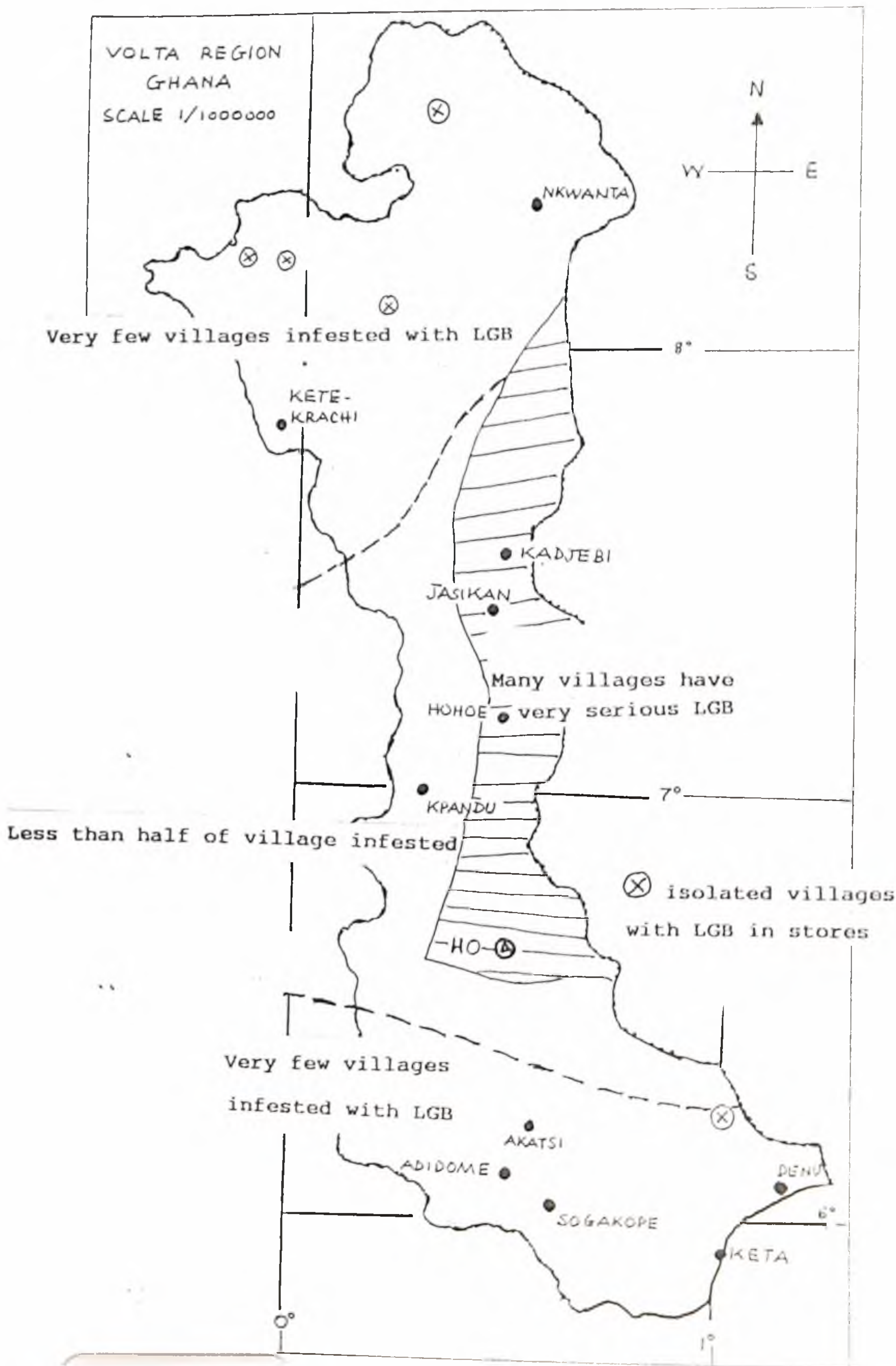
Maize in the field in some parts of Ghana (for example around Dodi Papase in the Kadjebi district of the Volta Region) has also been observed to be infested with bamboo borers such as *Dinoderus* spp. before harvest (personal communication with District Post Harvest Officer in charge of Kadjebi district). Maize coming in from the field sometimes has high levels of *Sitophilus* spp. infestation, and appreciable numbers of *Cathartus quadricollis*, *Tribolium* spp., *Carpophilus* spp. and *Cryptolestes* spp. Usually cobs from the field have high earworm (Lepidoptera) attack especially for major season harvests (personal observation of cobs and laboratory cultures)

1.3. LGB in Ghana

LGB was first recorded in eastern Volta region using pheromone traps. A 1989 survey showed that LGB was present in villages along a 150km stretch of border with Togo from Kpetoe in the south to Ameyoe in the north (Dick *et al.*, 1989). By 1993, a GLGBP survey showed that LGB was present in all the districts of the Volta Region (GLGBP, 1993a)(refer to Figure 2).

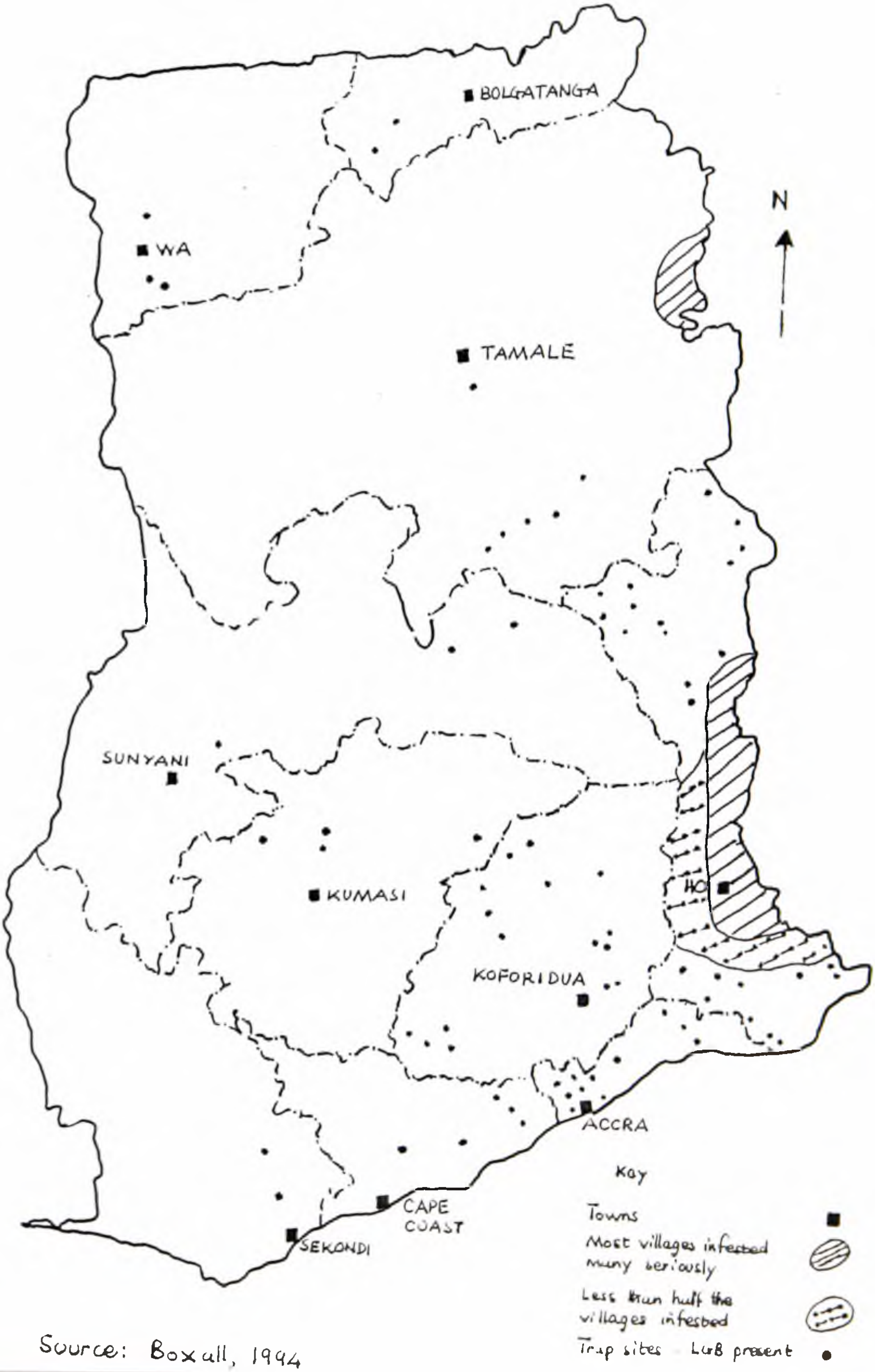
LGB is also spreading to other regions of Ghana. Its presence in Greater Accra was first confirmed by Allotey (1993)

Figure 2: Distribution of LGB in stores in the Volta Region



National monitoring of LGB in which every district had at least one trap set every fortnight revealed how serious the LGB situation is in Ghana. By September 1994, LGB had been trapped in all the regions of Ghana (Boxall, 1994) (refer to Figure 3). The most affected part of the country apart from the Volta Region are the Saboba district of the Northern region, the Dangbe West district of Greater Accra and the areas of the Eastern Region bordering Volta Region. LGB has also been found in maize and dried cassava chips in the Upper West Region, south of Wa (Robin Boxall, *pers. comm.*).

Figure 3 Distribution of LGB in Ghana.



Source: Boxall, 1994

A group of small-scale farmers was interviewed during a participatory training workshop of staff of GLGBP (1993b). One group of farmers ranked perceived solutions to the LGB as shown in Table 5.

Table 5: Ranking of farmers' solutions to LGB problem

Rank	Solution	Criteria used
1	Use Actellic Super dust to treat maize	Very effective, easy to apply.
2	Use of `Phostoxin' (Phostoxin tablets)	Very effective, easy to apply.*
3	Using Actellic 25EC	Effective for all other insects except LGB, costly and not easy to formulate
4	Shell maize early and bag untreated	Quite effective for some insects but not LGB
5	Use of neem leaves	No cash cost but not effective against LGB
6	Frequent sun drying	Has some effect on fast-moving insects like weevils
7	Smoking of barns	Effective for other insect pests but not LGB

* Note: Farmers were unaware of chemical hazards.

Source: S. Addo, P Magrath and P Ahiable, unpublished data.

The current recommendation by the Postharvest Unit of Ministry of Food and Agriculture (MoFA) is to shell the maize and treat with the chemical protectant called "Actellic Super" which is a dust containing 1.6% pirimiphos-methyl and 0.3% permethrin. Although Actellic Super is very effective, it is hardly used by most farmers because of its cost. Some farmers complain of lack of sacks and storage space. Farmers who readily accept the use of Actellic Super are mostly those who have already experienced severe LGB attacks to their stored maize.

1.4 Objectives

The long-term objective of this research is to help in understanding maize storage problems in Ghana, establish the missing but important facts about the larger grain borer, thus enabling better pest management tactics against this destructive insect pest in Ghana. The peasant farmer is the target, having to take a new look at his present way of maize storage in order to avoid high losses from larger grain borer attack. The research is also intended to assist the Post Harvest Development Unit and Plant Protection and Regulatory Services, and research institutions on what policies to implement in the control of LGB. The outcome of this project will also assist the government and the Ministry of Food and Agriculture to save our major maize producing areas of Brong Ahafo, Ashanti, Northern and Eastern Regions from the LGB menace.

The short-term objectives are to:

(i) look for alternative non-chemical methods for protecting maize and storage woods against LGB. These methods should be accessible to the low-income farmer and on the national level, save foreign exchange,

(ii) identify maize varieties and maize storage woods which are resistant to LGB infestation and can be used by the farmer

For this purpose, the investigation was designed with the following specific objectives in mind:

(i) to investigate the susceptibility of selected maize varieties to the larger grain borer under no-choice laboratory conditions including:-

(a) effect of maize husk type,

(b) effect of grain type,

(c) rate of penetration of husk.

(ii) to investigate the susceptibility of maize varieties held under `free choice' conditions in traditional stores in the Volta Region.

(iii) to identify the main maize storage structures and wood/plant species used as components in store construction in the Volta Region of Ghana.

(iv) to undertake laboratory studies to assess the survival and development of larger grain borer in woods and other materials commonly used in storage structures.

(v) to undertake a scientific study of smoking of LGB-infested storage platforms as a traditional method of disinfestation.

CHAPTER TWO

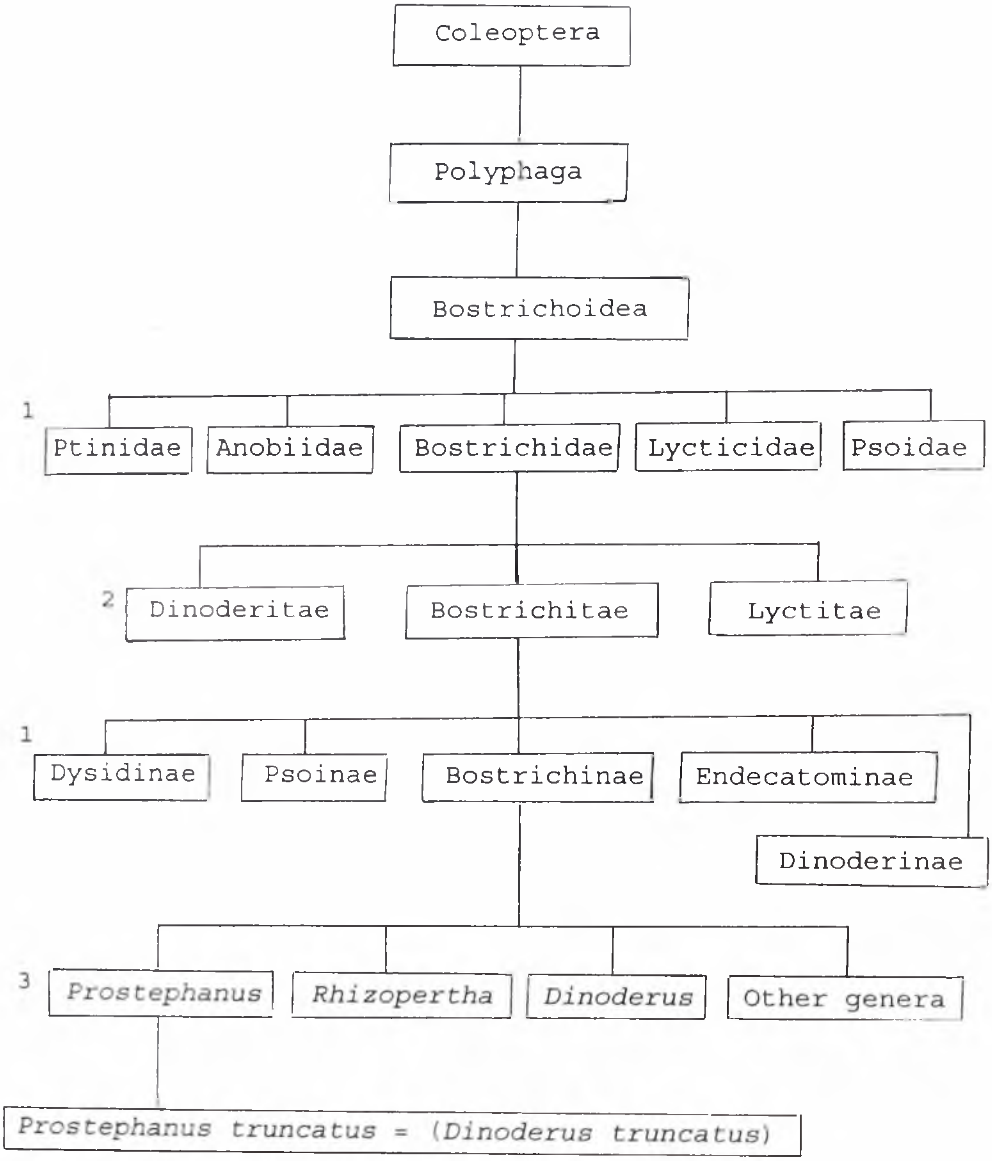
LITERATURE REVIEW

2.1. Systematics of P. truncatus

2.1.1. Classification of *P. truncatus*

A full account of the systematics of *P. truncatus* and other bostrichids was given by Potter (1935). The evolutionary tree of LGB is shown in Figure 4.

Figure 4: The evolutionary tree of *P. truncatus*



1= Boving and Craighead, 1930; CSIRO, 1970; Arnett, 1971
2= Lesne, 1924 (not currently accepted)
3= Lesne, 1924

2.1.2. Recognition and identification of *P. truncatus*

Keys relating to the identification of *P. truncatus* and other bostrichids are that of Fisher (1950) and, to a lesser extent, those of Kingsolver (1971) and Hodges (1986). Detailed descriptions of adults (Horn, 1878; Lesne, 1897) and the larva and pupa (Spilman, 1984) have been used extensively in works involving *P. truncatus*. Adults may be sexed using clypeal tubercles (Shires and McCarthy, 1976) and pupae according to the size and shapes of the genital papillae (Bell and Watters, 1982).

The adults of LGB can be distinguished by the following features (Haines, 1991):

- typical bostrichid shape, the body cylindrical and dark brown to black in colour.
- the head is ventral to the prothorax.
- the pronotum bears rows of teeth on the anterior part.
- the antennae are 10-segmented and have a loose three-segmented club.
- the funicle is slender and clothed with long hairs.
- posteriorly, the elytra are flattened and quite steeply inclined.
- the tarsi are all five-segmented.

Larvae of bostrichidae can be distinguished by the following features:

- body C-shaped (grub-like or scarabaeiform)
- head retracted into prothorax.
- mesotergum, metatergum, or abdominal terga are all divided into 2 or 3 folds.
- abdominal spiracle VIII smaller or larger than other abdominal spiracles
- spiracles oval or circular
- setae simple, hairlike, not flat not dense.

2.2. LGB: a review of its biology and ecology

2.2.1. Distribution of LGB

LGB was first noted in Central America including Mexico, tropical South America and the southern region of the United States of America (U.S.A.) (Chittenden, 1911). Quite recently LGB has spread to a number of African countries and there is evidence of the pest in the Middle East. Various reports of this beetle have been summarized in the reviews of Howard (1983); Krall, (1984); Hodges (1986); Dick, (1988); Golob, (1988); Dick *et al.*, (1989) and Markham *et al.*, (1991).

Records of the pest in various areas have been documented as shown in Table 6 below:

Table 6: Distribution of LGB in affected areas.

Country	Reference
The Americas	
U.S.A.	Chittenden, 1911*
	Back and Cotton, 1922*
Guatemala	Cotton and Good, 1937*
Peru	Wright, 1984
Honduras, El Salvador and Panama	McGuire and Crandall, 1967*
Nicaragua	Giles and Leon, 1975
Costa Rica	Fisher, 1950*
Brazil	Cotton and Good, 1937*
Colombia	Posada *et al.*, 1976*
Mexico	Chittenden, 1911;*
	Delgado and Hernandez Luna, 1951*;
	Quintana *et al.*, 1960*
Middle and Far East	
Israel	Calderon and Donahaye, 1962*
Iraq	Al-Sousi *et al.*, 1970*
China	Lesne, 1939*
Hong Kong	Zimmerman, 1990
India	Verma and Lal, 1987;*
	Verma *et al.*, 1988*
Africa	
Tanzania	Dunstan and Magazini, 1981;
	Golob and Hodges, 1982
Togo	Krall, 1984; Harnisch and Krall, 1984
Kenya	Kega and Warui, 1983
Burundi	Golob, 1988
Ghana	Dick *et al.*, 1989
Burkina Faso	Bosque-Perez *et al.*, 1991
Nigeria	Pike *et al.*, 1992

* Cited in Markham *et al.*, 1991

LGB is becoming a major pest problem, especially in the last decade in tropical Africa Dunstan and Magazini, (1981); Dick *et al.*, (1989); Pike *et al.*, (1992). The mechanism of arrival of LGB in a previously uninfested area is not thoroughly understood, but it is believed that most of the spread is through trade. Most major market centres in the Volta Region, with high influx of traders have been among the first areas in the region to become infested with LGB (personal observation of markets)

2.2.2. Development of LGB

The optimum conditions for LGB development on maize are 32°C and 70-80% relative humidity (r.h.) (Shires, 1979, 1980; Bell and Watters, 1982; Hodges and Meik, 1984) The life cycle of LGB can be completed within a fairly wide range of temperature and r.h. as shown in Table 7.

Table 7· Lower and upper limits of temperature for the development of LGB

R.h. (%)	Lower ($^{\circ}$C)	Upper ($^{\circ}$C)	Source
40	25	32	Bell and Watters, 1982
70	18	37	

Under optimum conditions of temperature and r.h., the medium on which LGB is reared influences the developmental period, as shown in Table 8.

Table 8: Developmental periods of LGB on different development media

Development media	Life cycle (days)	Source
Whole grain	24-25	Bell and Watters, 1982
Packed flour	24-25	Bell and Watters, 1982
Loosely packed flour	35.4	Shires, 1979, 1980

Differences in the developmental period were attributed to the degree of packing of the development medium. Bell and Watters (1982) observed that in firmly packed flour the larvae made narrow tunnels against which they could brace themselves and hence were able to force their mandibles into the forward end of the tunnel for effective chewing. In low density media, the tunnels were wider and larvae often twisted back and forth without moving their heads, and this useless expenditure of energy may have retarded their growth rate.

Oviposition in LGB has been reviewed by many authors (Hodges, 1982; Howard, 1983; Markham *et al.*, 1991) Neat round holes are made as a result of adults boring into maize grains and large quantities of maize dust are produced. Adult females lay most fertilized eggs within the grain, in blind-end chambers bored at right angles to the main tunnel (Hodges, 1982; Howard, 1983). Oviposition on stabilized grain and maize cob is more productive than on loose grain as oviposition periods become longer (sometimes equal in length to the life of the female) on loose grains (Cowley *et al.*, 1980).

Howard (1983), studying this in more detail, worked with adult pairs confined to damaged grains embedded in maize flour and maintained at 25°C and 70% r.h. Under these conditions, pre-oviposition was about 5 days, average length of oviposition period 14 weeks and mean life-time fecund period as high as 114 days. Even higher figures were reported for LGB confined to simulated cobs at 30°C and 70% r.h., when the life-time egg production averaged 430 and two individuals each laid over 600 eggs (Howard, 1983).

The quantity of food provided for LGB may influence the rate of oviposition, as shown in Table 9.

Table 9: Oviposition rates for LGB on different quantities of maize and cassava

R.h. (%)	Temp. (°C)	Quantity of food (g/LGB)	Number of eggs laid/day
Maize			
70	27	1	1.4
		6	3.9
Cassava			
70	27	1	1.1
		6	2.3

Source: Nyakunga, 1982

Larvae hatch from eggs after about three days at 27°C and 70% r.h. and seem to thrive on the dust produced by boring adults. The egg to adult development time of LGB is influenced by environmental conditions as shown in Table 10.

Table 10: Egg to adult development of LGB under various environmental conditions.

Food media	R.h. (%)	Temp. (°C)	Period (days)	Source
Maize flour	70	32	25 4	Bell and Watters, 1982
Cassava	70	27	43.1	Nyakunga, 1982
Maize grain (America No.3)	70	27	39.2	

2.2.3 Sexual differences in development and life span of LGB

Hodges *et al.* (1985) found some differences in emergence time between the sexes developing on dried cassava. At 70% r.h., the females emerged at an average of one half day after the males, while at 50% r.h., the difference was more substantial, females emerging on average 1-2 days after the males.

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 for female and male respectively. In contrast at 25°C and

70% r.h., on maize flour and grains, males were found to outlive females (Howard, 1983). These differences in female longevity may be due to different oviposition rates; the females in Howard's studies having a much higher rate, hence a shorter longevity.

2.2.4. Losses due to LGB

Larger grain borer appears to cause very high weight losses within a few months of maize storage. The average weight losses in stores for maize and cassava are shown in Table 11.

Table 11: Weight losses in stored maize and cassava due to LGB

Country	Storage period (months)	Storage form	% wt. loss	Reference
Weight losses due to LGB in maize				
Nicaragua	6	cob	40	Giles and Leon, 1975
Honduras	3-6	cob	30	Hoppe, 1986
Tanzania	3-6	cob	34	Hodges *et al.*, 1983
	6	cob	17.9	Keil, 1988
	8	cob	41.2	
Togo	8	cob	44.8	Pantenius and Schulz, 1986
Ghana	6	cob	14-20	Golob, Addo and Harding, unpublished data
Weight losses due to LGB in cassava chips				
Tanzania	4	dried tubers	70	Hodges *et al.*, 1985
Togo	3	dried tubers	9 7	Wright *et al.*, 1993
	7	dried tubers	19.5	

By comparison, damage in traditional storage systems (on the cob) caused by more common storage pests such as *Sitophilus* spp. is typically much lower, as shown in Table 12.

Table 12: Losses caused by *Sitophilus* spp. to maize in one storage season

Country	Species	% wt. loss	Reference
Zambia	*S. oryzae*	2-6	Adams, 1977
Kenya	*S. zeamais*	3-5	De Lima, 1979
Malawi	*S. cereallela*	2-5	Golob, 1981

The most obvious cause of loss in LGB attack is the conversion of maize grain into flour by adult boring rather than consumption by the larvae during the course of development. Large quantities of dust are associated with infested maize cobs (Hodges *et al.*, 1983). The production of dust and frass by LGB is much higher than with *S. zeamais*. Farmers in Ghana as in Togo (Compton, 1991) reject for human consumption the large amounts of 'flour' produced by LGB. LGB is less efficient at utilization of its diet than *S. zeamais* and may produce a lot of dust from maize grains when feeding (Demianyk and Sinha,1987) and this may explain the higher weight losses.

As might be expected, insect damage to maize is reflected in economic loss. A study of the relationship between maize retail price and the degree of insect infestation was carried out by GLGBP In this study, groups of maize traders were presented with a range of bowls containing previously-prepared maize samples of known damage levels. Four markets in the Volta Region were used. The percentage of damaged grains in the sample due to damage by LGB and *Sitophilus* spp. had a consistent relationship to retail price. The relationship appeared almost linear, with about a 0.75% drop in retail price for every 1% increase in damaged grains (Compton, 1993, 1994)

2.3. LGB as a wood borer

The presence and behaviour of LGB in various woody materials have been of interest to many workers on the biology of the LGB because of the idea that these materials might be potential alternative hosts and thus sources of infestation. A considerable amount of work on LGB in woody materials has been performed and has shown that while some wood species only allow for survival of adults, others actually support reproduction.

Earlier works on the survival and reproduction of LGB in wood were undertaken in Mexico, Honduras, Togo and Benin. Recent studies using pheromone traps show that the larger grain borer is widespread in natural vegetation in Tsavo National Park, Kenya. Laboratory and field experiments to determine alternative hosts of LGB have shown it capable of feeding and breeding in tree species in the families Leguminoceae, Sterculiaceae, Euphorbiaceae, Burseraceae and Anacardiaceae (Nang'ayo *et al.*, 1993; Nang'ayo and Hill, 1994) These works have been summarised in Table 13 below.

Table 13: Survival and reproduction of LGB in woods.

Country	Wood species	Reference
<u>Woods supporting survival</u>		
Mexico	*Schinus molle* *Prosopis* spp	Rios Ibarra, 1991
Honduras	*Spondias purpurea*	Wright and Novillo[1], unpublished observation
Mexico	*Bursera fagaroides* *Spondias purpurea*	Ramirez *et al.*, 1991
<u>Woods supporting reproduction</u>		
Togo & Benin	*Manihot esculenta* *Poincinia regia*	Helbig *et al.*, 1990
Benin	*Tectona grandis* *Fagara xanthoxyloides* *Azadirachta indica* *Mallotus oppositifolius*	Kossou, 1992
Kenya	*Commiphora campestri* *Commiphora riparia* *Commiphora* spp. *Euphorbia tirucalli* *Delonix regia* *Cajanus cajan* *Acacia mellifera* *Cassia abbreviata* *Cassia siamea* *Prosopis* spp. *Leucaena* spp. *Calliandra* spp. *Lannea* spp. *Sterculia africana*	Nang'ayo *et al.*, 1993.

1= Cited in: Markham *et al.*, 1991

The breeding success of LGB is dependent upon the wood's age, and its moisture content (Nang'ayo *et al.*, 1993). LGB breeding in wood under different constant humidity regimes confirms that breeding occurs within a relatively narrow range of wood moisture content, with an optimal range at around 10-12% (Nang'ayo and Hill, 1994) Nang'ayo and Hill (1994) also observed that the proportion of immatures and adults in LGB populations of susceptible wood species is quite different, suggesting that LGB has different growth characteristics on different host plants.

2.4. Maize varietal tolerance to postharvest insects.

2.4.1 Variety and seed selection

Farmers in the Volta Region tend to use local maize varieties for storage and planting . A major problem with the adoption of high-yielding maize varieties has been the high level of damage due to *S. zeamais* sustained by high-yielding varieties in storage (Kossou *et al.*, 1993a) Some improved varieties grown in Africa, for example, SR52 selected in Zimbabwe, also suffer severe damage from larger grain borer (Keil, 1988).

In some Southern African countries, where marketing boards until recently offered good prices for maize, farmers are growing both the local and high-yielding varieties. The high-yielding varieties are grown for immediate sale to the marketing boards while the traditional, low-yielding but storage durable varieties are grown for home consumption (Adams and Harman, 1977; Hindmarsh and Macdonald, 1980; Giga and Katerere, 1986; cited in Coulter and Compton, 1991).

Improving resistance of maize to storage insects, especially LGB, could be of immense value in rural storage system and it will serve as an additional weapon in pest control strategies. Farmers already take storage pest resistance into account when selecting their planting materials. In Mexico and Central America, farmers are happy with the local "criollo" varieties, which they feel are somehow resistant to LGB (In: Markham *et al.*, 1991) This may possibly have influenced the lower damage levels experienced in the region. In the Ashanti Region of Ghana, Nyanteng (1972) observed that a local maize variety (called 'Mampong maize') is preferred to other maize types because the grains have a hard testa which most storage insect pests find difficult to penetrate. Surveys on farmer practices in the Moroceli and Jamastran provinces of Honduras have similarly shown that the criteria for cob selection include: tightness of husk, coverage, freedom from damage, cob size and weight of cob (Espinal, *pers. comm.*)

In the Volta Region of Ghana there are two basic strategies for seed selection. Some farmers select cobs (with good husk cover) at harvest and store this

Similarly, Appiah (1980) who looked at the susceptibility to attack by rice weevils (*Sitophilus oryzae*) of four maize varieties, 'Composite 4', 'La Posta', 'Golden Crystal' and a local, in a laboratory experiment reported that La Posta was the most resistant variety in terms of percentage of damaged kernels, viability of grains, least population increase of weevils, grain weight loss, fat acidity production and moisture after a 12-week infestation period.

In maize, the value of a complete, well fitting set of husks for reducing pre-shelling infestation by *Sitophilus* spp. has been recognised by post-harvest scientists for many years (see e.g. Giles and Ashman, 1971; Dobie, 1977) However, the detailed effects of husk cover have only been examined recently (Kossou *et al.*, 1993a)

The effect of husk cover has also been examined in a lot of experiments. In one of these trials, the susceptibility of cob maize to maize weevil, *S. zeamais*, in field and traditional storage systems between two international improved maize varieties introduced into the Republic of Benin, one partially improved local variety and a local variety obtained from farmers were looked at. Results showed that the international improved varieties had significantly higher yield but had significantly poorer husk cover. Due to their superior husk cover, local varieties were significantly more resistant to weevils when infested in the traditional,