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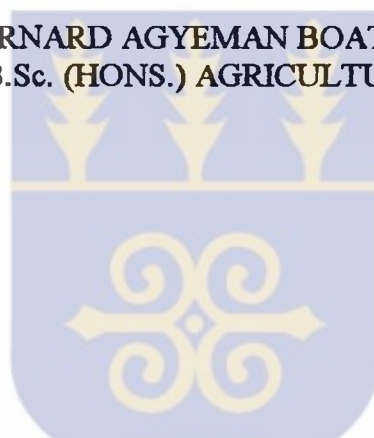
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**EFFECTS OF MAIZE VARIETY AND SEASON ON POPULATION DYNAMICS OF
THE LARGER GRAIN BORER, *PROSTEPHANUS TRUNCATUS* (HORN) (COL.:
BOSTRICHIDAE) AND THE MAIZE WEEVIL, *SITOPHILUS ZEAMAI*
MOTS.(COL.: CURCULIONIDAE) AND GRAIN LOSSES IN THE TRADITIONAL
'EWE' STORAGE BARN IN GHANA**

BY

**BERNARD AGYEMAN BOATENG
B.Sc. (HONS.) AGRICULTURE**



**A THESIS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON, IN PARTIAL
FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF
PHILOSOPHY (M. PHIL.) IN CROP SCIENCE (ENTOMOLOGY)**

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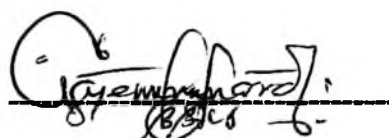


ABSTRACT

The effects of three maize varieties and two storage seasons on the population dynamics of *Prostephanus truncatus* and *Sitophilus zeamais* were observed in the traditional 'Ewe' barn on the field. Two local varieties, Dzolokpuita and Abutia and an improved variety, Abelechi, were stored with the husk on, during the long season, and Abutia only during the short season, of the 1994/1995 storage period. Destructive sampling techniques were applied to obtain data at monthly intervals for eight months. Maize variety showed significance ($P < 0.05$) on *P. truncatus* density in the first four months of the long season but was barely so during the late storage phase. However, it did not influence the population dynamics of *S. zeamais*. Trend analysis showed significant increase in densities of *P. truncatus* over time especially during the late phase of the long season with a maximum densities of 131.1, 43.7, and 16.9 adults per kg. grain for Abutia, Abelechi and Dzolokpuita, respectively. *S. zeamais* however peaked at between 280 and 350 adults per kg grain on all varieties after only three months of storage, then stabilized at about 250 insects per kg. grain for the rest of the season. Maize variety also influenced weight loss with Dzolokpuita faring better. Good husk cover and relatively harder grains of Dzolokpuita may explain the lower *P. truncatus* density and weight loss recorded for this variety. Season did not to affect *P. truncatus* density but it influenced *S. zeamais* dynamics, and weight loss levels. The relative economic value loss also increased with time with value loss of 21.1%, 21.5%. and 19.4% for Abutia, Abelechi and Dzolokpuita, respectively after eight months of storage.

DECLARATION

I do hereby declare that, except for references to work of other researchers which have been duly cited, this thesis consists entirely of my original research work conducted at the Ministry of Food and Agriculture Research Station, Kpeve, Volta Region and that no part of it has been presented for another degree elsewhere.

**BERNARD AGYEMAN BOATENG****(Student)****Prof. J. N. AYERTEY****(Principal Supervisor)****Dr. W. G. MEIKLE****(Co-Supervisor, IITA-Benin)**

DEDICATION

This thesis is dedicated to my parents, Mr. and Mrs. Onwona-Agyeman, my brother, Tony, and my sisters Naana, Mother, Mary and Nana Yaa for their love and prayers.

ACKNOWLEDGEMENTS

Thanks and praise to Almighty God for giving me life to complete this work. I am very much indebted to the following personalities with whose invaluable help and diverse contributions this work has been successfully completed.

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TABLE OF CONTENTS

ABSTRACT.....	i
DECLARATION.....	ii
DEDICATION.....	iii
ACKNOWLEDGEMENTS.....	iv
TABLE OF CONTENT.....	vi
LIST OF TABLES.....	ix
LIST OF FIGURES.....	xi
LIST OF PLATES.....	xii
1.0 GENERAL INTRODUCTION.....	1
1.1 Maize: Production And Importance In Ghana.....	1
1.2 Farm Level Maize Storage And Problems.....	2
1.3 Need For Improved Rural Storage.....	3
1.4 Objectives.....	6
2.0 LITERATURE REVIEW.....	7
2.1 The Larger Grain Borer, <i>Prostephanus truncatus</i> (Horn).....	7
2.1.1 Taxonomy and Description.....	7
2.1.2 Geographical Distribution.....	7
2.1.3 <i>Prostephanus truncatus</i> in Ghana.....	8
2.1.4 Hosts.....	9
2.1.5 Host Selection.....	10
2.1.6 Life History of <i>P. truncatus</i>	11
2.1.7. Pest Status and Losses.....	13
2.1.8. Population dynamics in rural stores.....	14
2.2 The maize weevil, <i>Sitophilus zeamais</i>	16
2.2.1 Taxonomy and Description.....	16
2.2.2 Distribution and pest status.....	17
2.2.3 Bionomics.....	18
2.3. The Predator, <i>Teretriosa nigrescens</i> Lewis (Coleoptera: Histeridae).....	19
2.3.1 Taxonomy and Morphology.....	19
2.3.2. Biology And Ecology.....	20
2.3.3 Classical biological control of <i>P. truncatus</i> using <i>T. nigrescens</i>	21
2.4.1 Rapid Loss Assessment Method.....	23
2.4.2 Visual Scales.....	24
2.4.3 Analysis and interpretation of results from visual scale data.....	25
2.4.4 Visual scales and economic value loss of stored commodity.....	27

3.0 MATERIALS AND METHODS.....	28
3.1 Experimental stores.....	28
3.2 Experimental design: Maize varieties	30
3.3 Sampling for baseline data	30
3.4 Sampling Procedure	31
3.5 Sampling for weight loss.....	32
3.6 Rapid loss assessment.....	33
3.7 Rearing out.....	34
3.8 Study site.....	34
3.9 Analyses of results.....	34
4.0. DESCRIPTION OF EXPERIMENTS	36
4.1 Effect of maize variety on population dynamics of <i>P. truncatus</i> and <i>S. zeamais</i>	36
4.1.1 Introduction	36
4.1.2 Materials and Methods.	36
4.1.3 Results and Discussion.....	37
4.1.3.1. Insect species recorded on the stored maize.....	37
4.1.3.2 Population dynamics of <i>P. truncatus</i> and <i>S. zeamais</i> in the long season.....	40
4.1.3.3 Spatial Distribution Within Stores.....	49
4.1.3.4. Distribution of oviposition sites of <i>P. truncatus</i> and <i>S. zeamais</i> on maize cobs.	51
4.2 Weight losses among different varieties in the long season	54
4.2.1 Introduction:	54
4.2.2 Materials And Methods	55
4.2.3 Results And Discussion.....	55
4.2.3.1 Weight Loss.....	55
4.2.3.2 Relationship Between Pests And Losses.....	58
4.2.3.3 Association Of <i>P. Truncatus</i> And <i>S. Zeamais</i> With Some Secondary Pests.	60
4.2.3.4 Dynamics of <i>T. nigrescens</i> population.....	63
4.3 Comparison of pest dynamics and weight loss between long and short seasons	68
4.3.1 Introduction	68
4.3.2. Materials And Methods.	68
4.3.3 Results And Discussion.....	69
4.3.3.1 Insect Pests Of The Short Season.....	69
4.3.3.2 Population densities of <i>P. truncatus</i> and <i>S. zeamais</i> in the short season.	70
4.3.3.3 Weight losses in the short season.	73
4.4 Economic and Weight loss measurement using the Visual scale of damage	74
4.4.1 Introduction	74
4.4.2 Materials And Methods	75

4.4.2.1 Weight and Economic Loss Assessment.....	75
4.4.3 Results And Discussion.....	77
4.4.3.1 Structure of cob damage.....	77
4.4.3.2 Dry weight loss by visual scales.....	80
4.4.3.3 Economic Value Loss.....	84
5.0 SUMMARY AND CONCLUSIONS.....	88
6.0 LITERATURE CITED	91
APPENDIX.....	106

List of Tables

Table 1: Insect species found in the maize stores.....	39
Table 2: Densities of <i>Prostephanus truncatus</i> adults recorded on cobs of three maize varieties stored during the long season (October 1994 to May 1995).....	42
Table 3: Densities of <i>Sitophilus zeamais</i> adults recorded on cobs of three maize varieties stored during the long season (October 1994 to May 1995).....	45
Table 4: Cob characteristics of three maize varieties used in experiment.....	47
Table 5: Grain hardness of the three maize varieties used in the experiment.....	47
Table 6: Densities of <i>Prostephanus truncatus</i> adults recorded in the sections of a barn compartment.....	50
Table 7 Densities of <i>Sitophilus zeamais</i> adults recorded in the sections of a barn compartment.....	51
Table 8: Percentage weight loss suffered by the three maize varieties stored during the long season (October 1994 to May 1995).....	56
Table 9: Correlation coefficients of percentage weight loss with <i>Prostephanus truncatus</i> and <i>Sitophilus zeamais</i> density.....	59
Table 10: Correlation coefficients of <i>Prostephanus truncatus</i> with some secondary insect pests.....	61
Table 11: Correlation coefficients of <i>Sitophilus zeamais</i> with some secondary insect pests.....	63
Table 12: Correlation coefficients of <i>T. nigrescens</i> with <i>P. truncatus</i> and loss.....	65

Table 13: Changes in the ratio of <i>T. nigrescens</i> (Tn) to <i>P. truncatus</i> adults in the stores in the long and short seasons.....	65
Table 14: Density of <i>P. truncatus</i>. recorded on <i>Abutia</i> variety stored during the long and short seasons.....	71
Table 15: Density of <i>S. zeamais</i>. recorded on <i>Abutia</i> variety stored during the long and short seasons.....	71
Table 16: Percentage weight loss suffered by three varieties stored in barns during the long and short seasons.....	74
Table 17: Damage development of maize cobs of <i>Abutia</i> variety stored during the long season.....	78
Table 18: Damage development of maize cobs of <i>Abelechi</i> variety stored during the long season.....	78
Table 19 Damage development of maize cobs of <i>Dzoloakpuita</i> variety stored during the long season.....	79
Table 20: Percentage weight loss using the visual scale for the three maize varieties stored during the long season.....	83
Table 21 Percentage relative economic value loss using the visual scale for the three maize varieties stored during the long season.....	86

List of Figures

Figure 1: Diagram of the experimental store showing compartments.....	31
Figure 2: Transverse section of a barn compartment showing the vertical sections.....	33
Figure 3: Densities of <i>Prostephanus truncatus</i> adults recorded on three maize varieties stored during the long and short seasons.....	41
Figure 4 Densities of <i>Sitophilus zeamais</i> adults recorded on three maize varieties stored during the long and short seasons.....	44
Figure 5: Percentage moisture content of the three maize varieties stored during the long short seasons.....	46
Figure 6: Ovipositional distribution of <i>Sitophilus zeamais</i> and <i>Prostephanus truncatus</i> on maize cobs.....	53
Figure 7: Percentage weight loss suffered by three maize varieties stored during the long and short seasons.....	57
Figure 8: Densities of <i>Teretriosoma nigrescens</i> adults collected from the three maize varieties stored during the long and short seasons.....	67
Figure 9: Percentage weight loss (by visual scale of damages) for the three maize varieties stored during the long season.....	82
Figure 10: Percentage relative economic value loss using the visual scale for the three maize varieties stored during the long season.....	85

List of Plates

Plate 1: Visual Scale showing damage classes of maize cobs.....	76
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1.0 GENERAL INTRODUCTION

1.1 Maize: Production and importance in Ghana

Maize (*Zea mays*) is one of the most important food crops in Ghana. It is grown in all the agroecological zones of the country, although the intensity of cultivation and production systems differ in these ecological zones. Between 1986 and 1989, about 49% or 620,000 ha. of land area allocated to cereals was planted with maize (CIMMYT, 1990). Maize grows best on well-drained loamy soils, and is also grown in low lying areas and valley bottoms as a way of getting early crop outside the main growing seasons (NARP, 1993). However, the major maize belt of Ghana is the forest-savanna transition zone, which largely comprises the Ashanti, Brong-Ahafo, and parts of Eastern and Volta regions. Here, maize features as a major food crop with respect to production and monocropping of the crop accounts for 60% of the land area cropped to maize, with mixed cropping providing the remaining 40% of maize area (GGDP, 1991).

Depending on agroecological location, there may be one or two cropping seasons of maize in Ghana. Although, rainfall can be erratic, especially with regard to onset, duration and distribution, two rainfed crops of maize a year are successfully produced in most agroecological regions of the southern half of the country, where rainfall is bimodal. There are two rainy seasons in the important production areas of the forest belt and the forest-savanna transition zone. These are the long (major) and the short (minor) seasons. Rainfall in the long season begins in March/April and ends in July/August while that of the short season normally begins in September and ends in October/November. With supplemental irrigation, three crops per year are easily obtainable (NARP, 1993) although this is scarcely done. The dry spell in August allows for harvesting of the long season crop and land preparation for the minor season. In the Northern parts of Ghana covering

the Guinea savanna areas, the unimodal rainfall pattern spanning, over five months from May to September, provides for only one crop.

In some years, rainfall, or more importantly the lack of it, in concert with incidence of Lepidopteran stem and cob borers, reduce the success rate of the short season crop. In spite of these drawbacks, maize production continues to grow nation-wide. The average annual yield increased from 141,000 metric tonnes in 1983 to 533,000 metric tonnes in 1987. It further increased to 961,000 metric tonnes in 1993 (PPMED, 1993) and is currently estimated to be 1,000,000 tonnes.

Maize constitutes an important part of the diet of rural and urban Ghanaians and many traditional dishes use of maize have been compiled by MOA/WFED (1990). To the urban dweller it is a politically sensitive crop and a popular food prepared from it, 'Kenkey' was once brought to Parliament where the size of a ball was used as a measure of the state of the economy (NARP, 1993). It is an important source of protein in Ghana, ranking only after fish and legumes in terms of annual protein production (Twumasi-Afriyie *et al.*, 1992). The importance of maize during the lean season is considerable since it stores longer than root crops.

1.2 Farm level maize storage and problems

Maize production is largely done by small-scale farmers whose farm sizes are usually less than five hectares (CIMMYT, 1990). Large scale production of the crop is done mainly in the maize belt of Ejura-Techiman-Wenchi-Odumasi area in the forest-savanna transition zone. The annual yield of maize is usually beyond the immediate needs of the small scale farmer. This, in addition to other factors discussed by Nyanteng and van

Apeldoorn (1971) calls for the storage of the surplus. At farm level maize is stored in cribs, barns, mud granaries, baskets, platforms, mudpots or gourds mostly as unshelled maize; husked (undehusked) or dehusked. Rawnsley (1969) and Nyanteng (1972) have reviewed the structures used for storage at the farm level. In the Volta Region, where the work was conducted, the 'Ewe' barn is the most predominantly used store type, with about 90% of all stores being variations of this type (Addo, pers. com.). Proper storage protects the produce from damage by storage pests such as insects, mites, rodents and fungi.

Insects are undoubtedly the most important pests of stored maize in Africa. Hall (1970) reported weight losses of 20% in stored maize due to the maize weevil *Sitophilus zeamais* Motschulsky in Ghana, and 50% in Uganda due to *Tribolium castaneum* (Herbst). De Lima (1979) also reported 4-5% weight loss in stored maize in Kenya due to *Sitotroga cerealella*. However, with the outbreak of the larger grain borer (LGB), *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) on the African continent, weight loss figures have risen considerably. When *P. truncatus* becomes established in stores, it has enormous destructive potential which often surpasses that of *S. zeamais* and *S. cerealella* (Hoppe, 1986; Novillo, 1991). In Ghana, the pest status of *P. truncatus* has greatly increased, becoming most severe in the Volta Region, which shares a common border with Togo where the pest was first reported in West Africa (Krall, 1984).

1.3 Need for improved rural storage

Previously, traditional maize varieties, usually stored on-farm with husks intact, often suffered only moderate losses from the maize weevil, *Sitophilus zeamais* (Dobie, 1977; McFarlane, 1988). Surveys of traditional stores carried out in the late 1970s and early 1980s in eastern and southern Africa revealed average weight losses ranging from 2 to 6%

(Adams, 1977; De Lima, 1979; Golob, 1981a & b). Most improved varieties have however been reported to be more susceptible to pests across Africa; Benin (Anon, 1989), Cameroun (Almy and Asanga, 1988), Ghana (Badu-Apraku *et al.*, 1992), Kenya (Giles and Ashman, 1971). Indeed, this apparently high susceptibility of traditionally-stored improved varieties to *S. zeamais* attack has been a major constraint to the adoption of these varieties in traditional maize-growing regions of West Africa (Kossou *et al.*, 1993). With the accidental introduction of the larger grain borer, which attacks stores of small scale farmers in the rural areas, the food security of these farmers, which is already precarious, is further threatened.

Efforts to improve on-farm storage techniques have had varying degrees of success. Insecticide-based techniques for protecting maize in small traditional granaries are arguably the most commonly used control method. This has been further intensified following *P. truncatus* outbreak on the African continent. Chemical control methods based on the direct application on cobs of the binary insecticide dust, consisting of an organophosphorus and a pyrethroid (usually pirimiphos-methyl and permethrin) (Golob, 1988), or (pirimiphos-methyl and deltamethrin) (Biliwa, 1988) have been found to control both *P. truncatus* and other storage insects in Tanzania and Togo, respectively. Although these techniques have been used with some success in some parts of East Africa (Markham *et al.*, 1994a) they have not always been acceptable to farmers. The reasons are many and varied. The high humid conditions in farmers stores in the tropics cause the active ingredients of most insecticides to break down (Markham, 1981). Insect pests often become resistant to synthetic pyrethroids, and Golob *et al.*, (1990) have already observed resistance in laboratory populations of *P. truncatus*. Also, problems with cost and availability of appropriate chemicals cause farmers to use unsuitable pesticides, and with

their poor insecticide-use culture (where pesticides are applied unevenly or at inappropriate doses) accelerate the development of resistance by the insect pests.

There is, therefore, the need for an improved small-scale, on-farm storage system based on methods that can be well integrated with traditional methods with a reduced dependence on chemical control methods (Markham *et al.*, 1994c). The use of resistant crop varieties and biological control measures present cheaper and ecologically-sustainable alternatives for managing losses caused by storage insects. But the effectiveness of these control alternatives depends greatly on the knowledge of the pests' ecology in the storage environment as well as the inter-relationships with other pests and natural enemies.

The most important pests of stored maize in Ghana are *S. zeamais* and *P. truncatus*. Recently, a histerid predator, *Teretriosoma nigrescens* Lewis (Coleoptera: Histeridae) has been released in an effort to control *P. truncatus*. There are, however, indications that the prospect for complete classical biological control of *P. truncatus* may not appear very bright (Markham *et al.*, 1994a). There is, therefore, the need to examine how other processes, such as susceptibility of the maize substrate, which is one of the key factors that could influence the relationship between the predator and prey, can augment biological control. However, there is virtually no information on how the differential susceptibility of maize varieties in the country influence the population changes and distribution of these major pests in rural stores. Also very little is known about how results of laboratory screening tests for resistance translate in pest population dynamics and losses in the field.

1.4 Objectives

The general objectives of these field studies were:

1. To understand the effects of relative varietal susceptibility of maize on population dynamics of *Prostephanus truncatus* and *Sitophilus zeamais* in maize stores and on losses.
2. To compare population densities of the pests and losses incurred over the long and short seasons.
3. To understand how the economic value of stored maize changes during storage

Specific questions addressed include the following;

1. What effect does maize variety have on insect densities and on grain losses, and whether this effect changes over time?
2. What important variables explain the loss rate?
3. What is the distribution of *P. truncatus* and *S. zeamais* in the entire store, and the ovipositional distribution on cobs?
4. How is *T. nigrescens* distributed on maize and is it associated with lower *P. truncatus* densities?
5. How are important secondary insects associated with primary pests?
6. What are the differences in insect densities and losses between long and short seasons?
7. How does the economic value of the maize change over time, and is the change different for different varieties?

2.0 LITERATURE REVIEW

2.1 The Larger Grain Borer, *Prostephanus truncatus* (Horn)

2.1.1 Taxonomy and description.

Prostephanus truncatus was first described by Horn (1878) as *Dinoderus truncatus* Horn. The genus *Prostephanus* was erected by Lesne (1879). There are other species of *Prostephanus* but *P. truncatus* is the only one known to be associated with stored products (Hodges, 1986). Horn (1878), Lesne (1898) and Fisher (1950) provided an elaborate key for identification of *P. truncatus* adults. Shorter identification keys are provided by Kingsolver (1971) and Hodges (1982). Spilman (1984) gives detailed descriptions of the larvae and pupae but unfortunately there are no identification keys for these stages. The greatest distance between the ventrally sclerotised lateral structures of the frontoclypeus has been used by Subramanyam *et al.* (1985) for instar recognition. However, Haines (1981) gives a description of all the developmental stages. The clypeal tubercles (Shires and McCarthy, 1976) may be used to sex the adults, while for pupae it can be determined according to the size and shape of the genital papillae (Bell and Watters, 1982).

2.1.2 Geographical distribution

The distribution of *P. truncatus* is considered very phenomenal, compared to some major storage pests, in that it is very discrete and delimited (Markham *et al.*, 1991). Although, the insect was originally described from specimens 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). The Larger grain borer outbreak in Africa apparently resulted from separate introductions; first in Tanzania (Dustan and Magazini, 1981) then Togo (Krall, 1984)

and again into Guinea (Kalivogui and Mück, 1991). From Tanzania the insect has spread to the nearby countries of Kenya (Kega and Warui, 1983), Burundi (Gilman, 1984), Malawi and Rwanda (GTZ, unpublished data cited by Hodges, 1994). The Togo introduction has apparently spread to Benin (Krall and Favi, 1984), Ghana (Dick *et al.*, 1991) and Nigeria (Pike *et al.*, 1992).

2.1.3 *Prostephanus truncatus* in Ghana

As a consequence of an earlier introduction of the Larger Grain Borer into Togo in 1984, a survey was carried out in 1986 in Ghana on the Ghana-Togo border to determine the presence of the beetle in the country (Ofosu, pers. com.), but the results proved negative. It was not until 1989 when a second survey revealed that LGB was present in villages in the Volta region over a 150km stretch of the border with Togo; from Kpetoe in the south to Ameyoe in the north (Dick *et al.*, 1989). Another survey in April 1991 revealed considerably higher population build-up at places where the insect had been found in the earlier survey (Ayertey and Brempong-Yeboah, 1991). Two years later, a Ghana LGB Project survey showed that LGB was present in all districts of the Volta Region (GLGBP, 1993). A national monitoring programme, with 101 permanent trapping sites, has revealed the incidence of the insect in every region of the country (Robin Boxall pers. com.). The most seriously affected parts 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 Eastern regions bordering the Volta Region (Addo, 1994).

2.1.4 Hosts

Although *P. truncatus* has been reported to attack a wide range of substances (Mushi, 1984) not all can be considered as satisfactory hosts for the beetle. Intensive research efforts in recent years however continue to reveal the expanding host range of the beetle. *P. truncatus* has been known to infest both stored maize (Giles and Leon, 1975; Hodges *et al.*, 1983a) and maize in the field before harvest (Giles, 1975), although there is much variation in the extent to which this occurs (Henckes, 1992; Wright *et al.*, 1993; Tigar *et al.*, 1994). It also infests dried cassava (*Manihot esculenta* Crantz) as well (Nyakunga, 1982; Hodges *et al.*, 1985). *P. truncatus* develops and reproduces on both of these crops. Reproduction was also recorded on soft wheat and chickpeas (Howard, 1983). More recently, previously par-boiled dried tubers of white yam (*Discorea rotundata* Poir) and sweet potato (*Ipomoea batatas* (L.) Poir) have been shown in the laboratory to support reproduction of the insect (Li, 1988; Jalloh, 1989).

With the advent of pheromone-baited flight-traps to monitor the pest, it has been observed that there are large populations of *P. truncatus* in the natural environment away from maize fields and stores (Rees *et al.*, 1990; Nang'ayo *et al.*, 1993). Laboratory investigations in Togo (Helbig *et al.*, 1990) and Kenya (Nang'ayo *et al.*, 1993) have shown that the pest is capable of developing and reproduction on dried twigs of a range of tree species. In Kenya, this includes about 15 tree species from the families Leguminosae, Burseraceae and Anacardiaceae. The woody stems of cassava and Flamboyant (*Delonix regia*) have also been shown to support the reproduction of Larger grain borer (Detmers *et al.*, 1990), a capacity that the authors attribute to the high starch content of these materials.

Very little information is available so far on the natural origins of the Larger grain borer. Maize cannot, as pointed out by Markham *et al.* (1991), be the natural host of the insect since the plant itself does not exist in nature and seems to have been selected by man only within the last 5000 years. Chittenden (1911) concluded that roots and tubers were the natural hosts of *P. truncatus*, after finding that various root crops imported into the United States from Mexico and Guatemala were infested with the pest (Riley, 1894). The problem is to clarify the field conditions under which naturally occurring root and tubers would become sufficiently dry to provide a satisfactory substrate for the development of *P. truncatus* (Markham *et al.*, 1991). The laboratory demonstration by Li (1988) of development of the pest in acorns (from English oak, but not on those from scarlet oak) prompted Markham *et al.* (1991) to speculate that the great diversity of oak species in the area of origin of the insect might represent a natural host for the Larger grain borer.

2.1.5 Host selection

Very little is known about the host selection behaviour of *P. truncatus*. It has been postulated by Markham *et al.* (1994c) that initial infestation levels are determined by seasonal migration patterns and host finding behaviour of *P. truncatus*, in relation to local farming practices (such as timing of harvest, selection of cobs for storage, choice and management of the storage structure, among others). However, Hodges (1994) suggested that host selection, particularly in the case of maize and cassava, may occur largely by chance. This resulted from the observation that *P. truncatus* adults are attracted over short distances to maize grains (Detmers, 1990) and dried cassava (Wright *et al.* , 1993) but there is no long-range attraction to these stored products in the field (Tigar *et al.*, 1994; Wright *et al.*, 1993). Pike *et al.*, (1994) identified hexanoic

acid and nonanal as the major active component of maize and cassava volatiles, respectively.

It is thought that adult males, arriving at a suitable site make test burrows, which are normally 1-2 cm long (Hodges, 1986) in search of food. The beetles leave these burrows and try again elsewhere if no suitable food is found. However, once suitable food is located, the male secretes a pheromone to attract females and other males (Dendy *et al.*, 1989; Cork *et al.*, 1991) which also arrive to exploit both food and mates. Aggregation of both male and female *P. truncatus* may occur in this way (Hodges, 1994) leading subsequently to reproduction, pest damage and population increase. These activities depend, of course, on the biotic potential of the particular *P. truncatus* population in relation to local climate, maize variety, activities of natural enemies and competition with other storage pests.

2.1.6 Life History of *P. truncatus*

The developmental biology of *P. truncatus* has been studied, on maize (Shires, 1977, 1979, 1980; Bell and Watters, 1982; Howard, 1983) and on cassava (Nyakunga, 1982). There are a number of apparent discrepancies (reviewed in Hodges, 1986) among the various laboratory studies. This variation probably reflects differences in aspects of the experimental technique, such as form and consistency of food substrate presented (Dick, 1988). But Subramanyam and Hagstrum (1991) suggest a contribution could have come from the different strains used by these researchers.

The optimum conditions for development on maize are approximately 32°C and 70-80% relative humidity (r.h.). Under these conditions, Bell and Watters (1982) observed

that the life cycle was completed in 24-25 days on tightly packed ground maize or on whole grain. This contrasts sharply with Shires (1979, 1980) who observed a developmental period of 35.4 days on loosely packed maize flour. *P. truncatus* is relatively long-lived as an adult and does not lay eggs as rapidly or as haphazardly as shorter-lived stored product beetles. The eggs are laid within maize grains, in blind end tunnels created by the adults. Grain stability influences oviposition rate (Howard, 1983). Under optimum conditions, larvae hatch after 4.1 days and the mean larval period is 16.1 days (Bell and Watters, 1982). There are three larval instar stages (Bell and Watters, 1982; Subramanyam *et al.*, 1985). The mean pupal period for *P. truncatus* lasts 4.7 days. The mean development period on yellow 'American No. 3' maize and blocks of dried cassava at 27°C and 70% r.h were 39.2 days and 43.1 days respectively, suggesting that maize is more suitable for development of *P. truncatus* than cassava (Nyakunga, 1982).

Adult longevity is also variable, although differences observed were not statistically significant. Shires (1980) found that on maize flour at 32°C and 80% r.h, females generally outlived males; the mean life expectancies being 61.1 days and 44.7 days, respectively. However, the opposite was found to be the case when Howard (1983) maintained adults at 25°C and 70% r.h on maize flour and grain. The differences in female longevity observed may be correlated with differences in oviposition rates; females in Howard's studies having a much higher rate and hence perhaps shorter life span.

P. truncatus is tolerant to dry conditions. Maize with moisture contents in the range of 9-10.6% have been found to be heavily infested. This was demonstrated by Young *et*

al., (1962) and confirmed in laboratory studies by Shires (1979), Hodges and Meik (1984), and in the field by Giles and Leon (1975) and Hodges *et al.* (1983a).

2.1.7. Pest status and losses.

Larger Grain Borer is a pest with high damage potential. The insect infests cobs shortly before harvest and during storage, but appears to spread during the storage season. Hodges (1984) found in Tanzania that the pest could be found in 20% of stores, immediately after harvest and at the end of a 5-month storage period, 80% of the granaries were infested by *P. truncatus*. Also the timing of onset of attack may vary from year to year. Hodges (1986) noted that at one location in a particular year, the infestation may be extremely severe, but at the same place and time the following year, few if any, beetles may be found. The reasons for this seemingly sporadic pest incidence are not clearly understood, but might include weather influences, exhaustion of food resources the previous season or density-dependent mortality factors.

Weight losses after six months of storage of maize cobs have increased from 7.1% before the advent of *P. truncatus* to 30.2% afterwards, and up to 44.8% over 8 months of storage has been recorded in Togo (Pantenius, 1988). As the cobs affected were unfit for human consumption, Pantenius (1988) therefore concluded that real loss could be some 10% higher. In Tanzania, after being in store for 3-6 months, maize cobs showed weight losses of up to 34%, averaging 9% (Hodges *et al.*, 1983a). Comparison with earlier published data suggests a major increase in losses following the introduction of the Larger grain borer (Laborius *et al.*, 1989). Keil (1988) reported particularly severe losses also in Tanzania, averaging 17.9% after six months and 41.2% after 8 months of storage in maize cobs.

In the Neotropics, the pest status has been the subject of considerable debate. Giles (1977) reported the occurrence of weight losses of 40% after 24 weeks with heavy infestation of *P. truncatus* in Nicaragua. Also Hoppe (1986) has reported serious losses of over 30%, particularly associated with heavy *P. truncatus* infestation from Honduras. However, lower loss figures reported by Böye (1988) from Costa Rica; averaged 5% after six months of storage during the rainy season and 12% after six months of storage during the dry season. As Markham *et al.*(1991) rightly pointed out, the impression that losses are generally higher in Africa than in the Neotropics persists (Böye *et al.*, 1988; Laborius *et al.*, 1989; Laborius, 1990a), despite serious local losses that had been reported (see also Barnes *et al.*, 1959; Ramirez, 1959).

The most obvious cause of this loss is the conversion of the maize grain into flour by the boring adult beetles (Li, 1988). Until a large population of larvae is established, Hodges (1986) pointed out, feeding activity of the larvae would represent a secondary source of loss.

P. truncatus also causes extensive damage to dried cassava chips. In a trial in Tanzania, Hodges *et al.*, (1985) recorded losses of up to 70% in fermented and 50% in unfermented cassava after only 4 months of storage.

2.1.8. Population dynamics in rural stores.

The optimum developmental conditions of *P. truncatus* are similar to those of other storage pests. Thus the physical and biological constraints that affect the dynamics of these pest populations would similarly affect *P. truncatus*. However, with its comparatively limited geographical distribution and erratic incidence in both space and

time, it is not clearly certain which factor might determine its incidence. Until recently, data on the dynamics of *P. truncatus* with respect to different environments, storage practices and pest associations have been scanty. Most of these studies, as reviewed by Markham *et al.* (1991) were conducted in the Neotropics, but they nevertheless provide useful information which can help in providing a better understanding of the behaviour of this pest in West African stores.

Markham *et al.* (1991) noted that in almost all these studies, the maximum numbers of the three primary pests; *Sitophilus zeamais* Mots., *Sitotroga cerealella* (Olivier) and *P. truncatus* occur at different points in the storage cycle. Data on the interactions between these species in their natural storage environment are scarce. Results of a farm storage survey in Honduras indicated that 90% of the samples infested by *P. truncatus* were also infested by *S. zeamais*, although there was no relationship between the numbers of the two species present in individual samples (Hoppe, 1986). Studies in the laboratory have also provided some insight into competitive interactions between *P. truncatus* and *S. zeamais*. (Howard, 1983, Haubruge and Verstraeten, 1987).

In traditional stores, there are differing relationships between secondary pests and primary pests. The incidence of *Cathartus quadricollis* (Guérin) and *Carpophilus spp.* where present, appears to be independent of that of *P. truncatus*. The dynamics of *Gnatocerus maxillosus* (Fabricius) on the other hand correlates closely with *P. truncatus* abundance (Novillo, 1991 cited in Markham *et al.* 1991). A close association was also observed between the incidence of *Tribolium castaneum* (Herbst) and *P. truncatus* in Africa (Hodges *et al.*, 1983) but Novillo (1991, cited in Markham

et al., 1991) reported the apparent displacement of *T. castaneum* by *G. maxillosus* later in the season .

A small number of natural enemies have been found associated with *P. truncatus* in the Neotropics, the most important among them is the predator *Teretriusoma nigrescens* Lewis, a species not known to be present in Africa. *T. nigrescens* has since been introduced into East and West Africa. In African maize stores, a number of species of natural enemies are associated with the indigenous pests, but it is not clear at present whether any of the indigenous species of insect predators or parasitoids may have any effect on *P. truncatus* as a host.

Previous infestation of the wooden storage structure has been noted to influence the population dynamics of *P. truncatus* by hastening recolonization of the maize and early establishment of the beetle on the new grain placed in storage.

2.2 The maize weevil, *Sitophilus zeamais*

2.2.1 Taxonomy and description

The maize weevil, *Sitophilus zeamais* Motschulsky is a coleopteran stored grain pest (Family *Curculionidae*, subfamily *Calandrinae*). There are three species in this genus. The others are the rice weevil, *S. oryzae* (L.) and the granary weevil, *S. granarius* (L.); the taxonomy of this genus has been revised by Floyd and Newsom (1959).

In the tropics and subtropics, the important species are the *S. zeamais*, which is more common on maize, and *S. oryzae* , which is frequently associated with small grains. These two species are difficult to separate morphologically. Their body size ranges

from 2.4 to 4.5 mm but *S. zeamais* is invariably the bigger, whilst body colour varies from light brown to black. Both have four reddish patches on the elytra but those of *S. zeamais* are more clearly defined (Apert, 1987). They have an elongated characteristic rostrum with capitate, elbowed antennae. However, the species can be separated by examination of the internal genitalia (Halstead, 1964). The dorsal surface of the aedeagus of *S. zeamais* has two parallel grooves while that of *S. oryzae* is smooth and convex (Proctor, 1971). In the female *S. zeamais*, the prongs of the Y-shaped sclerite are pointed at the ends and the gap between is wider than their combined width. However, in *S. oryzae* these prongs are rounded and the gap between them is narrower than their combined width (Anon, 1989). Again, the arrangements and patterns made by the pronotal pits has been used in separating these two species (Fisher, 1987).

2.2.2 Distribution and pest status

Sitophilus zeamais is cosmopolitan in its distribution, and is found in the tropics and all warm climates. *S. zeamais* attacks all kinds of cereals but is predominantly found on maize (Longstaff, 1981; Ayertey and Akibu, 1982). *S. zeamais* is a strong flier and can readily fly from stocks of stored grain over distances of 400-800 meters (Chestnut, 1972) into growing maize. At harvest time all stages of development of this insect are present. Adults first emerge just before harvest and emergence continues for some time thereafter (Giles and Ashman, 1971).

Most studies have shown that among several factors affecting distribution and numbers of *S. zeamais* in the maize growing crop, the proximity and intensity of a source of infestation (usually infested cereals in store) and the degree of kernel coverage by the husk appear to be most important (Giles and Ashman, 1971; Dobie, 1977; Golob,

1984). Colonising weevils, which are predominantly males, aggregate on cobs (Markham, 1981; Dix and All, 1985). This behaviour is thought to be due to male-produced aggregation pheromones.

Before the accidental introduction of the Larger grain borer, the maize weevil used to be one of the most important primary pests of stored grain in Ghana, causing estimated weight losses of 7-20% (Anon, 1978; Hall, 1970) in stored maize, and in some cases up to 35% after 6 months of storage (Wheatly, 1973 cited in Yoshida, 1983). Generally, most damage and weight loss figures due to *S. zeamais* reported in local maize stores have been low. Schulten (1975) for instance, reported weight losses of 1-2% and 10% in local and improved varieties respectively. In some cases the introduction of higher yielding maize varieties has exacerbated storage pest problems, especially in the rural areas, as these improved varieties store poorly in rural granaries compared to the traditional varieties. Similar trends were reported from studies in other African countries (see Kossou *et al.*, 1993). It is important to note that the extent of damage and weight loss recorded is often influenced by time of storage as well as form of storage.

2.2.3 Bionomics

Aspects of the basic developmental biology of the maize weevil have been carried out on shelled kernels by Schoonhoven *et al.*, (1974), Tipping (1986) and Urrelo and Wright (1989), and more recently on unshelled maize by Kossou *et al.* (1992, 1993) and Vowotor *et al.* (1994, 1995a).

In a study of Walgenback and Burkholder (1987) it was observed that in *S. zeamais* populations, several matings may take place, with copulation lasting for about 4.8 hours

on the average. Eggs are laid throughout the adult life of the insect. The eggs are laid individually into small cavities chewed into the surface of the grain by the female *S. zeamais* and covered with a waxy secretion which when hardened is referred to as 'egg plug'. At all moisture contents above 10% and between 20 - 32°C at 70% r.h (Anon 1984; Okelana and Osuji, 1985) oviposition rates are at their maximum. Optimum conditions for development are 25 - 27°C and 70% r.h. (Dick, 1988). Under these optimal conditions, the apodous larva takes 6-7 days to hatch and there are four larval instars. The larva chews through the grain kernel, leaving a characteristic tunnel and it is this chewing activity of the larva which causes weight loss of the stored maize (Urrelo and Wright, 1989; Shade *et al.*, 1990). The total length of the larval and pupal stages are 18-22 days and 6-7 days, respectively.

The newly developed adults chew their way out, leaving characteristic emergence holes. The total development period of *S. zeamais* under optimal conditions has been shown to vary from 31-37 days, depending on the variety of maize used as food as well as storage form (Urrelo and Wright, 1989; Dick, 1988; Vowotor *et al.*, 1995a). Shorter developmental periods have been reported in susceptible varieties (Dobie, 1974; Kossou *et al.*, 1993) and lower numbers of weevils have emerged from cobs than from shelled grains (Kossou *et al.*, 1992; Vowotor, 1992).

2.3. The predator, *Teretriosoma nigrescens* Lewis (Coleoptera: Histeridae)

2.3.1 Taxonomy and morphology

Teretriosoma nigrescens, first described by Lewis (1891), belongs to the family *Histeridae*, which has over 3700 species, but Hinton (1945) identified only 14 species as associated with stored products worldwide. However, until recently, evidence of the

presence of *T. nigrescens* was found only in Mexico and Central America (Haines, 1981; Böye, 1988; Rees *et al.*, 1990) in association with a pest of erratic importance, *P. truncatus*, on farm stored maize (Hoppe, 1986). It has now been introduced into Tanzania, Togo (Rees, 1991), Benin and Ghana as part of biocontrol efforts in Africa against *P. truncatus*.

T. nigrescens, like all other histerid beetles is about 2.3mm in size (Leliveldt, 1990) with unusually hard chitinous cuticle which is shiny black. The hard elytra do not completely cover the abdomen, leaving two abdominal segments uncovered. The antennae are jointed and thicken up toward the tip like a club. The tibia of the first pair of legs is toothed and is a feature used to define the species (Pöschko, 1994). External sexual dimorphism is not apparent in *T. nigrescens* so sex is determined after dissection.

2.3.2. Biology and ecology

Early investigations into the development cycle of *T. nigrescens* by Rees (1985) revealed that the developmental time from egg to adult to be 56 days at 26°C 70% r.h. while Leliveldt and Laborius (1990) observed complete development in an average of less than 50 days at 30°C and 70% r.h. However, Oussou *et al.*(1995) observed a significantly shorter overall development period of 23.5 days at 30°C and 70% r.h.

According to Rees (1985) the relatively large eggs (1.1 x 0.5 mm) laid singly amongst the commodity, hatch in about 7 days at 27°C. The compodeiform larvae, 2-3 mm long on eclosion, have flattened head bearing large sickle-shaped mandibles. The head and prothorax are heavily sclerotized. There are two larval instars lasting between

about 12 days (Oussou *et al.*, 1995) and 26 days (Leliveldt, 1990) all together at 30°C, 70% r.h. and 30°C, 75% r.h., respectively. Rees (1985) observed that the fully grown larva, 1.0-1.2 cm long, pupates within a chamber in presumably already damaged grain, fashioned with its mandibles. The pupation stage takes 11-18 days at 30°C (Leliveldt and Laborius, 1990; Oussou *et al.*, 1995). *T. nigrescens* is a long-lived insect. During long-term experiments, *T. nigrescens* imagines reached an age of over 20 months. They were still able to reproduce after 16.5 months (Pöschko, 1994).

T. nigrescens is a polyphagous predator with a distinct preference for *P. truncatus* as a host. Although it has shown the ability to reproduce on two species of *Dinoderus*, on *Sitophilus oryzae*, *S. zeamais*, *Rhizopertha dominica*, and *Tribolium castaneum*, comparative experiments however confirmed that *P. truncatus* is the host preferred by this predator (Rees, 1987; 1991; Pöschko, 1994). Like other histerids, *T. nigrescens* hunts aggressively for its prey. Indeed, large numbers of adult *T. nigrescens* have been caught in maize fields in traps baited with *Prostephanus* pheromone, indicating that this predator is capable of locating *P. truncatus* over much greater distances (Böye, 1989). Pöschko (1994) found that *T. nigrescens* is not purely a predator but can also make use of plant food. However, Pöschko (1994) felt that the fear that it could be a pest on stored food itself was unfounded, since the losses to plant materials were low enough to be neglected.

2.3.3 Classical biological control of *P. truncatus* using *T. nigrescens*.

The conventional response to *P. truncatus* outbreak in Africa, according to Markham *et al.* (1994a) has gone through a familiar cycle; attempted eradication, containment by

statutory and other regulatory measures and testing of insecticide-based strategies for long-term management of the pest. A considerable success was reported by Golob (1988) integrating the application of a binary insecticide with modification of traditional storage practices in East Africa. But in West Africa, the humid conditions have apparently limited the adaptability of this strategy (Markham *et al.*, 1994b).

Classical biological control, especially with *T. nigrescens*, amongst the limited arthropod natural enemies of *P. truncatus*, has clearly been an appealing alternative. The body similarity in dimensions and in environmental requirements of *T. nigrescens* and *P. truncatus* suggest that the predator is well adapted to the habits and habitat of *P. truncatus*. Significantly, *T. nigrescens* can perceive the aggregation pheromone produced by *P. truncatus* and is therefore able to search specifically for its prey. Also since *P. truncatus* could be found in a wide range of habitats, the use of *T. nigrescens*, an insect that appears to be closely associated with its prey both within and outside the storage environment, may offer the only practical means to control it. *T. nigrescens* adults and larvae consume both eggs and larvae of *P. truncatus*. Laboratory studies on the predatory behaviour of *T. nigrescens* by Leliveldt and Laborius (1990) showed that one *T. nigrescens* adult consumes an average of 5.7 eggs or 4.9 larvae of the pest during a 24 hour period in the dark, although Rees (1985) found an average of 1.7 *P. truncatus* larvae per day. Results from further experiments on suppression of the growth of *P. truncatus* population are very promising. On maize in jars in the laboratory, Rees (1985) found that at a predator-prey ratio of 1:10, numbers of prey declined in all treatments containing predators after 8 weeks, whereas numbers of prey in controls increased by at least 10-fold.

Again in Costa Rica, Böye (1988) reported a decline of 87% of *P. truncatus* population on shelled maize by the predator after 110 days, compared to the control. In a corresponding test using maize cobs, the population of *P. truncatus* was reduced by 72%. By using *T. nigrescens*, the loss of shelled maize and cob maize could be reduced by 76% and 62% respectively whereas damage to the grain and the cobs caused by *P. truncatus* was reduced by 47% and 21% respectively (Böye, 1988).

Similar results were achieved in Togo according to Pöschko (1994, citing Helbig *et al*, 1992) in small stores of maize under semi-practical conditions within a storage period of 9 months. *T. nigrescens* reduced the number of *P. truncatus* adults by 46.5% and damage to the grain by about 42% compared to control. The mean population of *T. nigrescens* increased within the experimental period from 67 to 876 adults per 100 cobs.

The predator had been readily maintained in the laboratory, where it proved hardy and long-lived. It is felt that the voracious predation by both adults and larval *T. nigrescens* would outweigh any disadvantages from the predator's somewhat slow development time and low reproduction rate. Overall, the potential of *T. nigrescens* as a control agent looks sufficiently promising to justify field releases, which in the end provides one of the best complementary control strategies in a holistic approach to the control of *P. truncatus*. Field releases have, however, been made in Togo, Benin, and Ghana.

2.4.1 Rapid loss assessment method.

The primary aim of undertaking measurement of post harvest food losses is to establish the seriousness of the situation in order to determine whether intervention measures are

appropriate, and where feasible, to appreciate the impact of measures designed to reduce them, for example, new storage technologies, new varieties, etc. Several methods exist for the assessment of losses in stored grains (see Harris and Linblad, 1978; Boxall, 1986; Ratnadass and Fleurat-Lessard, 1991). However, most of these are unreliable, labour intensive and relatively slow, such that a number of researchers (Pantenius, 1988; FAO-PFL, 1990) have called for the development of simpler methods which are suitable for use in a rapid rural appraisal situation.

2.4.2 Visual scales

In response to the needs of a specific farm storage survey, a rapid loss assessment method using visual scales of loss was developed by the Ghana Ministry of Food and Agriculture / United Kingdom Overseas Development Agency Larger Grain Borer Project (MOFA/ODA LGBP). This method has been described in Compton *et al.* (1992). However, the method was originally developed for use in surveying farm stores in central Togo (Compton 1991; Stabrawa, 1992). The objectives of the survey were:

- a) to assess levels of post-harvest loss in maize cobs and dried cassava chips due to insect pests;
- b) to evaluate the relative importance of the larger grain borer or LGB (*Prostephanus truncatus*), a post - harvest pest new to central Togo; and
- c) to identify those aspects of production and storage practice which were associated with lower storage losses.

The use of visual scale of damage for rapid survey was appealing because of practical constraints encountered, namely; limited time and facilities, unavailability of data on the

condition of the commodities prior to storage, and the unreliability of many standard loss assessment measures such as the standard count - and-weigh and the converted percentage damage methods with particular reference to the nature of damage to maize cobs by *P. truncatus*. Four damage classes numbered from 1 (no damage) to 4 (severe damage) were defined from several fumigated cobs which had been previously attacked by a variety of insects (mainly stalkborer larvae, grain weevils and larger grain borer). Similarly five damage classes were distinguished for dried cassava chips mainly holed by *Dinoderus sp.* and *P. truncatus*. Representative cobs and cassava chips from each damage class, including the highest and lowest damage in each class, were photographed for use as a reference standard. The scales do not measure mould damage.

The scales were used in the Togo survey to score the damage in maize cobs and cassava chips sampled from farmers' stores. Full details of sampling methods and other data collection techniques can be found in Compton (1991) and Stabrawa (1992).

2.4.3 Analysis and interpretation of results from visual scale data.

Different ways of analyzing visual scale data have also been described by Compton *et al.*(1992). Basically, analysis can be performed on the original (ranked) data to investigate the relationship between damage levels and other survey variables be they qualitative factors (such as crop variety or store type) or quantitative factors (such as insect numbers or length of storage period). Moreover, by calibrating the scales the original data can be used to estimate weight loss (and other parameters) in stored produce.

Log linear modeling or cross-tabulation, in conjunction with chi-square tests of association can be used to investigate the effects on damage of qualitative factors (Compton *et al.*, 1992). However, the effects of quantitative variables can be studied by means of rank correlation or ordinal logistic regression (McCullagh, 1980). Multiple ordinal logistic regression was used in the Togo survey, for instance, to investigate the relationship between damage levels in maize and density of the two main pests; *P. truncatus* and *Sitophilus sp.* (Compton, 1991; Stabrawa 1992).

In using visual scales for weight loss estimation the scale should be calibrated against a widely used, reliable standard weight loss assessment measure to determine the mean weight loss for each damage class in the scale. Where practical constraints require modification of the loss assessment procedure it should be carried out. For instance, standard count - and - weigh technique for assessing grain losses caused by several insects species has been realized to underestimate weight loss of softer maize varieties stored on cobs when attacked by *P. truncatus*. Therefore, Compton *et al.* (1992) calibrated their visual scale against a modified version of the standard count-and-weigh method described in Compton *et al.* (1995) which incorporates destroyed and missing grains for accuracy of the mean weight loss values of each damage class. However, it is interesting to point out that Meikle (pers. com.) working with four maize varieties (two local and two improved) found no significant differences among varieties in the 'whole-kernel loss per cob' for the first six months. After eight months of storage, TZSR-W (an improved and the hardest variety, and the one with the highest *P. truncatus* density) had about 80% of the number of kernels on cobs from the first month, but Poza-Rica, also improved and softer, had 97%. Therefore, the standard count and weigh technique may not be that bad.

2.4.4 Visual scales and economic value loss of stored commodity.

Insofar as market value is related to the appearance of the commodity, it should be possible to devise and calibrate visual scales to give an estimate of economic value. In most areas farmers and traders use an informal visual grading system in the sale of shelled maize. Thus, in valuing stored maize, understanding how the farming family selects cobs and grains for sale and consumption is very important (Compton *et al.*, 1992).

The Ghana MOFA/UK ODA LGB Project is attempting to develop the visual scale to give a rapid estimate of economic value loss (Compton, pers. com.). The principle is the same as obtaining the weight loss. However, two measures of loss are calculated here, for each damage class. These are; (a) the average loss in volume of grain produced since grain is sold by volume in "standard" market bowls.

b) the average loss in price for the grade of grains produced by shelling cobs in each class. The value loss is then calculated as:

$$1 - ((1 - \% \text{ price loss}) \times (1 - \% \text{ volume loss})).$$

Several cob samples are needed for this calibration and it should be done over the entire season since price changes a lot in the course of a season, especially during the lean season.

3.0 MATERIALS AND METHODS

3.1 Experimental stores

The maize store structure used in this experiment was that of raised platform version of the traditional 'Ewe' barn (Fig. 1). In this structure a 2 m x 2 m split bamboo (*Bambusa vulgaris* Schrad ex Wendland) platform is supported by eight wooden legs of fan palm (*Borassus aethiopum* Mart.) on the exterior and one post in the center. This platform is 1m from the ground. Chicken wire is attached to each leg above the platform thus dividing a store into eight equal compartments. Below the platform rodent guard is fixed onto each of the legs, about 0.6 m from the ground.

On the platform, maize cobs were stacked with the husk-on in a circular fashion to mimic a typical traditional 'Ewe' barn. Large cobs were carefully stacked on the exterior with the remaining cobs filling the inside column into a compact cylinder. A store was about 1.8 m in diameter and approximately 0.8 m in height. As the chicken wire provided support, a compartment could be completely emptied and sampled without affecting the rest of the store. The advantage of this design is that it provides thorough sampling (in the exterior as well as the inner perimeter) of a traditional store. A thatch roof of available grass species, *Imperata cylindrica* (L.) Beauv., covered the maize against sun and rain. There were sixteen of these stores and each store was three metres apart within a block. Four extra stores were built to serve as replacement stores.

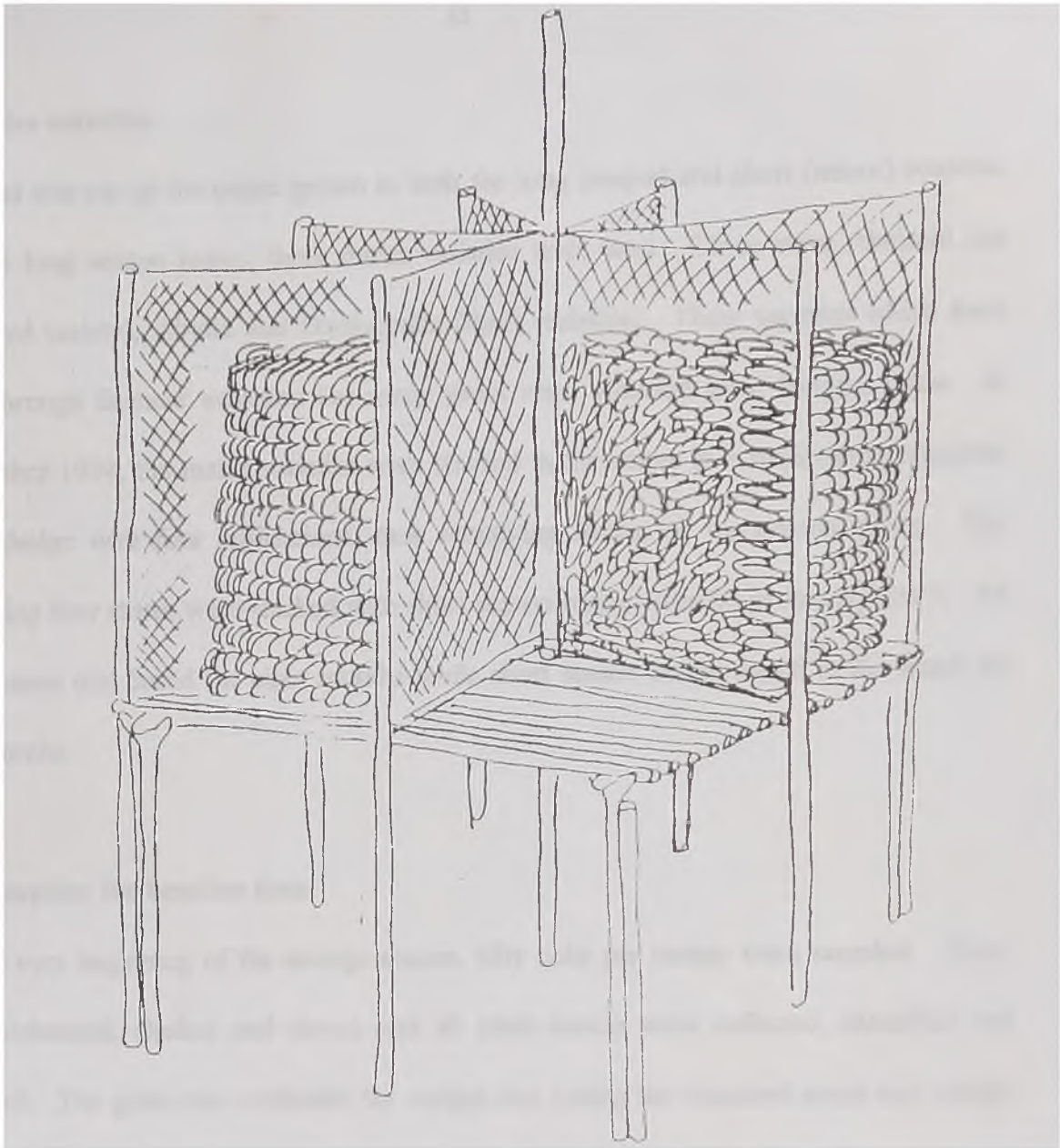


Fig 1: Diagram of the experimental store showing compartments. The post at the corner closest to the observer has been cut away. When the store is completely stacked with maize cobs, it is cylindrical (Adapted from Meikle *et al.*, 1996)

3.2 Maize varieties

The trial was set up for maize grown in both the long (major) and short (minor) seasons. For the long season maize, three maize varieties were used. These were Abeleehi (an improved variety), Abutia and Dzolokpuita (local varieties). These varieties which have gone through farmers' selection for many years were obtained from farmers fields. In September 1994, the maize varieties were stacked in the stores in a randomised complete block design with four replications, thus occupying twelve of the sixteen stores. The remaining four stores were stacked with short season maize (Abutia) in January 1995. the long season trial lasted for eight months while short season maize stayed in the barns for five months.

3.3 Sampling for baseline data

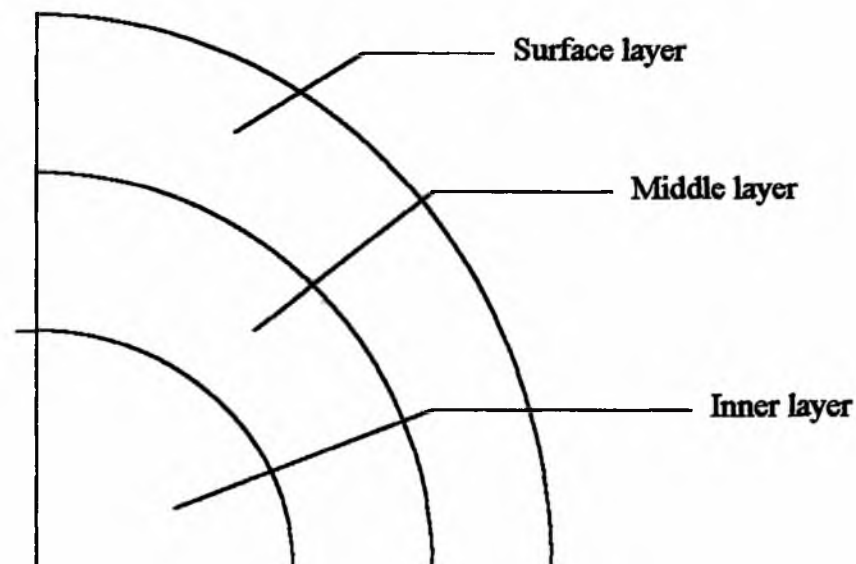
At the very beginning of the storage season, fifty cobs per variety were sampled. These were dehusked, shelled and sieved and all adult insects were collected, identified and counted. The grain was evaluated for weight loss (using the standard count and weight method) and for moisture content (using the 'Dole' grain moisture tester).

Again, 10 cobs per variety were weighed as units, their cob characteristics were measured, then dehusked and shelled. All components of the cobs were weighed to measure differences in varieties, including relative grain weight per cob.

3.4 Sampling procedure

A compartment was sampled from each store every four weeks and this was done only once for a compartment. The compartment to be sampled was selected at random (by assigning each compartment in each store a unique number and using a random number generator). A compartment was considered to consist of three main vertical sections; the surface (with the larger, carefully stacked cobs), the middle and the inner centre of the store) sections as shown in Fig. 2 below.

Fig. 2: Transverse section of a barn compartment showing the vertical sections



Thirty cobs were selected and removed from each section. The cobs on the surface were selected by marking with a permanent marker. Care was taken that selected cobs did not touch each other. While the compartment was being dismantled layer by layer from the top, each marked cob was removed along with a cob from the middle. When a third of the surface and middle cobs had been removed, ten cobs were picked randomly from the inner section. This procedure was followed until the whole compartment was completely

dismantled. Cobs sampled were kept separately in labelled plastic bags while those were kept apart according to their vertical zone. Thirty replacement cobs of the same variety from the replacement store were added to each vertical zone. These cobs were then used to re-construct the compartment after sampling to ensure that the store integrity and bulk were maintained. Sampled cobs were then taken from the field to the laboratory.

3.5 Sampling for weight loss

To determine grain weight loss twenty-six out of the thirty cobs sampled four-weekly from each section per store were used. They were dehusked, and shelled inside the plastic bags into which they were sampled to ensure that all insects as well as maize grains were retained. The insects were sieved out using sieve wire of mesh size 4 mm² and then put into small plastic bags before being frozen for later identification. The weight and moisture content of the maize grains were then taken. Two subsamples of 1000 grains were used for dry-weight loss assessment, using the standard count-and-weigh technique (Boxall, 1986). In this technique, the grain subsample was separated into damaged and undamaged grains and grains with any kind of boreholes were regarded as damaged. Both the damaged and undamaged grains were counted by hand with a 'safesport' hand Tally counter and weighed with the electronic scale (OHAUS Advanced type). Rodent damage was not important because the stores were protected with guards; except for a few rare cases of lizard damage. Few mouldy cobs were observed. However, few grains with very low fungal infection that also showed insect boreholes were counted as damaged. The percent dry-weight loss was calculated using the following equation (Boxall, 1986);

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

Where:

Nd = number of damaged grains

Nu = number of undamaged grains

D = weight of damaged grains

U = weight of undamaged grains.

3.6 Rapid loss assessment

Visual scale of damage developed by the Ghana Larger Grain Borer Project (GLGBP) for rapid loss assessment was also used to calculate weight loss and economic value loss of the maize varieties in store for only the long season. This was done on all the twenty-six cobs used for the standard count and weigh method described earlier (see section 3.5). After dehusking, each cob was classified into one of the six damage classes on the visual scale (see plate 2). Then total number of cobs in each damage class was recorded against the class (see section 4.4.2.1 for details).

Weight loss was calculated from the formula:

$$\Sigma Ni Mi / N$$

Where: **Ni** = Number of cobs in ith class

Mi = Average weight loss for ith class

N = Total number of cobs

3.7 Rearing out

Two cobs picked randomly from the thirty cobs sampled per section from each store were placed separately into labelled paper bags. Each was dehusked and insects associated with it identified and counted. Each cob was then shelled and the grains put separately in rearing jars. These bottles were examined once a week for four weeks and all emerging adult insects were collected. This provided information on the distribution of the oviposition sites of *P. truncatus* and *S. zeamais* populations as well as the variety and density of parasitoids.

3.8 Study site

This study was carried out from September 1994 until June 1995 at the Ministry of Food and Agriculture (MOFA) research station, Kpeve, Volta Region, Ghana, within the research activities of the IITA Larger Grain Borer Project.

3.9 Analyses of results

Several analysis packages were used for various sections of the work. They were StatView 4.0 (Abacus Concept, 1992) and SAS Statistical tools (SAS, 1987). The graphs were also drawn with Deltagraph Professional 2.0 and Microsoft Excel 4.0. The data were analysed after the following transformations were made: $\log_{10}(x + 1)$ for adult insect numbers and $\arcsin((x + 1)^{1/2})$ for weight and economic losses. For analysis purposes the long season was divided into two storage phases: early (sampling occasions 1-4) and late (sampling occasions 5-8) (see Borgemeister *et al.*, 1994). Repeated measure anova models ($\alpha =$

0.05) were used to evaluate treatment effects on insect densities and losses across time, separately within each phase.

4.0. DESCRIPTION OF EXPERIMENTS

4.1 Effect of maize variety on population dynamics of *P. truncatus* and *S. zeamais*

4.1.1 Introduction

Infestations of farm-stored maize by insect pests notably *P. truncatus* and *S. zeamais* pose economic and food security threats to the small-scale rural farmer since they decrease quantity, quality and marketability of maize. *S. zeamais* has for many years consistently been a major primary pest in farm-stored maize in most African countries before the accidental introduction of *P. truncatus* into this continent. However, *P. truncatus*, apparently a potentially dangerous pest seems to be displacing *S. zeamais* in terms of economic importance.

While efforts are being made to develop control strategies against these destructive pests, there are still gaps in knowledge on the ecology of these pests, especially in the West African farm stores. There is therefore the need to obtain information on the abundance and distribution patterns of these pests and how they are affected by maize variety and season.

4.1.2 Materials and Methods.

At every sampling occasion all the insects collected from grains shelled from the 26 cobs sampled from each section per store were put into small plastic bags. These plastic bags were frozen to kill all insects before contents were sieved and all insects identified and counted. (Refer to section 3.4).

4.1.3 Results and Discussion

4.1.3.1. Insect species recorded on the stored maize

A total number of twenty insect species including sixteen pests, two predators and two parasitoids were collected in both the long and short storage seasons. They belonged to the orders Coleoptera, Lepidoptera, Hymenoptera and Heteroptera (see Table 1).

In October, one month into the long storage season, only *S. zeamais*, *Cathartus quadricollis* (Guerin), *Palorus subdepressus* (Wollaston), *Carpophilus dimidiatus* (Fabricius) and the predatory bug, *Xylocoris flavipes* (Reuter) were found in all the stores. But seven months on, all the insect pests and natural enemies listed in Table 1 were present in all the stores with the singular exception of the predator *T. nigrescens*, which was present in only seven of the stores. Even though *P. truncatus* was present in four of the maize stores in October, the mean densities were very low (see Table 2). By the middle of the storage season, i.e. in February, the number of *Prostephanus* - infested stores increased to eight with half of these stores containing *T. nigrescens*. All the stores were infested with *P. truncatus* at the end of the long storage season although the densities varied tremendously, giving credence to the observation that *P. truncatus* spreads mainly during the storage season (Hodges, 1984). For instance, 547 adult insects were collected on 78 cobs from a store while only 12 adults were collected on the same number of cobs from a different store stocked with same variety.

It should also be pointed out that two stores stocked with Abelechi and Dzolokpuita varieties stood uninfested by *P. truncatus* until the eighth month, although adjacent stores were very heavily infested.

Eldana saccharina (Walker) was very rare. Occasionally only a few larvae were found in samples early in the storage season. But *Mussidia nigrevenella* (Ragnot) was common early in the storage season.

Table 1. Insect species found in the maize stores.

<u>ORDER/FAMILY</u>	<u>SPECIES</u>
<u>COLEOPTERA</u>	
Curculionidae	<i>Sitophilus zeamais</i> Motschulsky
Tenebrionidae	<i>Tribolium castaneum</i> (Herbst)
	<i>Palorus subdepressus</i> (Wollaston)
	<i>Gnathocerus maxillosus</i> (Fabricius)
	<i>Alphitobius diaperinus</i> (Panzer).
Nitidulidae	<i>Carpophilus dimidiatus</i> (Fabricius)
Bostrichidae	<i>Prostephanus truncatus</i> (Horn)
	<i>Dinoderus minutus</i> Fabricius
	<i>Xyloperthella picea</i> (Om.)
	<i>Rhizopertha dominica</i> (Fabricius)
Silvanidae	<i>Cathartus quadricollis</i> (Guerin)
	<i>Oryzaephilus surinamensis</i> (Linnae)
Cucujidae	<i>Cryptolestes ferrugineus</i> (Stephens)
Scolytidae	<i>Stephanoderes coffeae</i> Hagedorn
Histeridae	<i>Teretriosoma nigrescens</i> Lewis
<u>LEPIDOPTERA</u>	
Pyralidae	<i>Mussidia nigrevenella</i> (Ragnot)
	<i>Eldana saccharina</i> Walker
<u>HYMENOPTERA</u>	
Pteromalidae	<i>Anisopteromalus calandrae</i> (Howard)
	<i>Choetospila elegans</i> Westwood
Evanidae	Unidentified species
<u>HETEROPTERA</u>	
Anthocoridae	<i>Xylocoris flavipes</i> (Reuter)

4.1.3.2 Population dynamics of *P. truncatus* and *S. zeamais* in the long season.

In all the treatments *P. truncatus* numbers were very low during the first four months of storage (Fig. 3), although temporal analysis showed significant increase ($F_{1,9}=5.38$, $P=0.0046$) (see Appendix 2) in *P. truncatus* numbers between the first and the fourth sampling occasions. Maize variety showed significance ($F_{2,9}=7.75$, $P=0.011$) in the early phase of storage with the Abutia having the highest numbers of *P. truncatus*. There was also a significant interaction between maize variety and sampling occasion.

During the late phase, the density of *P. truncatus* increased for all varieties. However, differences among maize varieties were significant ($F_{2,9}=4.3$, $P=0.049$). This may be due to the sporadic distribution of *P. truncatus* (Markham *et al.*, 1991) which results in high within-treatment variance, thus, making significant differences difficult to detect. Throughout the storage season, granaries stocked with Abutia variety recorded the highest densities of *P. truncatus*. After the second sampling occasion, *P. truncatus* densities were significantly higher on Abutia than on any other variety and remained so throughout the storage season (Table 2) even though much of these densities could be explained by the high density found in a single store of Abutia variety. No significant differences could be detected between Abelechi and Dzolokpuita, which recorded the lowest densities of *P. truncatus* throughout the storage period.

Fig. 3 Density of *P. truncatus* adults recorded on three maize varieties stored during the long and short seasons

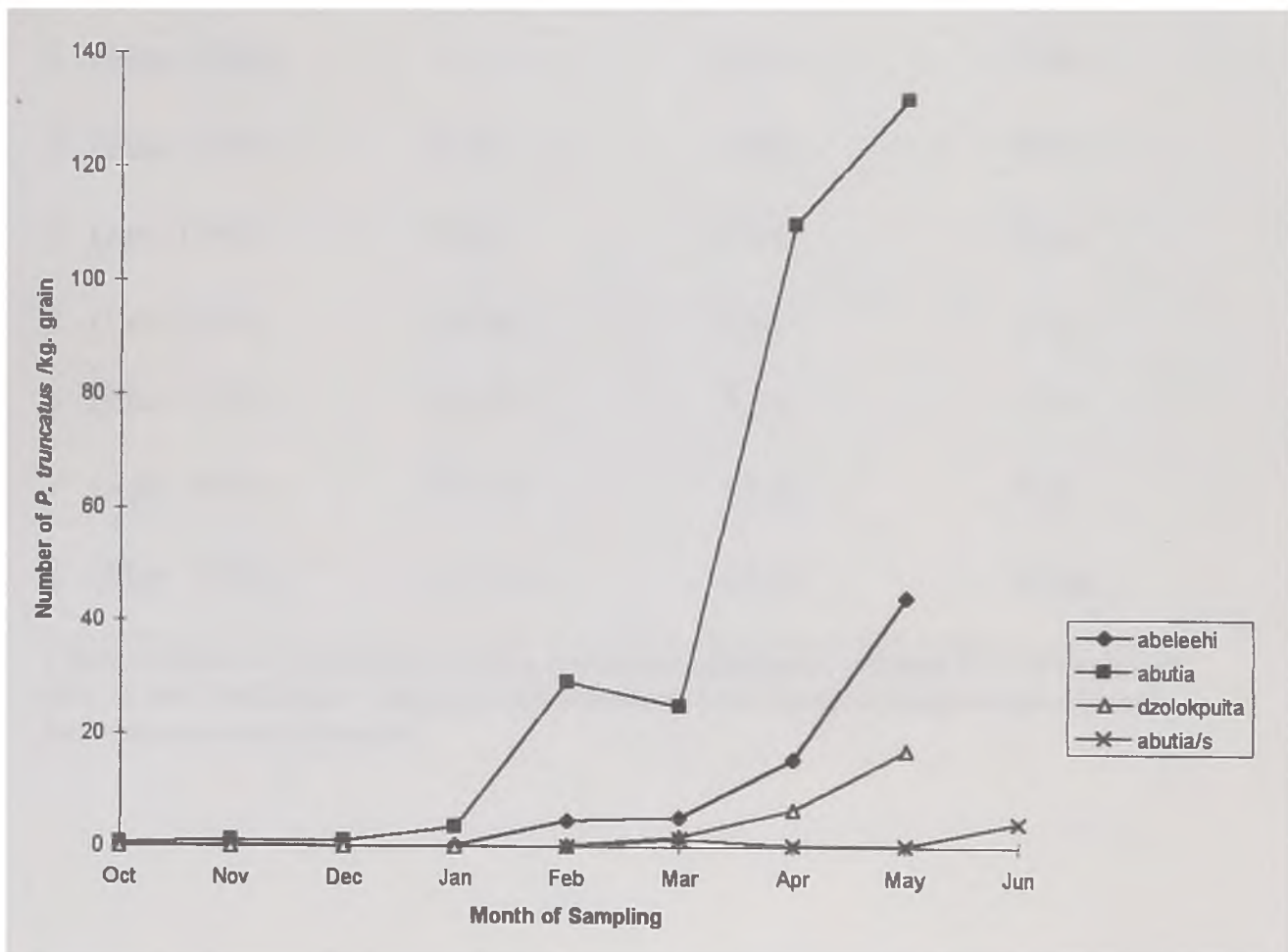


Table 2: Densities of *Prostephanus truncatus* adults recorded on cobs of three maize varieties stored during the long season (October 1994 to May 1995) .

Sampling Occasion	Mean density of <i>P. truncatus</i> *		
	Abutia	Abelechi	Dzolo kpuita
1 (Oct. 1994)	0.6a	0.2a	0.0a
2 (Nov. 1994)	1.1a	0.5a	0.0a
3 (Dec. 1994)	0.9b	0.0a	0.0a
4 (Jan. 1995)	3.9b	0.1a	0.1a
5 (Feb. 1995)	29.0b	4.6a	0.2a
6 (Mar. 1995)	24.6b	5.1a	1.7a
7 (Apr. 1995)	109.3b	15.4a	6.5a
8 (May 1995)	131.1b	43.7a	16.9a

* Means followed by same letter within a row are not significantly different ($P > 0.05$) from each other by the Scheffe's test. Insect numbers determined from 3 pooled 26-cob samples per barn. Each value is a mean of 4 barns.

P. truncatus density also showed significant differences over time in the late phase ($F_{3,27}=25.11$, $P=0.0001$) (see Appendix 2). The population significantly increased ($F_{1,9}=37.04$, $P=0.0002$) from the fifth to the eighth sampling occasion. The maximum densities of 131.1, 43.7 and 16.9 insects per kg. grain were recorded at the eighth sampling period for Abutia, Ablechi and Dzolo kpuita respectively. No interactions between maize variety and time of sampling was detected during the late phase.

Across all varieties, densities of *S. zeamais* were higher than those of *P. truncatus* (cf. Fig. 3 and 4) although, densities were not significantly different among varieties ($P > 0.05$) throughout the long season (see Appendix 3). However, *S. zeamais* population displayed significant differences over time during the early phase. Densities of *S. zeamais* on all treatments recorded in the first three sampling occasions increased sharply ($F_{1,9}=87.55$, $P=0.0001$), peaking in December at 281.7, 349.0 and 348.5 for Abutia, Abeleehi and Dzolokpuita varieties, respectively (Table 3). Thereafter the densities remained relatively stable up to April, fluctuating between 200 and 300 adult insects per kg of maize grains. Apart from Abeleehi, which recorded decreasing density between the months of April and May, Abutia and Dzolokpuita recorded increasing densities; an increase of 49 and 82 insects per kg of maize grains for the two varieties, respectively. It is interesting to note that unlike *P. truncatus* densities, which were significantly highest on Abutia, after the November sampling, no significant differences were found among varietal treatments for *S. zeamais* except on the first sampling occasion (Table 3) The reason for this significant difference at the beginning of the storage season may be partly due to field infestation of *S. zeamais*, particularly among cobs with damaged or poor husk cover (Markham, 1981)

Fig. 4 Density of *S. zeamais* adults recorded on three maize varieties stored during the long and short seasons

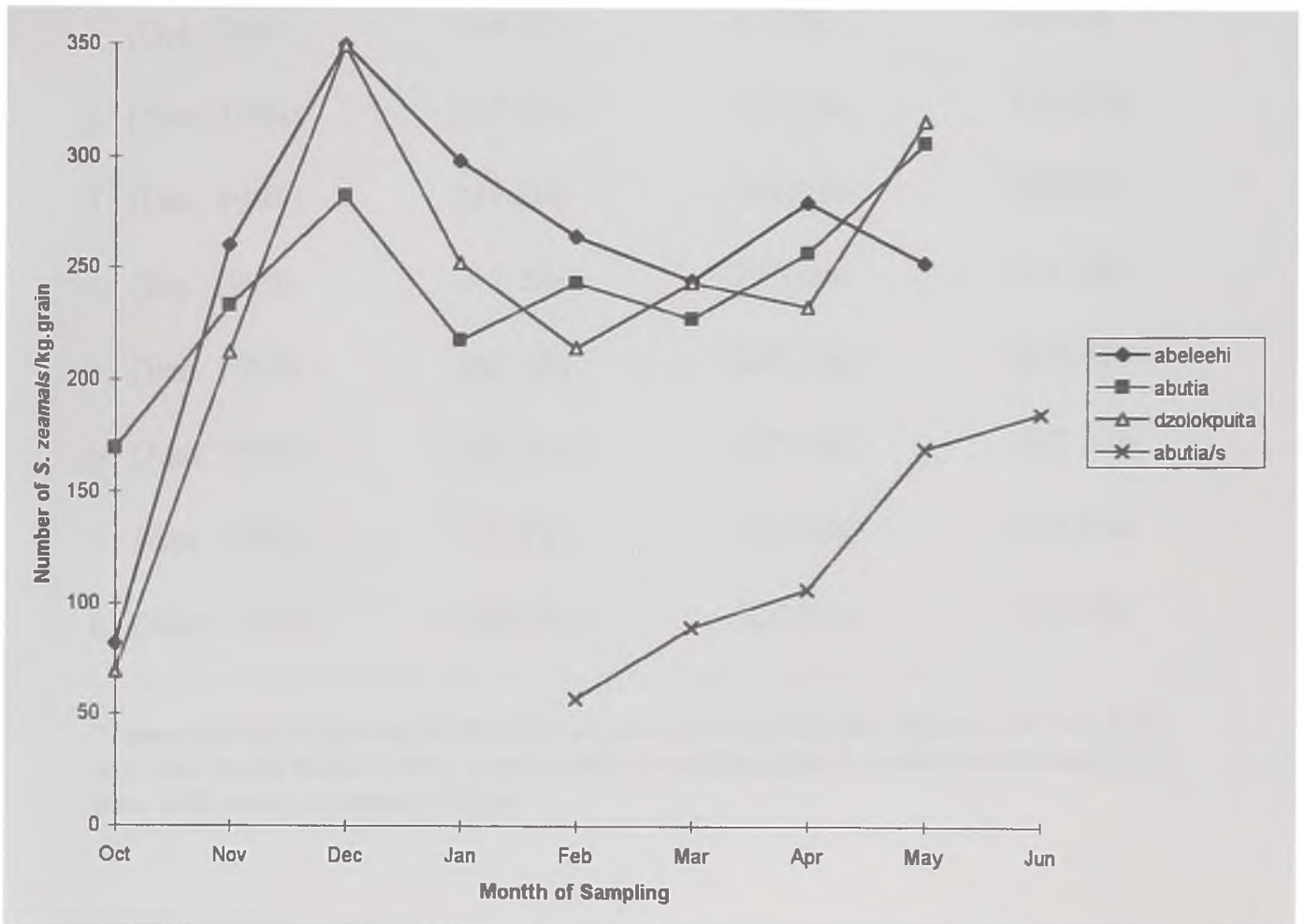


Table 3: Densities of *S. zeamais* recorded on cobs of three maize varieties stored in barns during the long season (October 1994 to May 1995).

Sampling Occasion	Mean density of <i>S. zeamais</i> *		
	Abutia	Abelechi	Dzoloakpuita
1 (Oct. 1994)	169.30b	81.70a	69.01a
2 (Nov. 1994)	232.50a	259.74a	212.28a
3 (Dec. 1994)	281.69a	349.03a	348.47a
4 (Jan. 1995)	217.24a	297.38a	251.68a
5 (Feb. 1995)	242.32a	263.28a	213.32a
6 (Mar. 1995)	226.19a	243.45a	242.52a
7 (Apr. 1995)	255.21a	277.80a	231.43a
8 (May 1995)	303.99a	250.84a	313.49a

* Means followed by the same letter within a row are not significantly different ($P > 0.05$) from each other by the Scheffe's test. Insect numbers determined from 3 pooled 26-cob samples per barn. Each value is a mean of 4 barns.

Fig. 5 Percentage moisture content of three varieties of maize stored during the long and short seasons

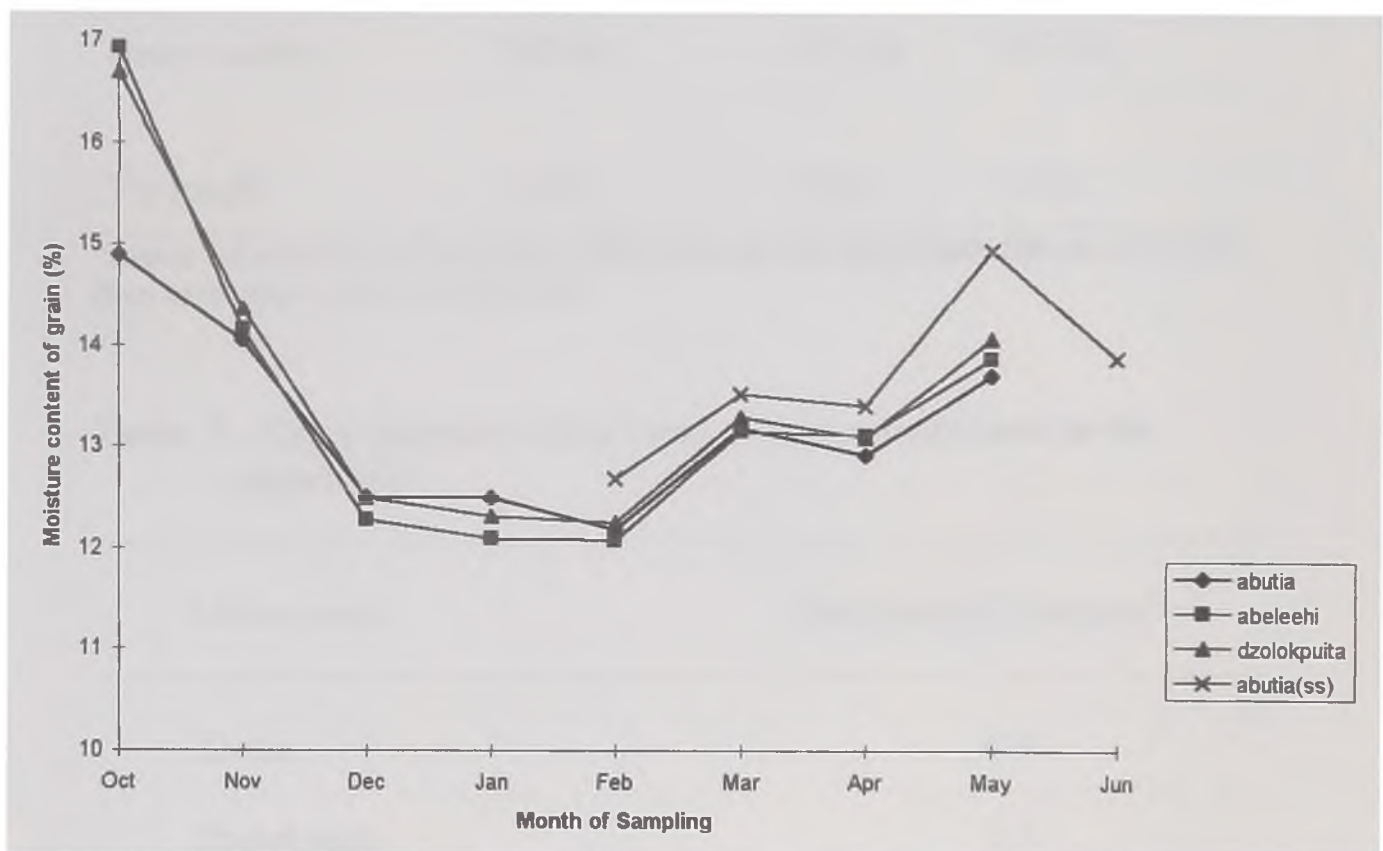


Table 4: Cob characteristics of three maize varieties used in experiment.

Character	Mean Weight/length (g./ cm)*		
	<u>Abutia</u>	<u>Abelechi</u>	<u>Dzokolpuita</u>
Core Weight	17.4a	16.0a	23.2b
Husk leaves number	8.0a	8.1a	10.2b
Grain number	343.4a	331.3a	357.2a
Tip length	10.9a	10.0a	11.7a

*Means followed by the same letter within a row are not significantly different ($P>0.05$) from each other by the Scheffe's test.

Table 5: Grain hardness of the three maize varieties used in the experiment¹

Maize variety	Coefficient of Hardness ²
Abutia	0.8
Dzokolpuita	1.5
Abelechi	1.8

¹ Grain hardness increases with magnitude of the coefficient of hardness

² (Adapted from Addo, 1994. See appendix 1)

The levelling - off period beginning in December for *S. zeamais*, which contrasts sharply with the increasing *P. truncatus* after this period, coincided with the dry and cool weather conditions of the harmattan, normally experienced during this time of the year. Low ambient humidity reduces grain moisture content and this may lower survivorship and reproductive rate of *S. zeamais* (Longstaff, 1981). Moisture content during this period remained at about 12% (Fig. 5). However, *P. truncatus* tolerates lower grain moisture content (Hodges *et al*, 1983a). It might also be due to *P. truncatus* immigrating into stores in response to environmental cues; volatiles from maize (Pike *et al*, 1994), pheromones (Hodges, 1994), temperature, etc. (Fadamiro and Wyatt, 1995) and other factors. Hence, the moisture content may merely be correlated with other factors that more directly influence infestation.

The number of husk leaves per cob (Table 4) showed Abutia to be inferior to the other varieties. From the values obtained by Addo (1994) who performed grain hardness tests using, among others, the varieties used in this experiment, Abutia ranked lowest with coefficient of hardness of 0.8 (Table 5). These two factors combined may explain why Abutia experienced the highest *P. truncatus* levels, although other husk cover characteristics such as strength of husk and length of husk beyond the tip of the cob have also been identified as providing important barrier between *P. truncatus* and maize grains on the cob (Keil, 1988; Addo, 1994). Howard (1983) and Li (1988) recorded reduced oviposition rate when *P. truncatus* was maintained on flinty and popcorn maize varieties. Li (1988) further explained that this was due to the higher energy cost of tunnelling the harder maize since the female had to lay eggs in blind-ending tunnels thereby leading to reduced fecundity and consequently population size is reduced on the harder maize variety.

With respect to *S. zeamais* numbers, however, the same assertion cannot be made since these varietal characteristics apparently did not influence it. Interestingly, other husk characteristics measured did not show any significant difference between varieties. However, the apparent lower degree of varietal effect on the *S. zeamais* was observed in laboratory studies by Howard (1983), although other works by Eden (1952), Dobie (1974), Kossou *et al* (1993) observed the contrary.

4.1.3.3 Spatial Distribution Within Stores.

There were no clear-cut trends in the vertical distribution of *P. truncatus* within stores (Table 6), although differences in *P. truncatus* densities have been noticed regarding horizontal layers (C. Borgemeister, pers. com.). The inner layer generally appeared to record lower densities than any of the outer layers with the exception of the April sampling, although these differences were not significant. This suggests that the *P. truncatus* adults may, probably, have colonised the stores from outside rather than the cobs themselves being previously infested from the field before storage. The baseline field insect data as well as the rearing out may confirm this view because no *P. truncatus* adults were found in them. The reason for this distribution trend remaining so for most sampling occasions was probably due to the low and late infestations and establishment of *P. truncatus* in the stores. The few adults that infested the surface and middle layer cobs had to live and multiply in these cobs before spreading to the inner layer. It might also have to deal with *S. zeamais* infestation: a careful look at *S. zeamais* distribution in the different sections of the stores showed that most *S. zeamais* adults were in the inner layer (Table 7). This might suggest *P. truncatus* adults were not attracted to such cobs or could not reproduce well in cobs previously infested with *S. zeamais* because of the aggressive behaviour of *S. zeamais* larvae (Sharifi and Mills, 1971; Vowotor *et al.*, 1995b). It may also suggest that

the *P. truncatus* individuals preferred the outer cobs for reasons that are not clear, although the small and insignificant differences ($P>0.05$), the low numbers of *P. truncatus* recorded and the significant interaction between variety and sampling occasion in the early storage phase (see 4.1.3.1) make it difficult to draw definite conclusions.

Table 6: Density of *P. truncatus* adults recorded in the sections of a barn compartment*

Sampling occasion	Surface	Middle	Inner
1 (Oct.)	0.2a	0.4a	0.2a
2 (Nov.)	0.4a	1.0a	0.1a
3 (Dec.)	0.4a	0.3a	0.2a
4 (Jan)	0.6a	1.9a	1.0a
5 (Feb.)	9.9a	13.6a	10.2a
6 (Mar)	10.8a	8.5a	12.2a
7 (Apr.)	48.4a	39.7a	43.0a
8 (May)	61.6a	78.4a	51.8a

* Means followed by the same letters within a row are not significantly different ($P>0.05$) by Scheffe's test.

Similarly, there were small differences between *S. zeamais* densities in the various vertical layers (Table 7), and no general pattern was discernible. Although a cursory look at the data reveals slightly higher densities in the inner layer where there were perhaps, suitable stable environmental conditions than the outer two layers, these small differences were not significant. The middle layer, however, recorded significantly lowest densities ($P<0.05$) during the fifth and the seventh sampling occasions.

Table 7: Density of *S. zeamais* adults recorded in the sections of a barn compartment

Sampling occasion	Surface	Middle	Inner
1 (Oct.)	98.2a	120.3a	101.6a
2 (Nov.)	192.7a	241.4a	270.4a
3 (Dec.)	312.6a	332.3a	334.3a
4 (Jan)	297.8a	219.2a	249.3a
5 (Feb.)	260.8a	179.0b	279.1a
6 (Mar)	272.7a	210.7a	228.9a
7 (Apr.)	265.1a	195.9b	303.5a
8 (May)	324.5a	257.8a	286.1a

* Means followed by the same letters within a row are not significantly different ($P > 0.05$) by Scheffe's test.

4.1.3.4. Distribution of oviposition sites of *P. truncatus* and *S. zeamais* on maize cobs.

In order to understand the competitive preference for oviposition sites on maize cobs by one species in the presence or absence of the other species, cob by cob examinations were carried out. Cob samples were kept singly in jars and reared out to obtain about one generation (four weeks) of insects.

Most cobs on which *P. truncatus* was found to be present also contained *S. zeamais*, although the relative numbers varied with the cobs on which they were found (Fig. 6). The populations of *P. truncatus* and *S. zeamais* were aggregated on cobs and did not occur at uniform average densities. Adult insect emergence for all treatments followed a similar trend; late incidence of low initial densities of *P. truncatus* which were aggregated onto few cobs, then increase in number of infested cobs and *P. truncatus* density with *S. zeamais* numbers generally decreasing. Although environmental conditions may have affected *S. zeamais* numbers, inter- and intra-specific competition for oviposition sites on the cobs may also have played a part. At the grain level, *S. zeamais* has been found to

out-compete *P. truncatus* (Vowotor *et al.*, 1995b) but the destructive nature of *P. truncatus* on cobs can prevent *S. zeamais* from finding any suitable oviposition site. This was shown clearly in Fig. 6 where high numbers of emerging *P. truncatus* adults were associated with low *S. zeamais* numbers.

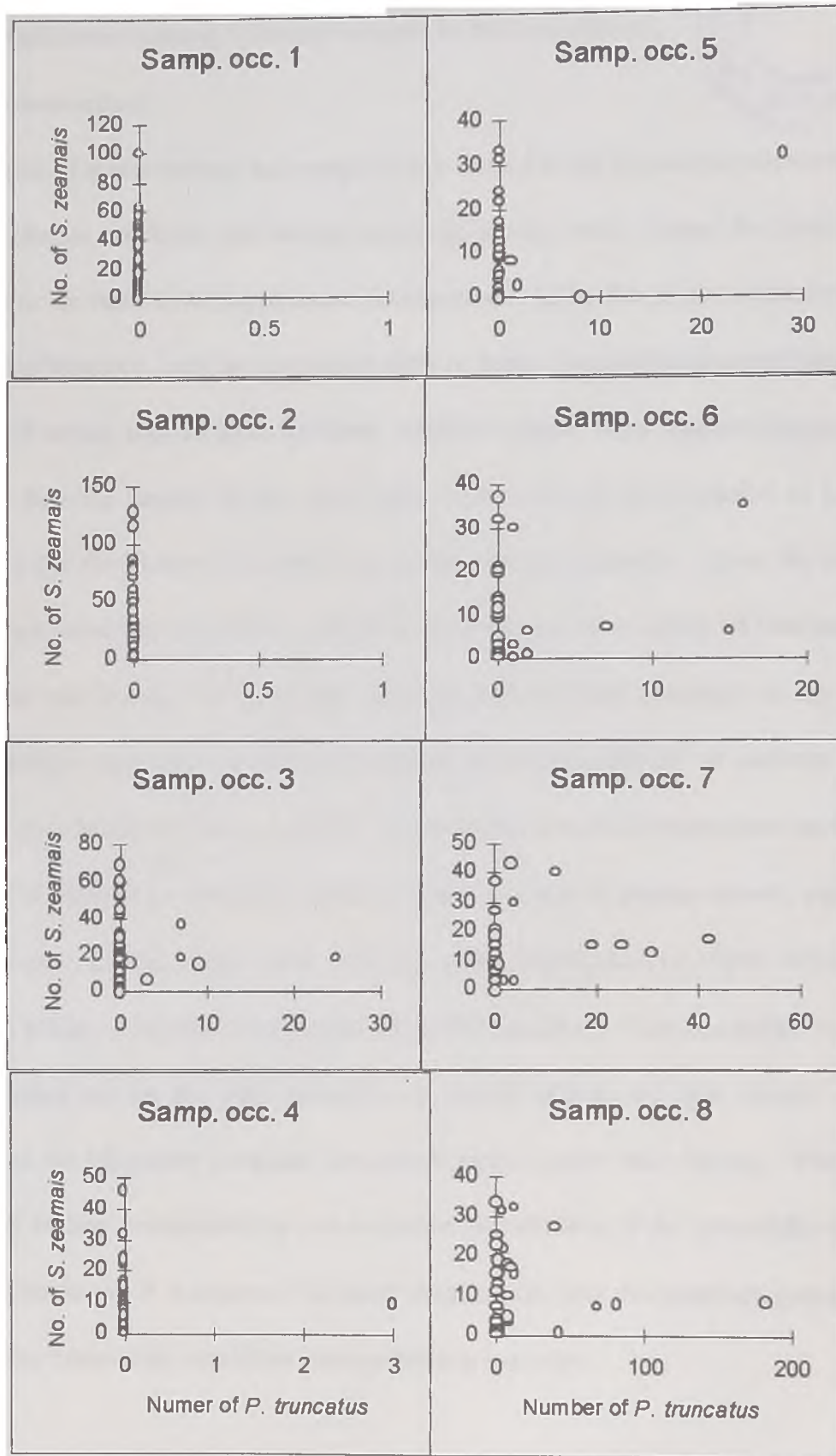


Fig. 6 Ovipositional distribution of *S. zeamais* and *P. truncatus* on maize cobs

4.2 Weight losses among different varieties in the long season

4.2.1 Introduction:

The extent of insect damage and weight loss is related to the physical characteristics of the maize, climate condition and storage practices, among other factors. In Ghana climatic conditions are suitable for rapid insect development. Infestation is also related to the type of storage structure, such as open-sided cribs or barns. Varietally-influenced properties of the stored maize, such as grain hardness, moisture content, husk tightness and numbers as well as phenolic content of the grain have all been found to be related to insect pest numbers and the extent of loss inflicted on the stored commodity. Over the years there have been numerous successes in breeding for resistance to a variety of field insect pests (Gutherie and Russel, 1989) but this approach has not been attempted to any extent in grain storage, although considerable variation in the susceptibility of cultivars to maize storage pests is known (Horber, 1989). Nevertheless, recent literature shows an increasing amount of interest in developing grain varieties resistant to storage insects, especially *S. zeamais* (see Bhatia, 1976; Dobie, 1974; Li, 1988; Markham *et al.*, 1991; 1994c). Most of these studies, however, were conducted in the laboratory. Few successful studies have been carried out on the field evaluation of varietal effects and how relative resistance shown in the laboratory translates into weight losses under rural storage. With the pest complex further complicated by the accidental introduction of the potentially destructive larger grain borer, *P. truncatus*, this study to determine how the popularly grown varieties would fare under field conditions was particularly important.

4.2.2 Materials And Methods

At every sampling occasion twenty-six cobs taken from each section per store were used. They were dehusked, shelled into the plastic bags and the insects were sieved out. The moisture content of the maize grains were then taken. Two subsamples of 1000 grains taken from each plastic bag were separated into damaged and undamaged grains. Both the damaged and undamaged grains were counted and weighed. The percent dry-weight loss was calculated using the standard count and weigh equation (Boxall, 1986) (refer to 3.5).

4.2.3 Results And Discussion.

4.2.3.1 Weight Loss

During the early storage phase of the long season, significant differences were observed in weight loss among the varieties ($F_{2,9}=17.5$, $P=0.0008$) (see Appendix 4). Weight loss also increased over time ($F_{3,27}=10.06$, $P=0.0001$). This increase was gradual as significant differences were not observed between successive sampling periods but between the weight losses of the first and fourth sampling occasions ($F_{1,9}=81.65$, $P=0.0001$). Significant interaction of weight losses sustained by the maize varieties and time was observed ($F_{6,27}=3.17$, $P=0.041$).

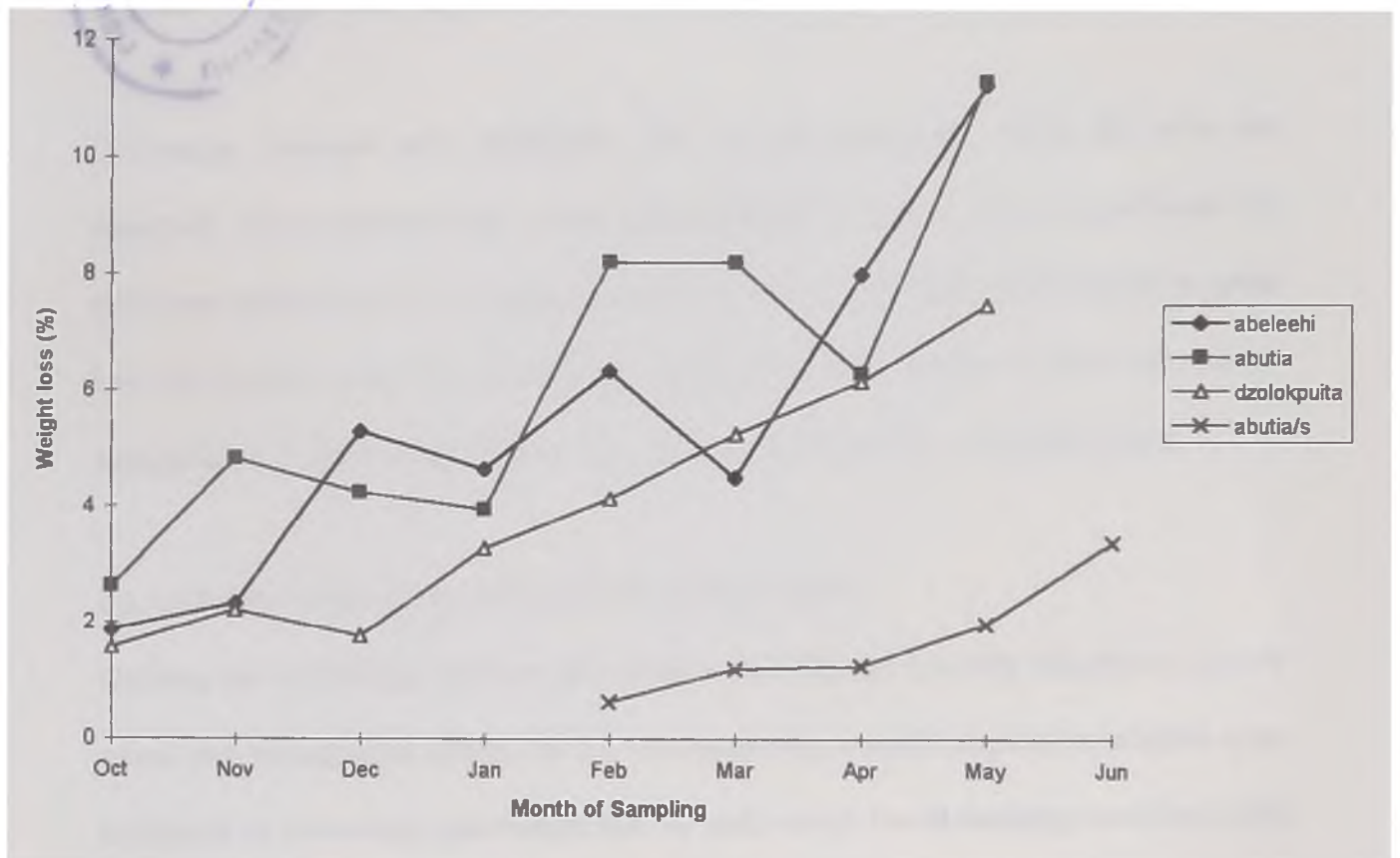
Similarly, weight losses significantly increased over time ($F_{3,27}=9.72$, $P=0.0002$) in the late phase (see Appendix 4). Varieties also showed significant differences ($P < 0.05$). However, there was no interaction between variety and time of sampling.

Table 8: Percentage weight loss suffered by three maize varieties stored in barns during the long season (October 1994 to May 1995).

Sampling Occasion	Mean percentage grain weight loss*		
	Abutia	Abelechi	Dzolokpuita
1 (Oct 1994)	2.6b	1.9ab	1.56a
2 (Nov 1994)	4.8a	2.3a	2.2a
3 (Dec 1994)	4.2b	5.3b	1.8a
4 (Jan 1995)	3.9a	4.6a	3.3a
5 (Feb 1995)	8.2b	6.3ab	4.1a
6 (Mar 1995)	8.2b	4.5a	5.2ab
7 (Apr 1995)	6.3a	8.0a	6.1a
8 (May 1995)	11.3b	11.2b	7.4a

* Means followed by the same letter within a row are not significantly different ($P > 0.05$) by the Scheffe's test. Each value is a mean of 4 barns.

Fig.7 Percentage weight loss suffered by three maize varieties stored during the long and short seasons



After eight months of storage the maximum weight loss recorded were 11.3%, 11.2% and 7.4% for *Abutia*, *Abelechi* and *Dzolakpuita* respectively (Table 8). *Dzolakpuita* recorded significantly lowest grain loss at almost every sampling occasion compared with the other two varieties. Indeed, it had the lowest score in seven out of the eight sampling occasions. It is interesting to note that of the two local varieties, *Dzolakpuita* variety performed better than *Abutia*. The fact that the grains of *Dzolakpuita* are harder than *Abutia* (Table 5 and Appendix 1) might partly explain this observation (Howard, 1983; Li, 1988).

Differences observed both graphically (Fig 7) and statistically (Table 8) were not consistent. This might probably be due to the sampling technique. One compartment of a store was sampled at each occasion (see section 3.2) so any spatial heterogeneity in grain loss, for instance, one side experiencing higher losses than another because of peculiar aggregation of insects within a given store, may be reflected in the treatment means.

4.2.3.2 Relationship Between Pests Density And Losses.

Defining the relationship between pest densities and damage is a very important basis for sound pest management (Stern, 1973). Consequently, multiple regression analyses were conducted on percentage grain weight loss for each variety for all sampling occasions using *P. truncatus* and *S. zeamais* as independent variables to establish this relationship for all the maize varieties. The analyses showed that *P. truncatus* and *S. zeamais* mean densities could not explain the weight losses recorded during storage, except in October (i.e. after a month's storage) for *Abutia* variety, where *S. zeamais* regression showed significance ($F_{2,9}=3.457$, $P=0.0294$). A significant standardised regression coefficient of 0.704 was recorded for *S. zeamais* indicating that *S. zeamais* density played a major role in explaining the variance in weight loss registered than did *P. truncatus*.

Table 9. Correlation coefficients of percentage grain weight loss with *P. truncatus* and *S. zeamais* density^a.

Weight Loss	<i>P. truncatus</i>	<i>S. zeamais</i>
L ₁	0.133	0.437
L ₂	0.009	0.512
L ₃	0.238	0.359
L ₄	0.076	0.317
L ₅	0.462	0.191
L ₆	0.229	0.279
L ₇	0.159	0.189
L ₈	0.327	0.166

^a: L_i = Percentage weight loss at *i*th sampling occasion.

r values > 0.325 have P < 0.05.

36 observations were used in this computation.

Correlation coefficients of the pests and losses were therefore used to estimate the relationship. Coefficients of the primary pests were considered since they generally initiate damage and cause loss to previously undamaged maize grains. It should however be pointed out that later in the storage season, when several grains have already been damaged, and are vulnerable to attack, the contribution of these opportunistic secondary pests to grain weight loss cannot be ignored.

Generally, there was a positive correlation between *P. truncatus* and *S. zeamais* densities and weight loss (see Table 9) throughout the storage season. *P. truncatus* density had significant correlation with weight loss at the fifth (0.462) and eighth (0.327) sampling occasions respectively, although they were not particularly strong. Similarly, *S. zeamais* density produced positive significant correlation with weight loss, although they were also not too strong. However, they occurred early in the storage season. The pattern of significance of the correlation coefficients for the two insect pests conform to findings in which *S. zeamais* density is often higher and cause most damage than *P. truncatus* early in the season, a situation which reverses later in the storage season (Novillo, 1991; Markham *et al.*; 1994c; Borgemeister *et al.*, 1994).

4.2.3.3 Association Of *P. truncatus* And *S. zeamais* With Some Secondary Pests.

In the tropics secondary pests tend to be abundant in rural maize stores and evidence of differing relationships with primary pests have been reported (Novillo, 1991; Markham *et al.*, 1991).

Table 10 Correlation coefficients of *P. truncatus* with some secondary insect pests^a.

P.trunc ^a .	Cath. ^b	Pal. ^c	Crypt. ^d	Others
Pt1	0.029	0.029	0.152	-0.128
Pt2	**	**	**	**
Pt3	0.467	0.461	0.954	0.132
Pt4	0.023	0.235	0.148	0.088
Pt5	0.336	0.505	0.555	0.560
Pt6	0.371	0.589	0.494	0.540
Pt7	0.265	0.167	0.495	0.330
Pt8	0.148	0.178	0.156	0.357

*: Pti = *P. truncatus* density at *i*th sampling occasion.

**= No *P. truncatus* adults recorded

r values > 0.232 have P < 0.05.

72 observations were used in this computation.

a: *P. truncatus*, b: *Cathartus quadricollis*, c: *Palorus subdepressus*

d: *Cryptolestes ferrugineus*.

In this study the association of secondary insect pests with *P. truncatus* and *S. zeamais* were examined at the cob level. *P. truncatus* association with the most abundant secondary pests, namely *C. quadricollis*, *P. subdepressus* and *Cryptolestes ferrugineus* were positive and generally significant after three months of storage up to and including the seventh month (see Table 10). The eighth month, which recorded the highest density of *P. truncatus*, irrespective of the maize variety (see Fig. 3 and Table 2) however showed a reduced association with each of these secondary pests. It appears the other secondary pests, namely, *Tribolium castaneum*, *Gnathocerus maxillosus* and *Carpophilus dimidiatus*

which were not abundant and were therefore lumped together as "others" (see Table 10), displaced *C. quadricollis*, *P. subdepressus* and *C. ferrugineus* as the season progressed and *P. truncatus* density increased. In fact, this group ("others") recorded significant correlation coefficients of 0.56, 0.54, 0.33 and 0.357, respectively from the fifth to the eighth sampling occasion of the long storage season. The reason for this apparent displacement is not clear. Probably, inter- and intra-specific competition coupled with an increase in the moisture content of the grains favoured some of these secondary pests. Schulten (1976) reported that at high grain moisture content, *Carpophilus* spp can act as primary pests. Admittedly, the moisture content indicated (about 30%) was quite high it nevertheless points to the fact that some of these secondary insects which tolerate high grain moisture content and take advantage of it in interspecific competition. Also the tolerance of *T. castaneum* to high temperatures and relative humidities (Beckett *et al.*, 1994) and its widely known predation behaviour (Markham *et al.*, 1991) may also explain this observation.

In relation to *S. zeamais*, there was a significantly close association with *C. quadricollis*, *P. subdepressus*, and *C. ferrugineus* throughout the major storage season (see Table 11). The group labelled "others" also showed similar association with *S. zeamais*.

Table 11: Correlation coefficients of *S. zeamais* density with densities of some secondary insect pests*.

<i>S. zeamais</i>	Cath ^b	Pal ^c	Crypt ^d	Others
Sz1	0.665	0.631	0.381	-0.030
Sz2	0.658	0.753	0.460	0.730
Sz3	0.596	0.468	0.253	0.458
Sz4	0.649	0.843	0.595	0.806
Sz5	0.639	0.872	0.822	0.843
Sz6	0.617	0.829	0.753	0.780
Sz7	0.415	0.521	0.493	0.418
Sz8	0.642	0.840	0.734	0.840

*: Sz_i = *S. zeamais* density at *i*th sampling occasion.

r values > 0.232 have $P < 0.05$.

72 observations were used in this computation.

b: *Cathartus quadricollis*, *c*: *Palorus subdepressus*

d: *Cryptolestes ferrugineus*.

4.2.3.4 Dynamics of *T. nigrescens* population

Teretriosoma nigrescens, which is an effective predator of *Prostephanus truncatus* under both laboratory (Rees, 1985; Leliveldt and Laborius, 1990) and semi-field conditions (Helbig, 1995) has been now introduced into Ghana. This study also examined its association with, and influence, if any, on *P. truncatus* population.

Densities of *T. nigrescens* recorded on the three maize varieties were quite low (Fig. 8).

However, the numbers followed the trend of the *P. truncatus* population dynamics (see

Fig. 3). *T. nigrescens* adults are able to specifically pursue *P. truncatus* because they can

also perceive the male-produced aggregation pheromone secreted by *P. truncatus* to attract mates (Rees *et al.*, 1990). Thus, most of the *T. nigrescens* were recorded on the Abutia variety and to a lesser extent on Abeleehi. Dzolokpuita recorded the least densities at all sampling occasions. No differences were observed within sampling occasions during the early phase. However, there were significant increases ($F_{3,9}=5.3$, $P=0.005$) during the late phase of the long season. Maize variety never had any effect on the *T. nigrescens* dynamics.

The highly positive significant correlation observed between *T. nigrescens* and *P. truncatus* densities (Table 12) during the season is indicative of the close association of the predator and its prey, even in the midst of other storage insects (see Table 1) in the open stores under field conditions (Boye, 1990; Rees *et al.*, 1990). This association became closer with time as both populations increased. The positive correlation observed over time suggests a numerical response of the predator to *P. truncatus* density, even though *T. nigrescens* could not establish early to have a restrictive overall effect on the *P. truncatus* population.

Table 12: Correlation coefficients of *T. nigrescens* with *P. truncatus* and Loss

<i>T. nigrescens</i>	<i>P. truncatus</i>	Loss
Tn1	*	*
Tn2	*	*
Tn3	0.609	0.125
Tn4	0.438	-0.08
Tn5	0.709	0.359
Tn6	0.767	0.259
Tn7	0.835	0.222
Tn8	0.801	0.253

* No *T. nigrescens* recorded.

Tni = *T. nigrescens* density at ith sampling occasion.

Loss = dry weight loss of maize grain by standard count and weigh method.

r values > 0.325 have P < 0.005

36 observations were used in this computation

Table 13 Changes in the ratio of *T. nigrescens* (Tn) to *P. truncatus* adults in the stores in the long and short storage seasons.

Season	Tn:	<i>P. truncatus</i> at sampling occasion							
		1	2	3	4	5	6	7	8
Long	1:	*	*	1.2	3.1	5.3	6.9	14.2	30.1
Short	1:	**	1.85	*	*	0.4			

*No *T. nigrescens* recorded

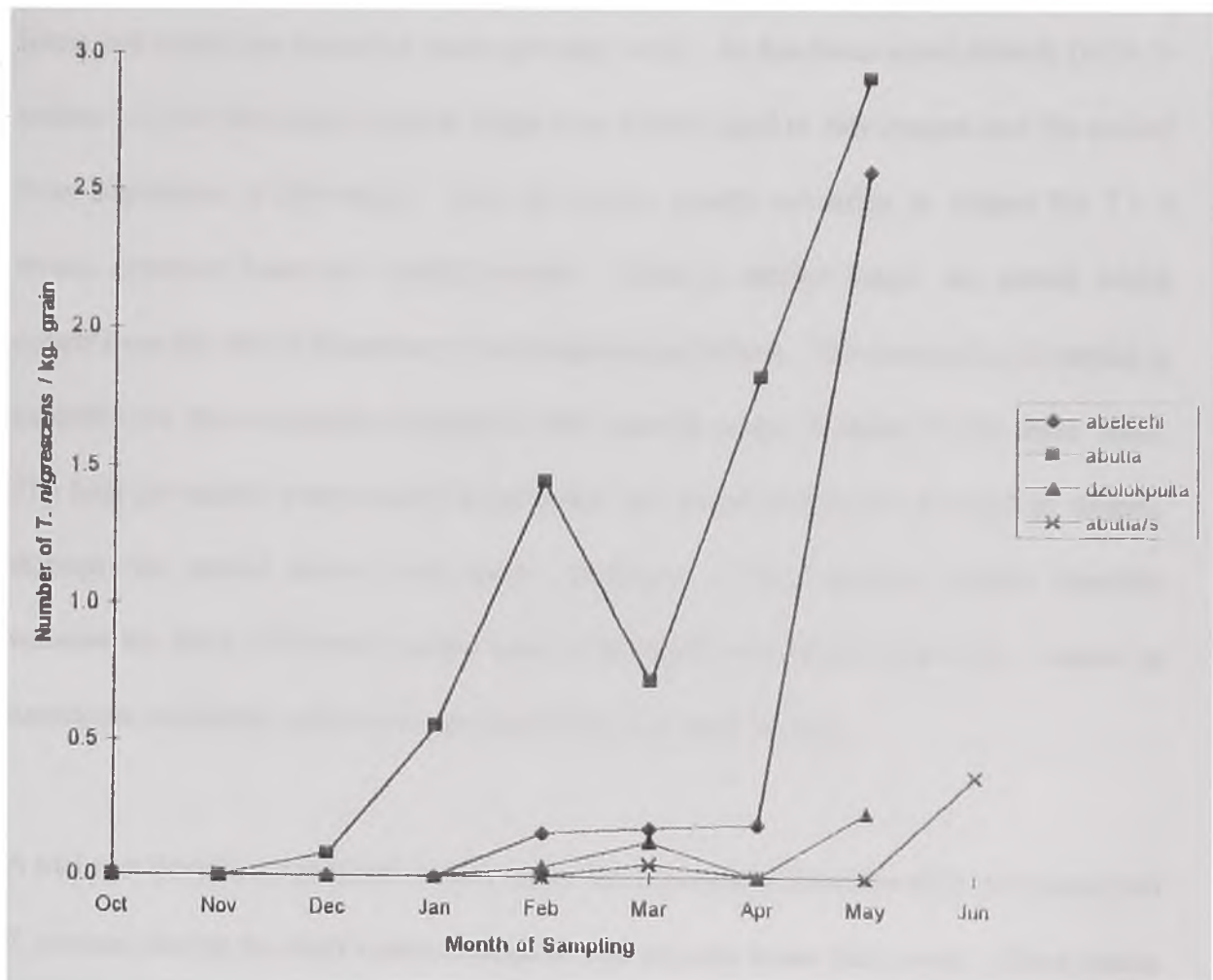
**No *T. nigrescens* and *P. truncatus* recorded

This is well illustrated by the changes in the predator-prey ratio (Table 13). The ratio decreased from 1:1.2 after three months of storage to 1:30.1 at the eighth sampling occasion. An increasing predator-prey ratio could either be due to increasing *P. truncatus*

density relative to *T. nigrescens*, or a decreasing *T. nigrescens* density relative to *P. truncatus* population. However, a look at *T. nigrescens* and *P. truncatus* densities over time (Fig. 3 and Fig. 8) coupled with the positive correlation (Table 12) show that the densities of *T. nigrescens* and *P. truncatus* increased with time. Therefore, the probable indications of increasing predator-prey ratio may be that the per capita growth rate of *P. truncatus* population outstripped that of *T. nigrescens*. The very high magnitude of the ratios, particularly at the seventh and eighth sampling occasions suggests very low densities of *T. nigrescens*.

Boye (1988) recorded mean ratios of *T. nigrescens*: *P. truncatus* of 1:8.4 and 1:7.2 after eight months of storage of maize in a farm in Costa Rica, where *T. nigrescens* effectively controlled *P. truncatus* in stores, during the 1985/86 and 1986/87 seasons respectively. These values were higher than the 1:30.1 recorded in the storage barns at Kpeve.

Fig. 8 Density of *T. nigrescens* adults collected on the three maize varieties stored during the long and short seasons



4.3 Comparison of pest dynamics and weight loss between long and short seasons

4.3.1 Introduction

Rainfall is bimodal in the southern half of the country, and in fact in most parts of the West African sub-region.. For Ghana, it covers the forest savanna transition areas and the forest belt which are important maize growing areas. As has been noted already (refer to section 1.0) the first rains normally begin from March/April to July/August and the second from September to November. The dry period, usually occurring in August for 2 - 4 weeks, separates these two rainfall seasons. There is another longer dry period which occurs from the end of November to the beginning of March. The seasonality of rainfall is exploited for the successful cropping of two rain-fed crops of maize in the these areas. The long (or major) season maize is harvested and stored during the dry spell in August, through the second season rains under conditions of high ambient relative humidity whereas the short (or minor) season crop is harvested and stored under dry - season or harmattan conditions, which are more favourable for grain drying.

A trial was therefore conducted to investigate the population dynamics of *P. truncatus* and *S. zeamais* during the short season storage as well as grain losses they cause. These results were compared with those of the long season trial.

4.3.2. Materials and Methods.

The stores used were similar to those used in long season experiment described in section 3.1. Only one variety, Abutia, was used in this study. The experimental design and sampling procedures were as described in sections 3.2 and 3.3. All measurements taken on

the long season samples were also conducted on the short season samples (see sections 3.3 - 3.7).

The trial was terminated in June after five months of storage. This was because by this time the storage conditions in the stores had become similar to those in the stores stocked with long season maize.

4.3.3 Results And Discussion

4.3.3.1 Insect Pests Of The Short Season

One month into the storage season most of the major insect pests recorded in the long season (see table 1) were also registered in the short season with the exception of *P. truncatus* and its predator, *T. nigrescens*. In addition *Rhizopertha dominica* which was not recorded in appreciable numbers in the long season was found in a store.

The first *P. truncatus* and *T. nigrescens* adults were encountered after two months in store. Although, the number of *Prostephanus*-infested stores as well as its density increased with the progress of the short season (see Fig. 3), no *T. nigrescens* adults were recorded in the subsequent until the last sampling period, when two out of the four stores recorded *T. nigrescens* incidence. Even here, the density was very low as a store recorded only one *T. nigrescens* adult on 78 cobs sampled.

S. zeamais and *R. dominica* commonly occurred in all stores, after five months of storage,. Tolerance of *R. dominica* to high temperatures and varying relative humidities is well documented (Becket *et al.*, 1994) . By the end of the short season storage, almost all other insects encountered in the long season had been recorded.

4.3.3.2 Population densities of *P. truncatus* and *S. zeamais* in the short season.

The population density of *P. truncatus* at all sampling occasions was very low (see Table 14). After its first occurrence at the second sampling occasion, *P. truncatus* density remained very low; 0.15 to 0.13 adults per kg. maize grains during subsequent sampling occasions until the fifth, when it increased to 4.17 adult pests per kg. of maize grains. The patterns of build-up of *P. truncatus* infestation in both the long and short seasons stores were similar. There was a relatively large increase in the mean density of the fourth to fifth sampling occasions for the two seasons, although at different rates, The difference between the resulting densities was not statistically significant ($P < 0.05$). However, it is interesting to observe this kind of sudden population density "jump" in both seasons even though sampling dates were different. Studying the grain moisture content patterns for the varieties (Fig. 3), the increase might partly be due to the drop in the moisture content of the grains between the fourth and fifth sampling occasions especially for the short season storage. The moisture content of the long season maize was already decreasing because of the harmattan conditions. *P. truncatus* is known to tolerate dry grains (Hodges, 1986).

Table 14: Density of *P. truncatus* recorded on *Abutia* variety stored during the long and short seasons

Sampling Occasion	Mean density of <i>P. truncatus</i> on <i>Abutia</i> *	
	Long season	Short season
1	0.6 \pm 0.3a	0.00b
2	1.1 \pm 0.6a	1.4 \pm 0.9a
3	1.0 \pm 0.5a	0.2 \pm 0.1a
4	3.4 \pm 1.2a	0.1 \pm 1.0b
5	29.0 \pm 17.7a	4.2 \pm 1.3a

* Means (\pm S.E.) followed by same letters within a row are not significantly different ($P > 0.05$). Insect numbers determined from 3 pooled 26-cob samples per barn. Each value is a mean of 4 barns \pm S.E.

Table 15: Density of *S. zeamais* recorded on *Abutia* variety stored during the long and short seasons.

Sampling occasion	Mean density of <i>S. zeamais</i> on <i>Abutia</i> *	
	Long Season	Short Season
1	169.3 \pm 13.7a	56.5 \pm 12.0b
2	232.5 \pm 17.8a	88.8 \pm 17.4b
3	281.7 \pm 29.6a	105.2 \pm 27.1b
4	217.3 \pm 35.1a	168.3 \pm 21.0a
5	242.3 \pm 30.1a	185.9 \pm 20.8a

* Means (\pm S.E) followed by same letters within a row are not significantly different ($P > 0.05$). Insect numbers determined from 3 pooled 26-cob samples per barn. Each value is a mean of 4 barns \pm SE.

Nevertheless, differences were observed in the densities of *P. truncatus* in stores. *P. truncatus* appeared in stores earlier in the long season than in the short season. Furthermore, at the fourth sampling occasion there was a significant difference between the mean *P. truncatus* densities ($t=3.23$, $P < 0.05$).

The population of *S. zeamais* increased progressively from the first to the fifth sampling occasions (Fig. 4). Comparing the densities of *S. zeamais* adults per kg. grain for the long and short seasons within sampling occasions (see Table 15) revealed significant differences ($P < 0.05$) during the first three samplings, with t -values of 7.58, 7.12 and 5.42 for the first, second and third sampling occasions, respectively. *S. zeamais* density during the short season were significantly lower. It is interesting to note that in stores stocked during the short season, *S. zeamais* increased throughout the harmattan season while the density in stores stocked during the long season had levelled - off (see Fig. 4). Part of the difference in the density patterns may have been due to density dependent effects, such as greater deterioration of the maize in the long-season trial, competition among beetles for oviposition sites, etc. resulting in *S. zeamais* leaving these stores to colonise the short season stores.

As with the density of *P. truncatus*, the density of *S. zeamais* at every sampling occasion in the short season was lower than that recorded for the long season.

4.3.3.3 Weight losses in the short season.

Percentage grain weight losses over time are shown in Fig 7. From the losses at harvest at 0.5%, losses increased to 3.4% after five months of storage. This was significantly lower than was recorded for the long season (see Table 8). Subtracting the initial loss at harvest leaves about 2.9% as real storage loss which is good enough loss level. This value was lower than what occurred in store after five months of storage in the long season: 7.7%. Losses recorded in the short season were consistently lower than those recorded in the long season at all sampling periods. The differences were also statistically different ($P < 0.05$) in four out of five occasions (see Table 16). It is interesting to note that the short season stores, although stocked near already infested stores of the long season still suffered less losses, apparently from low infestation of the primary insect pests especially *P. truncatus*.

Nevertheless, multiple regression analyses conducted on the percentage grain loss with *P. truncatus* and *S. zeamais* as independent variables revealed that most of the losses to the grains were caused by *S. zeamais*. All regression ANOVA F-tests and standardized regression coefficients were also significant for *S. zeamais* with the exception of the fifth sampling occasion. The low density of *P. truncatus* may explain its minor importance in this analysis.

Table 16: Percentage weight loss suffered by the Abutia variety in the long and short seasons.

Sampling Occasion	Mean Losses suffered by Abutia*	
	Long Season	Short Season
1	2.6 \pm 0.1a	0.6 \pm 0.1b
2	4.8 \pm 1.3a	1.2 \pm 0.2b
3	4.2 \pm 0.5a	1.2 \pm 0.2b
4	3.9 \pm 0.5a	2.0 \pm 0.6a
5	8.1 \pm 0.9a	3.4 \pm 0.5b

*Means (\pm S. E.) followed by same letters within a row are not significantly different ($P > 0.05$) by t-test. Each value is a mean of 4 barns.

4.4 Economic and weight loss measurement using the visual scale of damage

4.4.1 Introduction

Conventionally, storage losses are determined by quantitative methods. However, in rural maize trade, where maize is sold by volume, maize price is often determined by the quality of the grains. A visual scale of damage developed by the UK Overseas Development Agency (ODA)/ Ghana Ministry of Food and Agriculture (MOFA) Larger Grain Borer Project was therefore used to assess the relative economic value loss of maize stored in the long season. Here, dry-weight loss and the pattern of cob damage development in storage were observed using the visual scale.

4.4.2 Materials And Methods

4.4.2.1 Weight and economic loss assessment

The visual scale for rapid loss assessment developed by the Ghana larger Grain Borer Project (GLGBP, 1994) consists of six categories of damage numbered from 1 (no damage) to 6 (severe damage). Representative cob samples photographed as standard reference (see Plate 1) were used in assigning the maize cobs into their respective classes. This was applied to all the batches of twenty-six cobs used for the standard count and weigh loss assessment described earlier (see section 3.5). Here, after dehusking, each cob was classified into one of the six damage classes on the visual scale. The total number of cobs in each damage class was then recorded against the class. Weight loss and economic loss were calculated using the formula:

$$\frac{\sum N_t M_t}{N}$$

Where: N_t = number of cobs in t th class

M_t = Average weight (or economic) loss for t th class

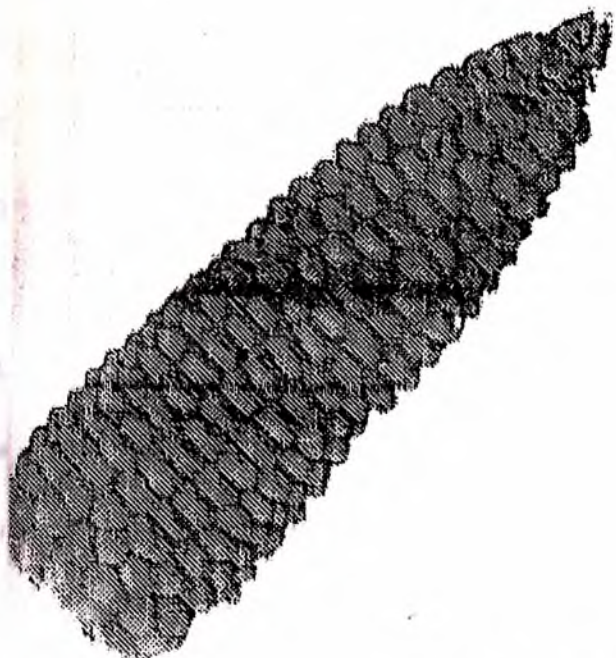
N = Total number of cobs

The average weight loss values or coefficients used in the calculation were: 0%, 2%, 10%, 30%, 50% and 90% for the damage classes 1, 2, 3, 4, 5 and 6 respectively. These values were obtained from calibration curves, by the GLGB Project at Ho.

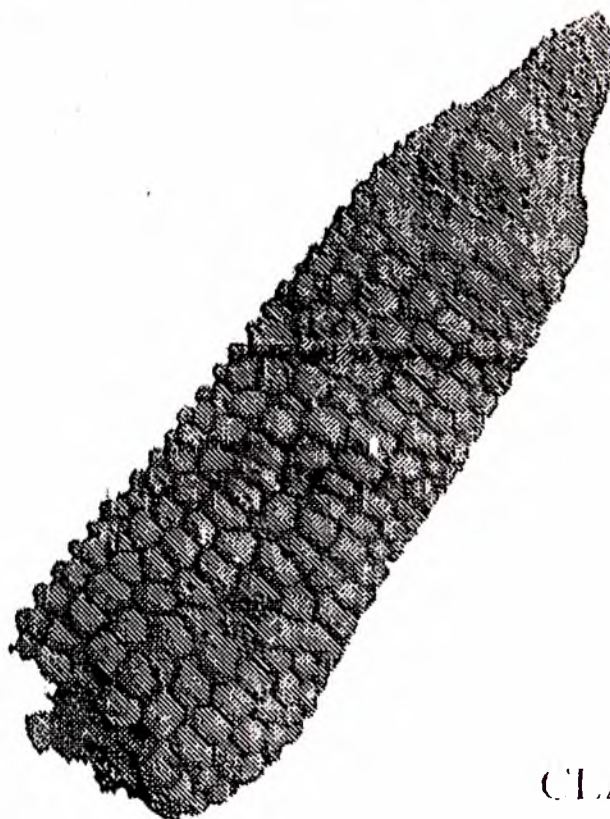
Similarly, the coefficients used for the economic loss were 0%, 0%, 12%, 47%, 75%, and 100% for the damage classes 1, 2, 3, 4, 5 and 6 respectively.

Plate 1: Visual Scale showing damage classes of maize cobs

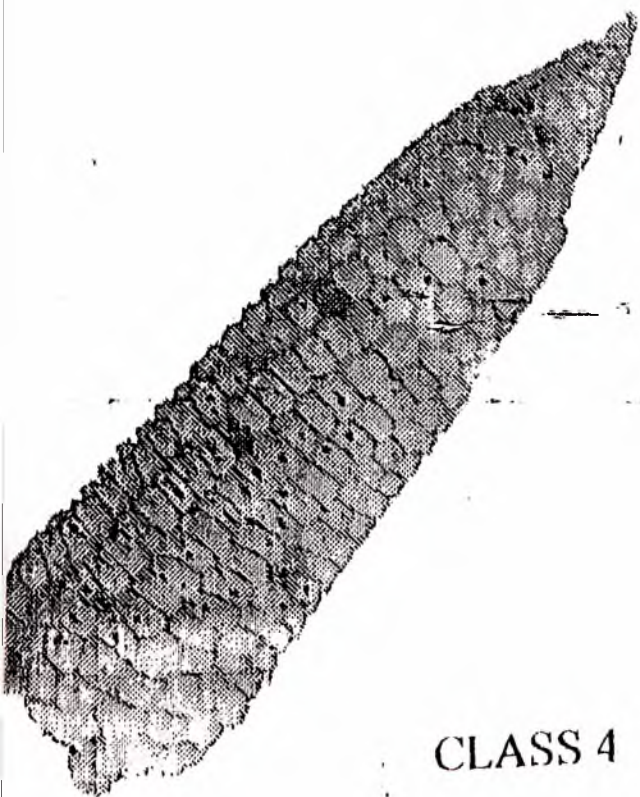
CLASS 1 = UNDAMAGED COB



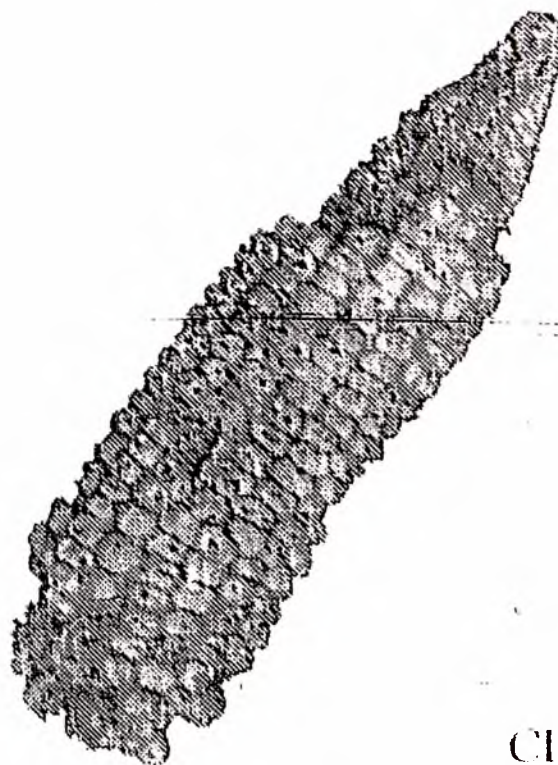
CLASS 2



CLASS 3



CLASS 4



CLASS 5

CLASS 6 = TOTALLY DAMAGED COB

4.4.3 Results And Discussion

4.4.3.1 Structure of cob damage

A critical observation of the damage to cobs across all varieties (Tables 17, 18 and 19) revealed that throughout the storage season about 46% of the cobs did not suffer any damage at all, i.e., they were found in the damage class 1, and almost none in class 6.

However, as the storage season progressed the proportion of cobs in damage classes 2 and 3 decreased while those in classes 4 and 5 generally increased.

Variety-wise, it could be seen that the damage development of Abeleehi and Dzolokpuita appeared similar while both differed from that of Abutia with slow increases in the damage levels of the two. A mean frequency of about 20 cobs were always recorded in classes 4 and 5 during the first seven months of storage compared with about 25 for Abutia. Moreover, a relatively higher proportion of cobs in damage class 3 was registered for Abeleehi and Dzolokpuita than for Abutia. However, during the last month of storage, over 30% of the cobs were found in this damage class for all varieties. The allocation of consistently fewer Abutia cobs into damage class 3, an occurrence that became more severe later in the season although proportion of cobs in class 2 decreased, may be evidence of the destructive nature of *P. truncatus*. It suggests that damage by this insect is very high. This is because the progression of cobs from class 2 through 3 to classes 4 and 5 could not be detected with a sampling frequency of one month. Abeleehi also exhibited this lower and decreasing proportion of class 3 cobs later in the season when *P. truncatus* density on the cobs increased (see Table 2).

Table 17: Damage development of maize cobs of Abutia variety stored during the long season

Sampling occasion	Damage Class					
	1	2	3	4	5	6
1	No data was taken for this month					
2	52.00	17.25	10.50	16.65	4.25	0.00
3	48.50	18.00	9.50	20.00	4.25	0.00
4	48.00	20.00	9.00	13.75	9.50	0.00
5	50.25	12.00	7.75	21.25	8.75	0.00
6	47.25	13.35	8.25	17.75	13.50	0.00
7	53.75	14.25	3.75	20.25	8.25	0.00
8	51.50	10.75	3.75	12.75	19.25	0.00

Table 18: Damage development of maize cobs of Abeleehi variety stored during the long season

Sampling occasion	Damage Class					
	1	2	3	4	5	6
1	No data was taken for this month					
2	39.75	27.00	14.25	8.00	0.50	0.00
3	43.00	23.25	17.00	13.50	3.25	0.00
4	43.75	22.00	11.50	15.25	7.50	0.00
5	47.25	17.75	13.50	18.00	3.50	0.00
6	43.25	18.25	9.00	19.50	10.25	0.00
7	50.75	10.75	10.50	19.50	8.75	0.00
8	47.50	10.00	7.50	20.75	14.50	0.00

Table 19: Damage development of maize cobs of Dzolokpuita variety stored during the long season.

Sampling occasion	Damage Class					
	1	2	3	4	5	6
1	No data was taken for this month					
2	45.25	30.75	12.75	9.00	2.25	0.00
3	41.75	28.25	16.00	10.25	3.75	0.00
4	42.25	26.50	12.50	16.25	2.25	0.00
5	41.25	24.25	10.75	17.25	2.50	0.00
6	44.75	18.75	10.00	19.75	6.50	0.75
7	43.25	19.25	11.25	16.50	9.50	0.00
8	42.25	17.50	14.25	18.00	13.25	0.00

But it is striking to note that about 50% of the cobs for the Abutia variety that experienced a particularly high density of primary insects, especially *P. truncatus* (see Tables 2 and 3), remained undamaged (i.e. allocated into class 1) and again no cob entered the class 6 category. Reasons for these observations are not very clear. It is possible that those insects that left these infested cobs, as a result of food and oviposition site limitation, were rather attracted to already infested cobs, probably due to aggregation pheromone secretion (Trematera and Girgenti, 1989; Cork *et al.*, 1991). It is also possible that with the generally low *P. truncatus* infestation during the season, comparison is not clear since the insect densities were calculated on per kilogramme basis rather than per cob. However, errors committed during the placement of damaged cobs into categories because of the fine distinctions between damage classes, cannot be discounted. This is a disadvantage of using visual scales.

4.4.3.2 Dry weight loss by visual scales

The trend in weight loss obtained using the visual scales (Fig. 9) was similar to that obtained from the standard count and weight data, although the magnitude of the values were larger (cf. Table 8 vrs. Table 20). The maximum weight loss values recorded after eight months of storage by the visual scale method were 13.4%, 13.0%, and 12.0% respectively for Abutia, Abeleehi and Dzolokpuita (Table 20). These values were between 1.8% and 4.6% higher than what was obtained using the standard count and weigh method. The higher magnitude of weight loss figure by using the visual scales method may be due to the fact that the coefficients of the various damage classes used in calculating this weight loss were calibrated against the modified count and weigh method (see Compton *et al.*, 1992). This modified version of the count and weigh takes into account grains that get completely destroyed as a result of insect pest activities as well as those grains that crumble during shelling. These 'missing grains' do not get considered by the standard count and weigh method. Thus, the standard count and weigh method usually underestimates dry weight loss of maize varieties with softer grains as well as those that suffer severe infestations of primary insect pests.

Varietal effects showed significance ($F_{2,9} = 5.06$, $P = 0.034$) (see Appendix 5). However, mean separation by Sheffe's test revealed significance ($P < 0.5$) only at the second sampling occasion for the early storage phase. There was also a significant difference ($P < 0.5$) at the fifth sampling occasion for the late storage phase (see Table 20). Weight loss by this method also changed with time ($F_{3,27} = 7.25$, $P = 0.001$). There was a significant increase in dry weight loss after two months in storage ($F_{1,9} = 18.14$, $P = 0.002$) i.e. between the second and third successive samplings, and again between the fourth and fifth successive

samplings ($F_{1,9} = 8.31$, $P=0.018$). After five months in storage, grain loss generally increased for all varieties but differences were not significant. However, a significant increase in weight loss ($F_{1,9} = 6.58$, $P=0.03$) was observed between the seventh and eighth sampling occasions. This might be due to the significant increase in *P. truncatus* during that period (see section 4.3.2). No interaction between variety and time of sampling was observed.

Fig.9 Percentage weight loss (by visual scale of damage) of three varieties of maize stored during the long and short seasons

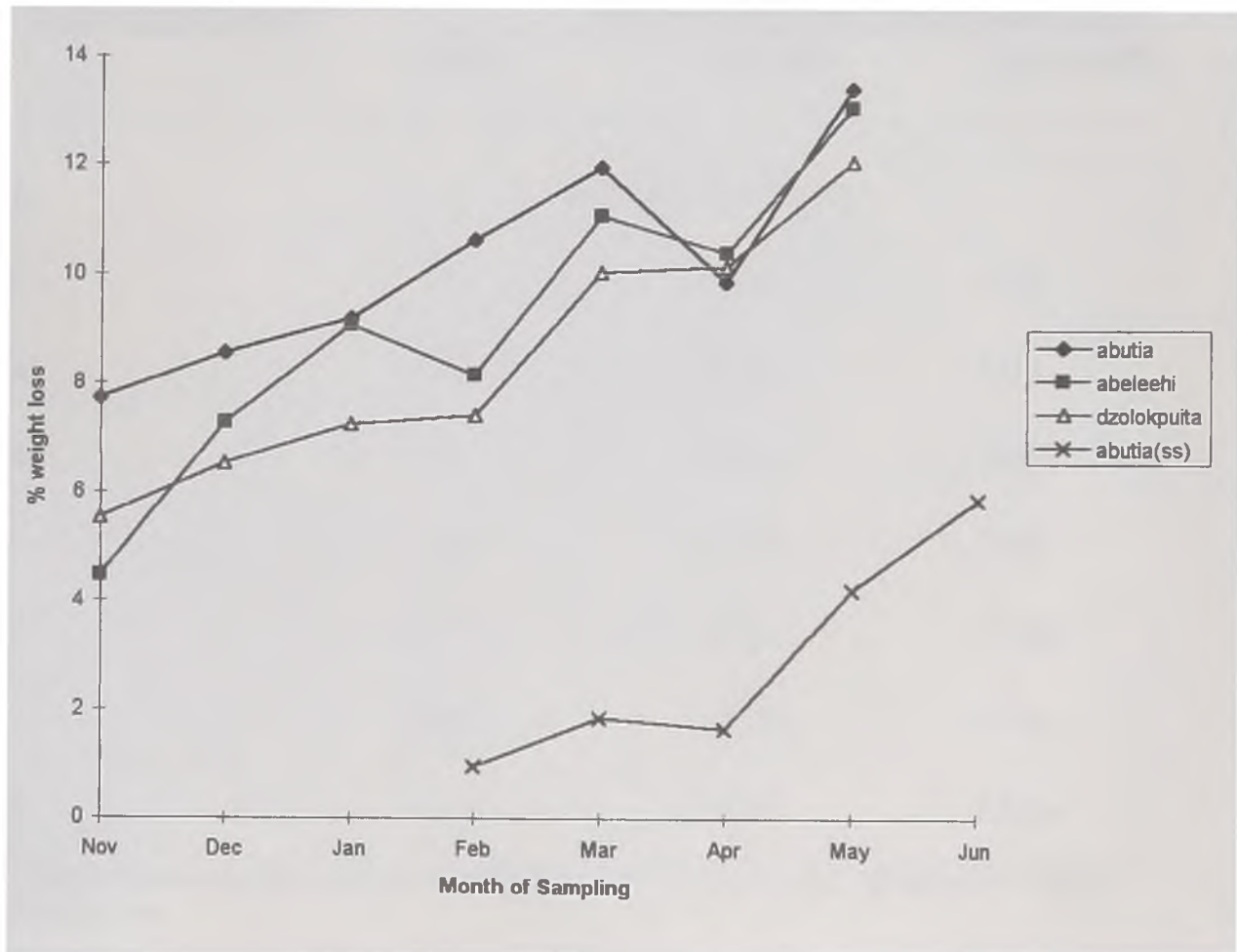


Table 20: Percentage weight loss using the visual scale for the three maize varieties stored during the long season.

<u>Sampling occasion</u>	<u>Mean weight loss (visual scale) (%)*</u>		
	Abutia	Abelechi	Dzolakpuita
1	No data was taken		
2	7.7a	4.5b	5.5b
3	8.6a	7.3a	6.5a
4	9.2a	9.1a	7.2a
5	10.6a	8.1ab	7.4b
6	11.9a	11.1a	10.0a
7	9.8a	10.4a	10.1a
8	13.4a	13.0a	12.0a

* Means followed by the same letters within a row are not significantly different ($P > 0.05$) by Scheffe's test.

4.4.3.3 Economic Value Loss

Maize is sold on the open market with high price variability among markets, depending on the location of the market with respect to the main production centers (see Henckes, 1991; Compton and Magrath, 1994). Maize prices also fluctuate during the course of the storage season, with extremely high prices usually in the pre-harvest lean season (between April and June). Price increases during this period could be as high as 200% (Magrath and Compton, 1994). Kartey (1992) analysing retail prices of a unit bowl (about 2.5 kg.) of maize between 1986-1991 in the Volta region, for instance, found that the storage of maize was profitable each year, since the nominal price increased significantly during the period. Taking inflation into consideration, Magrath (1994) agreed there were significant real price increases over the same period. With the out-break of *P. truncatus* in the region, making maize storage more risky, it is important that economic losses in maize storage are determined to provide information for sound decision-making by the farmers. Such information comes in handy when one is deciding on, for instance, whether to bring down a store because of post-harvest pest damage or hold on to the maize stock, in spite of the infestation, and wait for higher prices during the lean season, particularly in the deficit areas where prices are driven more by availability than by quality (Henckes, 1991; Magrath, 1994).

The economic value loss increased during both phases of storage in the long season (Fig. 10). Although Abutia recorded the highest value loss at almost every sampling occasion (Table 21), it was Abelechi which experienced the greatest economic loss of 15.5% in storage.

Fig. 10 Percent economic value loss of three varieties of maize stored during the long and short seasons

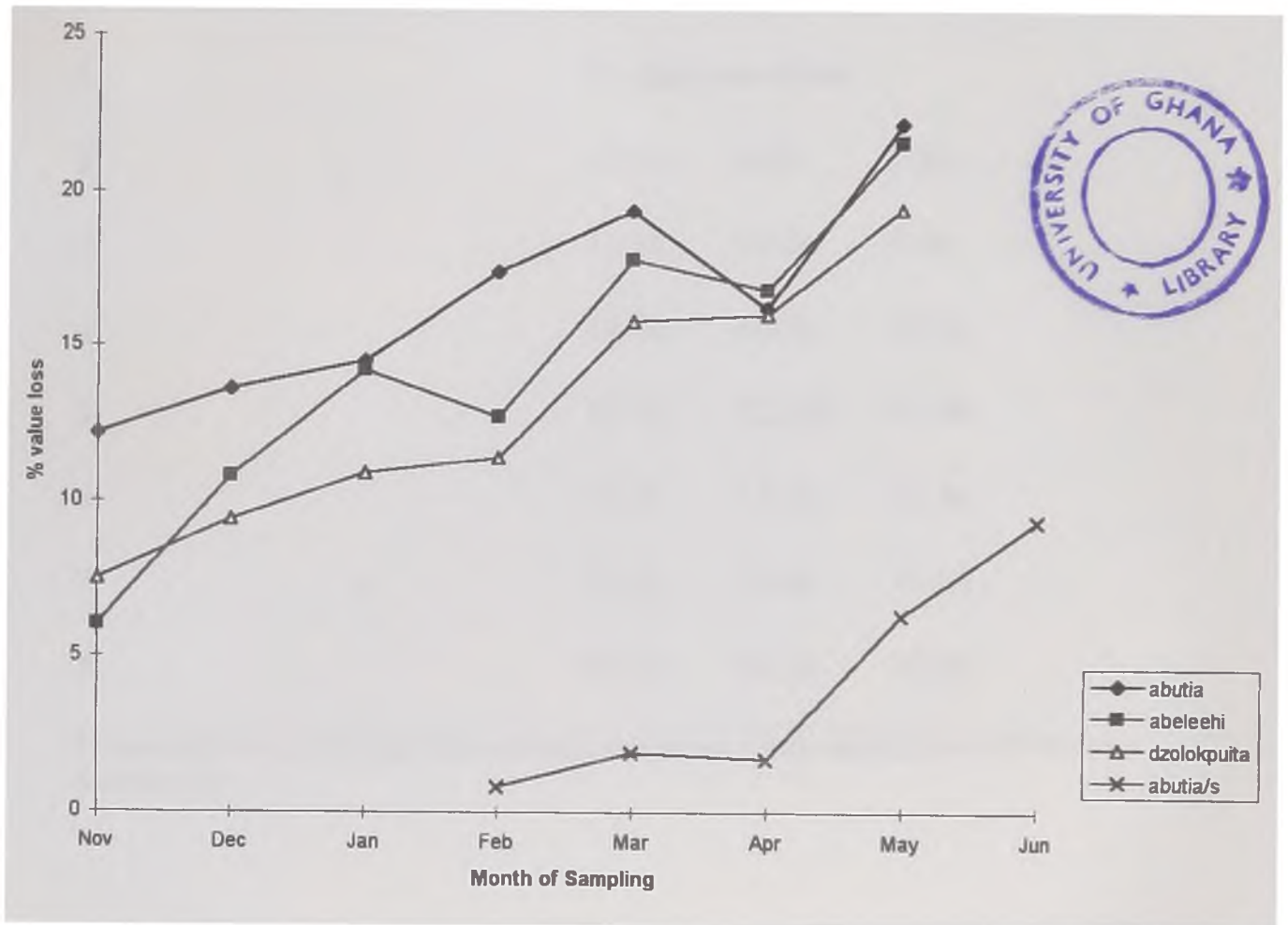


Table 21: Percentage relative economic value loss using the visual scale for the three maize varieties stored during the long season.

<u>Sampling occasion</u>	<u>Mean economic value loss (visual scale) (%)*</u>		
	<i>Abutia</i>	<i>Abelechi</i>	<i>Dzolo kputa</i>
1	No data was taken		
2	12.2a	6.0b	7.5b
3	13.6a	10.8a	9.4a
4	14.5a	14.2a	10.9a
5	17.4a	12.7ab	11.4b
6	19.4a	17.8a	15.8a
7	16.2a	16.8a	16.0a
8	22.1a	21.5a	19.4a

* Means followed by the same letters within a row are not significantly different ($P > 0.05$) by Scheffe's test.

It recorded the least value loss of 6.0% after two months in store, with Abutia and Dzolo kputa registering 12.2%, and 7.5% respectively. However, at the end of the long season storage period, Abelechi suffered a cumulative value loss of 21.5%, compared with 22.1% and 19.4% for Abutia and Dzolo kputa respectively. Significant differences ($P < 0.05$) among maize varieties, as well as sampling occasions, were observed in both

early and late storage phases. There were, however, no interaction between the economic losses suffered by the maize varieties and sampling periods in any of the two phases.

Analyses of variance of the contrast variables in the early phase revealed a significant difference ($F_{1,9} = 18.37$, $P=0.002$) (see Appendix 6) between the value loss levels of second and fourth sampling occasions in the early phase. This observation was not surprising, considering that insect pests, especially *S. zeamais* density sharply increased in this storage phase (see Fig. 3), most probably due to colonization and reproduction (Markham, 1981). Similarly, during the late phase the value loss increased significantly ($F_{1,9} = 19.16$, $P=0.002$) between the fifth and the eighth sampling occasions. However, this increase may have been gradual, as no differences were detected after the fifth sampling occasion except between the last two sampling occasions. This significant increase was possibly due to the surprisingly decreased value loss figures recorded for Abutia and Abelechi varieties at the seventh sampling period which might itself be due to experimental error.

5.0 SUMMARY AND CONCLUSIONS

The influence of maize variety and season on the dynamics of the larger grain borer, *Prostephanus truncatus* and *Sitophilus zeamais* population was studied in the traditional farm-level storage barn. The weight losses experienced by the different varieties as a result of infestation by the insect pests were also studied. Moreover, the study included the distribution of the primary pests in the vertical layers, their ovipositional distribution on cobs as well as their association with other secondary insects especially with *Teretriosoma nigrescens*, a predator of *P. truncatus* recently introduced into Ghana. Relative economic value loss of the cobs were also studied with the aid visual of a scale of damage.

From the study, the following results can be summarised:

1. The incidence of *P. truncatus* was generally low. However maize variety showed significance with Abutia consistently recording the highest pest densities throughout the storage season. *P. truncatus* densities also increased over time.
2. Densities of *S. zeamais* were similarly high on all varieties. *S. zeamais* population increased rapidly and reached its maximum after three months of storage. The densities on all varieties remained relatively stable after then, fluctuating slightly with an amplitude of 100 insects per kg grain.
3. Maize variety influenced weight losses early in the storage season but not in the late phase. Weight losses significantly increased with time. Dzolokpuita recorded the least weight loss at almost every sampling occasion
4. Husk number and grain hardness were thought to explain the low *P. truncatus* density and weight loss. But varietal characteristics did not influence *S. zeamais* population. No differences were observed among the distribution of either pest with

respect to the vertical section of the barn compartment. However the successful rate of emergence of *S. zeamais* adults from reared-out cobs early in the storage season decreased as more *P. truncatus* adults emerged from the these cobs later in the season.

6. Both *P. truncatus* and *S. zeamais* densities were significantly associated with the more abundant secondary pests, namely, *Cathartus quadricollis*, *Palorus subdepressus* and *Cryptolestes ferrugineus*.

7. *P. truncatus* density strongly and positively correlated with *Teretriosoma nigrescens* density. However, *T. nigrescens* did not have an overall restrictive effect on *P. truncatus* population growth.

8. *P. truncatus* density in the long season were not different from those of the short season. However *S. zeamais* densities were different for the first three sampling occasions. Weight losses sustained by the variety were similar for the two storage seasons

9. Cob damage development for Abeleehi and Dzolokpuita varieties appeared slower than for Abutia, presumably because of low *P. truncatus* incidence. However more cobs of Abutia escaped insect damage.

10. The economic value loss increased over time. Although Abutia recorded the highest value loss figures per sampling time, Abeleehi lost much of its economic value, about 16%, by the end of the storage season.

From the results presented, the relative varietal susceptibility of maize cultivars proved to be important in influencing the population build-up of *P. truncatus* and subsequent weight loss of stored maize. Husk numbers and grain hardness appeared to explain the relative resistance to *P. truncatus* damage. These and other varietal characteristics

such as strength and wholeness of husk, phenolic content should be further explored in a wider spectrum of maize cultivars. Since *P. truncatus* density and loss increased over time, length of storage should be considered important. The performance of *T. nigrescens* on *P. truncatus* in the introduced areas should be assessed. It is not clear whether the introduced *T. nigrescens* is undergoing establishment difficulties here in Ghana or *T. nigrescens* was actually responsible for the collapse of *P. truncatus* in the Volta region during the 1994/1995 storage season. For a successful integrated pest management package for the small-scale, resource-poor rural farmers for *P. truncatus* control, these problematic issues should be considered carefully.

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Appendix 1**Assessment of maize varieties from Ghana for resistance to *Prostephanus truncatus*****(Horn) (Coleoptera: Bostrichidae)****Summary of Materials and Methods**

Maize varieties were frozen and placed in a controlled temperature and humidity chamber (CTH) room at 27°C and 70% r.h. Moisture content of the grains was equilibrated between 13.5% - 14.5%.

Maize Hardness Testing

A Glen Creston mill was used at a speed of 6000rpm. Three 20g samples of maize were ground to warm up the mill. The mill was left for 20 seconds after being turned on to obtain a constant speed. Two replicates per sample of 20g were milled for 20 seconds. The flour left in the mill after this time was brushed out. The entirety was sieved through a 710um sieve for four minutes using an Endecotts Octagon 200 test sieve shaker on maximum amplitude.

Coefficient of hardness is the weight retained divided by the weight that passed through the sieve (i.e. the higher the coefficient obtained the harder the variety).

VARIETY	HARDNESS COEFFICIENT
SAFITTA-2	2.3
KAWANZIE	2.3
DZOLOKPUTTA	1.5
PENYI	1.5
ABUROTIA	1.9
LEKLEBI	1.2
ABELEEHY	1.8
DORKE-SR	1.3
CULTURE MAIZE	0.9
ABUTIA	0.8

SUMMARY OF ANALYSIS OF VARIANCE PROCEDURE
REPEATED MEASURES ANALYSIS OF VARIANCE
REPEATED MEASURES LEVEL INFORMATION

APPENDIX 2(*Prostephanus truncatus*)

Dependent variable		PT 1	PT 2	PT 3	PT 4
Level of PT		1	2	3	4
Test of Hypotheses for between subject effects					
Source	df	Anova SS	Mean square	F Value	Pr > F
Variety	2	0.8607	0.4304	7.75	0.0110
Error	9	0.4995	0.0555		

Test of Hypotheses for Within subject effects					
Source	df	Anova SS	Mean square	F Value	Pr > F
PT	3	0.1385	0.0461	3.17	0.0404
PT*Variety	6	0.2622	0.0435	3.0	0.0224
Error(PT)	27	0.3934	0.0146		

Analysis of variance of contrast Variables

PT.N represents the contrast between the nth level of PT and the last

Contrast variable: PT.1

Source	df	Anova SS	Mean square	F Value	Pr > F
Mean	1	0.2107	0.2107	5.38	0.0455
Variety	2	0.4074	0.2037	5.20	0.0315
Error	9	0.3524	0.0392		

Contrast variable: PT.2

Source	df	Anova SS	Mean square	F Value	Pr > F
Mean	1	0.0660	0.0660	1.49	0.2536
Variety	2	0.3157	0.1579	3.56	0.0727
Error	9	0.3993	0.0444		

Contrast variable: PT.3

Source	df	Anova SS	Mean square	F Value	Pr > F
Mean	1	0.2002	0.2002	10.38	0.0105
Variety	2	0.2372	0.1186	6.15	0.0207
Error	9	0.1736	0.0193		

Dependent variable		PT 5	PT 6	PT 7	PT 8
Level of PT		1	2	3	4
Test of Hypotheses for between subject effects					
Source	df	Anova SS	Mean square	F Value	Pr > F
Variety	2	9.4367	4.7183	4.3	0.0489
Error	9	9.877	1.0974		

Test of Hypotheses for Within subject effects

Source	df	Anova SS	Mean square	F Value	Pr > F
PT	3	6.1978	2.0659	25.11	0.0001
PT*Variety	6	0.2480	0.0413	0.5	0.8009
Error (PT)	27	2.2211	0.0823		

Analysis of variance of contrast Variables

PT.N represents the contrast between the nth level of PT and the last

Contrast variable: PT.1

Source	df	Anova SS	Mean square	F Value	Pr > F
Mean	1	10.6974	10.6974	37.04	0.0002
Variety	2	0.0533	0.0267	0.09	0.9127
Error	9	2.5660	0.2888		

Contrast variable: PT.2

Source	df	Anova SS	Mean square	F Value	Pr > F
Mean	1	7.1302	7.1302	40.52	0.0001
Variety	2	0.2601	0.1301	0.74	0.5044
Error	9	1.5835	0.1760		

Contrast variable: PT.3

Source	df	Anova SS	Mean square	F Value	Pr > F
Mean	1	2.4210	2.4210	22.34	0.0011
Variety	2	0.0753	0.0377	0.35	0.7155
Error	9	0.9751	0.1083		

APPENDIX 3 (*Sitophilus zeamais*)

Dependent variable	SZ 1	SZ 2	SZ 3	SZ 4
Level of SZ	1	2	3	4

Test of Hypotheses for between subject effects

Source	df	Anova SS	Mean square	F Value	Pr > F
Variety	2	0.0478	0.2339	0.87	0.4515
Error	9	0.2472	0.0275		

Test of Hypotheses for Within subject effects

Source	df	Anova SS	Mean square	F Value	Pr > F
SZ	3	1.8773	0.6258	51.92	0.0001
SZ*Variety	6	0.4003	0.0667	5.54	0.0008
Error(SZ)	27	0.3254	0.0121		

Analysis of variance of contrast Variables

SZ.N represents the contrast between the nth level of SZ and the last

Contrast variable: SZ.1

Source	df	Anova SS	Mean square	F Value	Pr > F
Mean	1	2.0336	2.0336	87.55	0.0001
Variety	2	0.5923	0.2962	12.75	0.0024
Error	9	0.2090	0.0232		

APPENDIX 4 (Percent weight loss)

Dependent variable		Loss 1	Loss 2	Loss 3	Loss 4
Level of Loss		1	2	3	4
Test of Hypotheses for between subject effects					
Source	df	Anova SS	Mean square	F Value	Pr > F
Variety	2	0.2842	0.1421	17.5	0.0008
Error	9	0.0731	0.0081		

Test of Hypotheses for Within subject effects					
Source	df	Anova SS	Mean square	F Value	Pr > F
Loss	3	0.3232	0.1077	10.06	0.0001
Loss*Variety	6	0.2034	0.0339	3.17	0.0175
Error(Loss)	27	0.0731	0.0081		

Analysis of variance of contrast Variables

Loss.N represents the contrast between the nth level of Loss and the last

Contrast variable: Loss.1

Source	df	Anova SS	Mean square	F Value	Pr > F
Mean	1	0.5677	0.5677	81.65	0.0001
Variety	2	0.0599	0.0299	4.3	0.0488
Error	9	0.0626	0.0069		

Contrast variable: Loss.2

Source	df	Anova SS	Mean square	F Value	Pr > F
Mean	1	0.1408	0.1408	4.46	0.0638
Variety	2	0.1623	0.0826	2.62	0.1270
Error	9	0.2841	0.0316		

Contrast variable: Loss.3

Source	df	Anova SS	Mean square	F Value	Pr > F
Mean	1	0.0217	0.0217	2.02	0.1886
Variety	2	0.1262	0.0631	5.89	0.0232
Error	9	0.0964	0.0107		

Dependent variable		Loss 5	Loss 6	Loss 7	Loss 8
Level of Loss		1	2	3	4

Test of Hypotheses for between subject effects					
Source	df	Anova SS	Mean square	F Value	Pr > F
Variety	2	0.1164	0.0832	4.25	0.0501
Error	9	0.1460	0.0196		

Test of Hypotheses for Within subject effects					
Source	df	Anova SS	Mean square	F Value	Pr > F
Loss	3	0.3363	0.1121	9.72	0.0002
Loss*Variety	6	0.1495	0.0249	2.16	0.0786
Error(Loss)	27	0.3112	0.0115		

Analysis of variance of contrast Variables

Loss.N represents the contrast between the nth level of Loss and the last

Contrast variable: Loss.1

Source	df	Anova SS	Mean square	F Value	Pr > F
Mean	1	0.4219	0.4219	38.79	0.0002
Variety	2	0.0236	0.0118	1.08	0.3790
Error	9	0.0978	0.0109		

Contrast variable: Loss.2

Source	df	Anova SS	Mean square	F Value	Pr > F
Mean	1	0.5720	0.5720	29.1	0.0004
Variety	2	0.1209	0.0604	3.07	0.0960
Error	9	0.1769	0.0197		

Contrast variable: Loss.3

Source	df	Anova SS	Mean square	F Value	Pr > F
Mean	1	0.2581	0.0258	9.99	0.1886
Variety	2	0.0477	0.0239	0.92	0.4318
Error	9	0.2326	0.0258		

APPENDIX 5 (visual scale loss)

Dependent variable	vsloss 1	vsloss 2	vsloss 3
Level of vsloss	1	2	3

Test of Hypotheses for between subject effects

Source	df	Anova SS	Mean square	F Value	Pr > F
Variety	2	29.15	14.57	5.06	0.0336
Error	9	25.91	2.88		

Test of Hypotheses for Within subject effects

Source	df	Anova SS	Mean square	F Value	Pr > F
vsloss	2	42.96	21.48	6.47	0.0076
vsloss*Variety	4	11.94	2.99	0.9	0.4851
Error(vsloss)	18	59.78	3.32		

Analysis of variance of contrast Variables

vsloss.N represents the contrast between the nth level of vsloss and the last

Contrast variable: vsloss.1

Source	df	Anova SS	Mean square	F Value	Pr > F
Mean	1	84.64	84.64	18.14	0.0021
Variety	2	23.4	11.7	2.51	0.1362
Error	9	41.99	4.67		

Contrast variable: vsloss.2

Source	df	Anova SS	Mean square	F Value	Pr > F
Mean	1	13.13	13.13	1.11	0.3188
Variety	2	3.42	1.71	0.15	0.8670
Error	9	106.06	11.78		

Dependent variable	vsloss 4	vsloss 5	vsloss 6	vsloss 7
Level of vsloss	1	2	3	4

Test of Hypotheses for between subject effects

Source	df	Anova SS	Mean square	F Value	Pr > F
Variety	2	19.44	9.72	3.61	0.0708
Error	9	24.26	2.7		

Test of Hypotheses for Within subject effects

Source	df	Anova SS	Mean square	F Value	Pr > F
vsloss	3	105.45	35.18	7.25	0.001
vsloss*Variety	6	15.42	2.57	0.53	0.7806
Error(vsloss)	27	130.94	4.85		

Analysis of variance of contrast Variables

vsloss.N represents the contrast between the nth level of vsloss and the last

Contrast variable: vsloss.1

Source	df	Anova SS	Mean square	F Value	Pr > F
Mean	1	200.17	200.17	17.3	0.0025
Variety	2	11.03	5.51	0.48	0.6357
Error	9	104.14	11.57		

Contrast variable: vsloss.2

Source	df	Anova SS	Mean square	F Value	Pr > F
Mean	1	39.04	39.04	3.39	0.0986
Variety	2	0.86	0.43	0.04	0.9636
Error	9	103.55	11.51		

Contrast variable: vsloss.3

Source	df	Anova SS	Mean square	F Value	Pr > F
Mean	1	87.53	87.53	6.58	0.0305
Variety	2	5.13	2.57	0.19	0.8278
Error	9	119.8	13.31		

APPENDIX 6 (value loss)

Dependent variable	vloss 1	vloss 2	vloss 3
Level of vloss	1	2	3

Test of Hypotheses for between subject effects

Source	df	Anova SS	Mean square	F Value	Pr > F
Variety	2	114.8716	57.4435	7.24	0.0133
Error	9	71.356	7.9284		

Test of Hypotheses for Within subject effects

Source	df	Anova SS	Mean square	F Value	Pr > F
vloss	2	130.4717	65.2358	6.92	0.0059
vloss*Variety	4	39.0867	9.7717	1.04	0.4158
Error(vloss)	18	169.7147	9.43		

Analysis of variance of contrast Variables

vloss.N represents the contrast between the nth level of vloss and the last

Contrast variable: vloss.1

Source	df	Anova SS	Mean square	F Value	Pr > F
Mean	1	258.54	258.54	18.37	0.002
Variety	2	77.32	38.66	12.75	0.1171
Error	9	126.64	14.07		

Contrast variable: vloss.2

Source	df	Anova SS	Mean square	F Value	Pr > F
Mean	1	44.85	44.85	1.39	0.2689
Variety	2	13.13	6.56	0.2	0.8189
Error	9	290.79	32.31		

Dependent variable vloss 4 vloss 5 vloss 6 vloss 7
 Level of vloss 1 2 3 4

Test of Hypotheses for between subject effects

Source	df	Anova SS	Mean square	F Value	Pr > F
Variety	2	77.81	38.91	5.22	0...0313
Error	9	67.12	7.46		

Test of Hypotheses for Within subject effects

Source	df	Anova SS	Mean square	F Value	Pr > F
vloss	3	319.86	106.62	8.15	0.0005
vloss*Variety	6	45.71	7.62	0.58	0.7414
Error(vloss)	27	353.4	13.09		

Analysis of variance of contrast Variables

vloss.N represents the contrast between the nth level of vloss and the last

Contrast variable: vloss.1

Source	df	Anova SS	Mean square	F Value	Pr > F
Mean	1	613.47	613.47	19.16	0.0018
Variety	2	37.81	18.9	0.59	0.5743
Error	9	228.19	32.02		

Contrast variable: vloss.2

Source	df	Anova SS	Mean square	F Value	Pr > F
Mean	1	130.02	130.02	4.22	0.07
Variety	2	2.11	1.06	0.03	0.9664
Error	9	276.99	30.78		

Contrast variable: vloss.3

Source	df	Anova SS	Mean square	F Value	Pr > F
Mean	1	260.4	260.4	6.65	0.0297
Variety	2	12.75	6.38	0.16	0.8522
Error	9	352.38	39.15		