

A SEARCH FOR INDIGENOUS PARASITOIDS FOR  
THE CONTROL OF THE LARGER GRAIN BORER,  
*Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae)

BY

SEIDU SHAIBU SEINI

B.Sc (HONS) BIOLOGY

A THESIS PRESENTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS  
FOR THE DEGREE OF M.PHIL. ENTOMOLOGY OF THE UNIVERSITY OF GHANA

INSECT SCIENCE PROGRAMME\*  
UNIVERSITY OF GHANA  
LEGON.



JANUARY, 1998.

*\* Joint interfaculty international programme for the training of entomologists in West Africa .  
Collaborating Departments: Zoology (Faculty of Science) & Crop Science (Faculty of Agriculture)*

## ABSTRACT

This study was conducted to identify indigenous parasitoids for the control of the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera : Bostrichidae). A search was conducted at various market stores in the Greater Accra and Volta Regions to collect and identify parasitoids associated with stored product pests. *Anisopteromalus calandrae* (Howard) (Hymenoptera : Pteromalidae) and *Dinarmus basalis* (Rondani) (Hymenoptera : Pteromalidae) associated respectively with *Sitophilus zeamais* Motschulsky (Coleoptera:Curculionidae) and *Callosobruchus maculatus* (Fabricius) (Coleoptera : Bruchidae), were found to be the most abundant and most frequent. These two parasitoids were thus selected for investigation into their possible controlling effect on *P. truncatus*. *A. calandrae* caused a significant suppression of 47.5% in *S. zeamais* population during a 16 weeks study period. *A. calandrae* also caused a significant suppression in *P. truncatus* population to the tune of 43.8% within the same period of study. In this study, *A. calandrae* was found to prefer larger and older (3rd instar) *P. truncatus* larvae for oviposition and development. All larger grain borer larval instars were however acceptable to *A. calandrae* for oviposition, with the 3rd instar being the most suitable for its development. *D. basalis*, on the other hand caused a profound 83.8% suppression in *C. maculatus* population at a mean parasitoid level of 26.7 in the treatment. *D. basalis* however did not attack *P. truncatus* at all. *A. calandrae* therefore has the potential to contribute substantially to an integrated control of *P. truncatus* in Ghana.

## DECLARATION

I do hereby declare that, except for references to works of other researchers which have been duly cited, this thesis consists entirely of research work conducted by me 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.



SEIDU SHAIBU SEINI

( Student)

PROF. J.N. AYERLEY

(SUPERVISOR)

## DEDICATION

This thesis is dedicated to my parents, Mr and Mrs Seidu Seini, My wife Fairuza, my children, Ridwa, Abdul-Kadiri, and my brothers Ahmed, Zakaria and my sister Fatimatu for their love and prayers.



## ACKNOWLEDGEMENTS

All praises be to the Almighty God for giving me life to complete this work. I am greatly indebted to the following personalities whose invaluable support in diverse ways enabled me to complete this work successfully.

-Professor J.N. Ayertey, my Principal Supervisor, for his patience, concern constructive criticism and fatherly support.

-Messrs P.E. Azidoku, Head of Ministry of Food and Agriculture (MoFA) Research Station. Kpeve and his Deputy E. Ray Adasi. Also Rebecca, Irene, Victor Anku and all other workers of the Research Station for their support, hospitality and encouragement.

-My colleagues: Kojo, Ferdinand, Alex, Ralph, Natala, Acheampong, Khardy and all other M.PHIL. students for their moral support.

-Mrs Fairuza Shaibu, for her prayers support and encouragement.

-Profound gratitude also goes to the National Agricultural Research Programme, NARP, for the research grant offered me to enable me complete the study.

-Finally, I wish to thank all my well-wishers: Your encouragement and support was definitely invaluable in urging me on to this successful end. GOD BLESS YOU ALL!

## TABLE OF CONTENTS

ABSTRACT.....	i
DECLARATION.....	ii
DEDICATION.....	iii
ACKNOWLEDGEMENTS.....	iv
TABLE OF CONTENTS.....	v
LIST OF TABLES.....	vi
<b>1.0 INTRODUCTION.....</b>	<b>1</b>
1.1 <i>Prostephanus truncatus</i> in Africa.....	1
1.2 Justification.....	3
1.3 Objectives.....	4
<b>2.0 LITERATURE REVIEW.....</b>	<b>5</b>
2.1 The larger grain borer.....	5
2.1.1 Identification of the LGB.....	5
2.1.2 Geographical distribution.....	5
2.1.3 <i>P. truncatus</i> in Ghana.....	6
2.1.4 Life History and behaviour.....	7
2.1.5 Pest status and Losses.....	9
2.1.6 Relationship of <i>P. truncatus</i> with other stored product pests.....	10
2.1.7 Natural enemies of <i>P. truncatus</i> .....	11
2.1.8 Control of the LGB.....	11
2.1.8.1 Chemical control.....	11
2.1.8.2 Growth regulators.....	12
2.1.8.3 Plant products.....	13
2.1.8.4 Drying and smoking.....	13
2.1.8.5 Irradiation.....	13
2.1.8.6 Hermetic storage.....	14
2.1.8.7 Host plant resistance.....	14
2.1.8.8 Biological control.....	15
2.2 The predator, <i>Teretriosoma nigrescens</i> Lewis (Coleoptera: Histeridae).....	17
2.2.1 Taxonomy and Description.....	17
2.2.2 Biology and Ecology.....	17
2.2.3 Classical biological control of <i>P. truncatus</i> using <i>T. nigrescens</i> .....	19
2.3 Hymenopterous parasitoids in the stored product system.....	21
2.3.1 A general overview.....	21
2.3.2 Braconid parasitoids in storage.....	21
2.3.3 Pteromalid parasitoids in storage.....	21
2.3.4 Bethyloid parasitoids in storage.....	22
2.3.5 Other less represented parasitoids in storage.....	22
<b>3.0 MATERIALS AND METHODS.....</b>	<b>24</b>
3.1 The search for parasitoids.....	24
3.1.1 Stored product sampling.....	24

3.1.2 Rearing out of parasitoids and hosts.....	24
3.1.3 Identification of insects.....	24
3.1.4 Selection of parasitoids for study.....	25
3.2 Culturing <i>Sitophilus zeamais</i> .....	27
3.3 Culturing <i>Callosobruchus maculatus</i> .....	27
3.4 Culturing <i>P. truncatus</i> .....	27
3.5 Culturing of parasitoids.....	28
3.6 Damage and dry-weight loss determination.....	28
3.7 Analysis of results.....	29
<b>4.0 DESCRIPTION OF EXPERIMENTS.....</b>	<b>30</b>
4.1 The effect of <i>A. calandreae</i> on <i>S. zeamais</i> population and activity.....	30
4.1.1 Introduction.....	30
4.1.2 Materials and Methods.....	30
4.1.3 Results and Discussion.....	32
4.1.3.1 <i>S. zeamais</i> density.....	32
4.1.3.2 Loss and damage.....	33
4.2 The effect of <i>A. calandreae</i> on <i>P. truncatus</i> population and activity.....	35
4.2.1 Introduction.....	35
4.2.2 Materials and Methods.....	35
4.2.3 Results and Discussion.....	37
4.2.3.1 Larger grain borer numbers.....	37
4.2.3.2 Damage and Loss.....	38
4.3 The acceptability and suitability of different <i>P. truncatus</i> larval instars for the development of <i>A. calandreae</i> .....	40
4.3.1 Introduction.....	40
4.3.2 Materials and Methods.....	40
4.3.3 Results and Discussion.....	42
4.3.3.1 Host instar preference, acceptability and suitability.....	42
4.4 The effect of <i>D. basalis</i> (Rondani) on <i>C. maculatus</i> population and activity.....	45
4.4.1 Introduction.....	45
4.4.2 Materials and Methods.....	45
4.4.3 Results and Discussion.....	46
4.4.3.1 Insect numbers.....	46
4.4.3.2 Loss and Damage.....	47
4.5 The effect of <i>D. basalis</i> on <i>P. truncatus</i> population and activity.....	49
4.5.1 Introduction.....	49
4.5.2 Materials and Methods.....	49
4.5.3 Results and Discussion.....	50
4.5.3.1 Insect numbers.....	50
4.5.3.2 Grain dry-weight Loss.....	51
<b>5.0 SUMMARY AND CONCLUSION.....</b>	<b>53</b>
<b>6.0 LITERATURE CITED.....</b>	<b>56</b>
<b>APPENDIX.....</b>	<b>72</b>

**LIST OF TABLES**

Table 1: The frequency and abundance of parasitoids obtained from sampled stored products....	26
Table 2: The effect of <i>A. calandrae</i> on <i>S. zeamais</i> numbers, damage and loss of maize.....	34
Table 3: Correlation coefficients of pairs of parameters.....	34
Table 4: The effect of <i>A. calandrae</i> on <i>P. truncatus</i> numbers, damage and loss of maize.....	39
Table 5: Correlation coefficients of selected pairs of parameters.....	39
Table 6: Host fate after parasitisation by <i>A. calandrae</i> .....	44
Table 7: Preference shown by <i>A. calandrae</i> for different LGB larval instars .....	44
Table 8: The effect of <i>D. basalis</i> on <i>C. maculatus</i> numbers, damage and loss of cowpeas.....	48
Table 9: The effect of <i>D. basalis</i> on <i>P. truncatus</i> numbers, and loss of maize.....	52

## 1.0 INTRODUCTION

### 1.1 *Prostephanus truncatus* in Africa.

The larger grain borer, *Prostephanus truncatus* (Horn) has long been recognized as a common pest of farm-stored maize in Mexico, Central and South America, and a sporadic pest in southern United States (Wright, 1984). During the early 1980s, *P. truncatus* was introduced into parts of East and West Africa, where it has now become established as the most destructive pest on farm-stored maize and dried cassava (Hodges et al., 1983a; Krall, 1987; McFarlane, 1988). In Africa this pest was first detected during 1980 in the Tabora region of Tanzania (Hodges et al., 1983a). *P. truncatus* is now widely distributed in Tanzania, and has spread via primary or secondary introductions to parts of other African countries such as Kenya, Burundi, Zaire, Togo, Benin, Uganda and Ghana (Schulz and Laborius, 1987., Rees et al., 1990). In Togo, insect-related dry weight losses of local maize varieties during 8 months storage prior to the occurrence or introduction of *P. truncatus* averaged 5.5%. Under the same conditions and duration of storage, these losses averaged 44.8% after the appearance of *P. truncatus* (Krall, 1987). Such high grain losses in farm-stored maize due to *P. truncatus* infestations have also been observed in Tanzania (Hodges et al., 1983a). *P. truncatus* is now considered a major threat to the maize producing regions of Africa.

*P. truncatus* can infest and breed on cobs as well as shelled maize and cassava (Bell and Waters, 1982; Hodges et al., 1983a). Rees et al.(1990) have captured adults of *P. truncatus* in forest plantations, and dry scrubland habitats devoid of maize and cassava. The presence of

*P. truncatus* in these habitats suggests that the pest is able to survive on several alternative host plants besides maize and cassava (Rees et al., 1990). Adults can cause greater damage to cob than shelled maize because the kernels are more stable on the cob (Cowley et al., 1980). Adults also bore into wooden structures, maize husks, maize core and kernels. Grain damage is primarily due to tunnelling by adults, resulting in the production of large amounts of maize flour. The tunnels in the grain serve as oviposition sites (Howard, 1984) and the flour serves as a food source for the emerging larva. Shires (1980) reported that, on an average, 68% of all eggs of a female are laid inside maize kernels where development of the immature is completed.

Infestations of *P. truncatus* may be found together with those of other storage insects. In dry conditions in Tanzania (Hodges et al., 1983a) and Nicaragua (Giles and Leon, 1974), *P. truncatus* was the predominant storage pest among at least seven other species. The ability of *P. truncatus* to develop at low moisture may be one reason for its success. Under such conditions many other storage pests are unable to increase in number. For example, *Sitophilus oryzae*, a species occurring in the same ecological niche, needs a grain moisture of at least 10.5% to be able to develop (Shires, 1979). Thus, in dry conditions *P. truncatus* probably benefits from the absence of any significant competition from other storage pests.

In attacking rural maize stores, *P. truncatus* threatens not only an important cash crop but the food security of vulnerable small scale farmers, in some cases in regions where lack of infrastructure and other constraints severely limit the possibilities for substituting alternative crops. The conventional response to the larger grain borer outbreak, orchestrated by the Food and Agriculture Organization of the United Nations (FAO) and the Natural Resources Institute

(NRI), followed a predictable cycle, beginning with attempted eradication. This was followed by measures to contain the outbreak, by statutory measures and the testing of insecticide-based strategies for longer term management of the pest (Golob, 1988a). One problem with the over-reliance on the synthetic pyrethroids has been the risk of pesticide resistance.

Laboratory studies have shown that the larger grain borer (LGB) is developing resistance to permethrin (Golob et al., 1990b). Other problems generally associated with the use of chemicals in Agriculture include pest resurgence due to pesticide misuse, pollution of the environment as well as effects on non-target organisms. For these reasons other alternatives such as biological control have been emphasized in recent times.

## 1.2 Justification

As a recently introduced outbreak pest, the LGB in Africa is a promising candidate for classical biological control. It is widely considered that the significantly lower grain losses due to the LGB in its area of origin, Central America, than in Africa may be due to the action of natural enemies. One promising predator, *Teretriosoma nigrescens* (Lewis) (Coleoptera: Histeridae), closely adapted to feeding on the LGB has been found in Costa Rica. In Ghana, under the auspices of the National Biological Control Programme and the International Institute of Tropical Agriculture (IITA), this predator was imported into the country, quarantined and screened. After obtaining satisfactory results from laboratory studies two releases have been made in the Volta region where devastations due to LGB have been most felt.

Other natural enemies have also been identified associated with the LGB. According to Boeye (1988), the wasp *Anisopteromalus calandrae* (Howard) (Hymenoptera: Pteromalidae) is an

important parasitoid of several stored product beetles including the LGB, *Sitophilus* spp. and *Callosobruchus maculatus* (F.). Also Markham et al. (1991), reported that the hymenopterous wasps *Anisopteromalus calandrae* (Howard) and *Chaestospila elegans* Westwood which were found to be parasitoids of the LGB in Costa Rica are native to Africa.

Since a number of parasitoids are already present in the tropics, there is the need to examine the effect these are likely to have on the new pest, *Prostephanus truncatus* (Horn), introduced into Africa. Indeed the effect of some of these on *P. truncatus* have been examined in Central America, but no similar work has been carried out in Ghana.

### 1.3 Objectives

The aim of the study was to determine:-

- (1) The occurrence of hymenopterous parasitoids associated with stored product pests in Ghana.
- (2) The extent to which the selected parasitoids, *Anisopteromalus calandrae* (Howard) (Hymenoptera: Pteromalidae) and *Dinarmus basalis* (Rondani) (Hymenoptera: Pteromalidae) could prevent a population of the larger grain borer, LGB, from increasing.
- (3) The most promising parasitoid for integration into the national biological control effort against the larger grain borer.

## 2.0 LITERATURE REVIEW

### 2.1 The larger grain borer

#### 2.1.1 Identification of the LGB

*P. truncatus* was first described by Horn (1878) as *Dinoderus truncatus* Horn. It has also been referred to as *Stephanopachys truncatus* by Back and Cotton (1922). The genus *Prostephanus* was erected by Lesne (1897) to include this and other species. *P. truncatus* is the only one of these species known to be associated with stored products. The name "larger grain borer" was first used by Chittenden (1911) in a paper on this species and its relative, "lesser grain borer", *Rhyzopertha dominica* (Fabricius).

There are detailed descriptions of both the adult (Horn, 1878; Lesne, 1897; Fisher, 1950) and the larva and pupa (Spilman, 1984). The adults may be identified using the extensive key of Fisher (1950) or the shorter key of Kingsolver (1971) or Hodges (1982). No keys are available for the identification of the larva or pupa. Adults may be sexed by reference to the clypeal tubercles (Shires and McCarthy, 1976) and pupa according to the size and shape of the genital papillae (Bell and Watters, 1982).

#### 2.1.2 Geographical distribution

In the New World, where the species is indigenous, there are records of the beetle from Southern U.S.A (Chittenden, 1911; Back and Cotton, 1922), Guatemala (Zacher, 1954), Brazil and Guatemala (Cotton and Good, 1937), Peru (Wright, 1984), Columbia (Posoda et al., 1976), Costa Rica (Fisher, 1950), Panama, Honduras and El Salvador (McGuire and Crandall, 1967).

Nicaragua (Giles and Leon, 1974) and Mexico (Chittenden, 1911; Delgado and Hernandez Luna, 1951). *P. truncatus* has been found on imports into Israel (Calderon and Donahaye, 1962) and Iraq (Al-Sousi et al., 1970). In both cases the beetle was introduced in maize but in neither country did it become established. It is recorded among a list of stored product insects of Thailand (Sukprakarn, 1976).

Prior to 1981 there were no records of this pest in Africa. But in that year the beetle was identified as the pest causing severe losses in farm stored maize in the hot and dry Tabora region of Tanzania (Golob and Hodges, 1982). Since 1981 *P. truncatus* has spread widely within Tanzania and has now reached Southern Kenya (Kega and Warui, 1983), and Burundi (Tropical Development and Research Institute (TDRI), Unpublished records). Early in 1984 a serious and sustained outbreak of the pest occurred in Togo (Harnisch and Krall, 1984). The LGB was also reported causing widespread devastation of stored maize in the Volta Region of Ghana in 1989 (Dick et al., 1989).

### **2.1.3 *P. truncatus* in Ghana**

The first survey to determine the presence of the larger grain borer in Ghana on the Ghana-Togo border was carried out in 1986 (Ayertey and Brempong-Yeboah, 1991). This was as a result of an earlier introduction of the LGB into Togo in 1984. The results however proved negative. A second survey carried out in 1989 however revealed that LGB was present in all villages in the Volta region over a 150km stretch of the border with Togo ; stretching from Kpetoe in the south to Ameyoe in the north (Dick et al., 1989). In April 1991, another survey revealed a considerably high population build-up at places where the insect had been found in the earlier survey (Ayertey

and Brempong-Yeboah, 1991). A Ghana LGB Project (GLGBP) survey conducted in 1993 showed that *P. truncatus* 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 (Boateng, 1997). Apart from the Volta region, the most seriously affected parts of the country are the Dangme West district of the Greater Accra Region, areas of Eastern region bordering the Volta region and the Saboba district of the Northern region (Addo, 1994).

#### **2.1.4 Life history and Behaviour**

*P. truncatus* is a pest of maize, infesting both the stored crop (Giles and Leon, 1974; Hodges et al., 1983a) and the standing crop (Quintana et al., 1960; Giles, 1975). The pest also thrives on dried cassava (Hodges et al., 1983a; Hodges et al., 1985). The method of presentation of maize grain may affect its susceptibility to *P. truncatus*. This has been confirmed in field studies (Golob et al., 1985) in which maize on the cob suffered considerably more damage than shelled grain. Attempts in the laboratory to rear the species on cowpea, haricot beans, cocoa and coffee beans, hard winter wheat and rough rice have failed and resulted only in the commodities being bored. However, the pest can breed on a soft variety of wheat (Shires, 1977). The pest would appear to bore into solid substrates irrespective of their nutritional quality, as the beetle has been observed penetrating a range of materials in which there is no evidence of breeding, e.g. some types of wood (Chittenden, 1911; Hodges et al., 1983a), beans (Giles, 1975), groundnuts (Hodges et al., 1983a), perspex and polythene (Howard, 1983).

Studies of the life cycle of *P. truncatus* over a wide range of temperatures (12-40 °C) and

humidities (30-90% r.h.) suggest that the optimum conditions for development on maize are 32°C and 70-80% r.h. (Shires, 1979 & 1980; Bell and Watters, 1982). The lower and upper limits for completion of the life cycle are 25 and 32°C at 70% r.h. and 20 and 30°C at 90% r.h. (Bell and Watters, 1982). Under optimum conditions on whole grain or on flour packed firmly into glass tubes, Bell and Watters (1982) observed that the life cycle was completed in 24-25 days. In contrast, Shires (1979), rearing the pest in loosely packed maize flour recorded a development period of 35.4 days. It is assumed that these widely different developmental periods relate to the degree of packing of the developmental medium or food quality. Adults bore into the maize grains making neat round holes, and as they tunnel from grain to grain, they generate large quantities of powder.

After mating adult females lay most eggs within the grain in blind-ending chambers bored at right angles to the main tunnels (Hodges, 1982; Howard, 1983). The eggs are laid in batches of up to 20 and covered with finely chewed maize powder. The ovipositional curve of *P. truncatus* includes an egg production peak at 20 days and thereafter a gradual decline (Shires, 1980; Bell and Watters, 1982). Shires (1980) found that when adult pairs were maintained on loose grains at 32°C and 80% r.h., females had a pre-oviposition period of 5-10 days, an oviposition period of 95-100 days and mean fecundity of 50.5 eggs. When eggs are maintained at 32°C and 70% r.h. they hatch after an average of 4.1 days and the mean larval period is 16.1 days (Bell and Watters, 1982). Using head capsule measurements, Bell and Watters (1982) observed that there are normally three larval instars. This has been confirmed using a technique involving fronto-clypeal measurements (Subramanyam et al., 1985). In *P. truncatus*, at 32°C and 70% r.h., the mean pupal

period lasts 4.7 days (Bell and Watters, 1982), so that an average development from egg to adult at 32°C and 70% r.h. takes 25.4 days.

On emergence female *P. truncatus* tend to weigh more than males. In a Mexican strain reared on maize flour at 25°C and 70% r.h., the average female weight was greater by 7% (Howard, 1983), while females of a Tanzanian strain developing on cassava at 23°C and 50-70% r.h. were heavier by about 13% (Nyakunga, 1982; Hodges et al., 1985). The sex ratio of adults reared on maize flour, maintained under a wide range of conditions has shown no significant deviation from unity (Shires, 1979).

Tolerance of dry conditions by *P. truncatus* has been confirmed during various laboratory studies (Young et al., 1962; Hodges and Meik, 1984). In Tanzania, Hodges et al. (1985) found heavy infestations in maize of 9-10.6% moisture content. Estimates of the intrinsic rate of increase of *P. truncatus* under favourable environmental conditions, on stabilized maize grain (Bell and Waters, 1982) or maize cobs (Hodges and Meik, 1984) are in the range of 0.7 - 0.8 per week.

Adult males and females may congregate at a food source in response to the male-produced aggregation pheromone (Hodges et al., 1984). The pheromone secretions are known to contain two physiologically active ingredients given the trivial names "Trun-call 1 and 2" (William et al., 1981).

### **2.1.5 Pest status and Losses**

*P. truncatus* appears to spread during the storage season. For example, in 1982 in a Tanzanian village, the larger grain borer could be found in 20% of stores just after harvest in May. But close to the end of the storage season in October, 80% of stores were infested (Hodges, 1984). The

timing of the onset of attack may however vary from year to year.

In Nicaragua, weight losses of up to 40% have been observed on maize cobs stored for six months on the farm (Giles and Leon, 1974). Losses of up to 34% have been recorded in Tanzania after 3 - 6 months of storage (Hodges et al., 1983a). Losses in dried cassava are also observed to be very high. The dried roots are readily reduced to powder through adult boring. And a weight loss of 70% has been recorded in an experimental maize crib in Tanzania after 4 months of storage (Hodges et al., 1985). *P. truncatus* is able to sustain its population at economically significant levels under the hot and dry conditions of Nicaragua and East Africa. It causes similar damaging infestations in the hot humid conditions of West Africa (Krall, 1984).

#### **2.1.6 Relationship of *P. truncatus* with other stored product pests**

Infestations of the larger grain borer may occur at the same time as other storage pests. In dry conditions in Tanzania (Hodges et al., 1983a) and in Nicaragua (Giles and Leon, 1974), *P. truncatus*, among at least seven other pest species, was observed to be the predominant storage pest. Under these dry conditions, many other storage pests are not able to increase in population. In Tanzania, maize cobs and shelled grains became heavily infested with *P. truncatus* and *Sitophilus spp.* after they were maintained for ten months in the same storage crib. The population of *P. truncatus* was always greater than that of *Sitophilus spp.* although with time, the populations were nearly equal. However, *Sitophilus spp.* remained strongly dominant when they were maintained on loose grain (Golob et al., 1985).

timing of the onset of attack may however vary from year to year.

In Nicaragua, weight losses of up to 40% have been observed on maize cobs stored for six months on the farm (Giles and Leon, 1974). Losses of up to 34% have been recorded in Tanzania after 3 - 6 months of storage (Hodges et al., 1983a). Losses in dried cassava are also observed to be very high. The dried roots are readily reduced to powder through adult boring. And a weight loss of 70% has been recorded in an experimental maize crib in Tanzania after 4 months of storage (Hodges et al., 1985). *P. truncatus* is able to sustain its population at economically significant levels under the hot and dry conditions of Nicaragua and East Africa. It causes similar damaging infestations in the hot humid conditions of West Africa (Krall, 1984).

#### **2.1.6 Relationship of *P. truncatus* with other stored product pests**

Infestations of the larger grain borer may occur at the same time as other storage pests. In dry conditions in Tanzania (Hodges et al., 1983a) and in Nicaragua (Giles and Leon, 1974), *P. truncatus*, among at least seven other pest species, was observed to be the predominant storage pest. Under these dry conditions, many other storage pests are not able to increase in population. In Tanzania, maize cobs and shelled grains became heavily infested with *P. truncatus* and *Sitophilus spp.* after they were maintained for ten months in the same storage crib. The population of *P. truncatus* was always greater than that of *Sitophilus spp.* although with time, the populations were nearly equal. However, *Sitophilus spp.* remained strongly dominant when they were maintained on loose grain (Golob et al., 1985).

### **2.1.7 Natural enemies of *P. truncatus***

In Central America, *Teretriosoma nigrescens* (Lewis), a predatory beetle is associated with *P. truncatus* (TDRI, unpublished records). In laboratory trials on loose maize grain, weighted with glass beads, at moisture content of 8.5 or 14%, 10 adult *T. nigrescens* were able to prevent a population of up to 100 adult *P. truncatus* from increasing (Rees, 1985). In Tanzania large numbers of *Anisopteromalus calandrae* (Howard), a parasitoid wasp, were found associated with the larger grain borer when relatively few other possible hosts were present (Hodges, unpublished). Although few parasites of the larger grain borer have been reported, laboratory tests at Savanna, Georgia (USA) showed that several species of parasitoids in the family Pteromalidae attack *P. truncatus* (Brower, 1992). *Anisopteromalus calandrae* (Howard), *Lariophagus distinguendus* Foerster, *Chaestospila elegans* Westwood, and *Pteromalus cerealellae* Ashmead all attacked the immature stages of *P. truncatus* within the corn kernel, but their success varied greatly.

### **2.1.8 Control of the LGB**

#### **2.1.8.1 Chemical control**

Various chemicals have been tried against the LGB. The superior performance of the synthetic pyrethroids against this pest was identified by Golob et. al. (1985), even though only permethrin had been tried on the field. Subsequently several pyrethroids have been found to be effective, especially permethrin and deltamethrin (Makundi, 1986). Application of dusts to cobs was largely ineffective as compared to shelled grains (Golob and Hanks, 1990). Thus in Tanzania, the basic recommendation for the large scale control of LGB involved shelled grain, storing in bags.

and treating with a binary "cocktail" consisting of 0.3% permethrin and 1.6% primiphos methyl applied at 100g per 90kg bag (Golob, 1988a). One problem with the over reliance on the synthetic pyrethroids has been the risk of pesticide resistance. Laboratory studies have shown the LGB to be developing resistance to permethrin (Golob et al., 1990b).

Fumigation with Phosphine, at a minimum rate of 1g per m<sup>3</sup> at 20°C has been tried against LGB in Togo. The efficiency of phosphine fumigation against LGB eggs has been confirmed (Haskem and Reichmuth, 1989). Methyl bromide has also been shown to be an effective fumigant against the most tolerant stage, the pupa (Detmers, 1990).

There are however, problems associated with the use of chemicals in Agriculture, especially pesticides. Misuse of pesticides has led to pest resurgence in some instances. Also included is the problem of environmental pollution by pesticides. Widespectrum chemicals, which form the bulk of pesticides are known to kill non-target organisms. For these reasons other alternatives such as biological control, have been emphasized in recent times.

#### **2.1.8.2 Growth Regulators**

Another group of compounds which have recently been investigated for their effect on the LGB are the insect growth regulators, diflubenzuron and trifluron, and their commercial formulations, Dimilin and Alsysting (Hell, 1988). These products show little or no toxicity to beneficial insects and mammals but disrupt insect pest metamorphosis. However, it is important to note that these products are not readily available to the rural farmer.

### **2.1.8.3 Plant Products**

Due to the hazards of synthetic pesticides to man and his environment, there has been renewed interest in the use of other materials for grain protection. Lime sprinkled on cobs at unspecified dosage has proved successful against LGB in its area of origin, Central America (Rodriguez, 1990b). Other plant products, such as dry seeds of *Crotalaria juncea* L. and leaves of *Vogelia* spp. have been tried at 5% (weight/weight), as well as an aqueous extract of pyrethrum at 1%, but all were found to be ineffective for the control of LGB at 32 and 40 weeks of storage (Golob and Hanks, 1990).

### **2.1.8.4 Drying and Smoking**

Traditionally, both in Africa and the New World Tropics, the exposure of cobs and grain to heat and smoke from cooking fires and to sunlight has been used as a means of both drying and directly warding off insects. In general LGB seems more resistant to these strategies than most other insects (Golob and Hodges, 1982). McFarlane (1989) explored the thermal tolerances of LGB in more detail and showed that a total kill could be achieved by exposing infested grain to 50°C in an oven for one hour or by exposure to simulated solar radiation in a solar cabinet for 2 - 3 hours. Direct exposure to sunlight without a cabinet, would not achieve the temperature required for disinfection.

### **2.1.8.5 Irradiation**

Although radiation has been successfully used to control insects in large scale grain facilities (Adem et. al., 1979), LGB can usually be satisfactorily controlled by more conventional methods.

especially fumigation. It therefore seems unlikely that control of this pest would normally justify the considerable investment involved in grain irradiation technology (Giles and Leon, 1974).

#### **2.1.8.6 Hermetic Storage**

Hermetic storage in metal drums is known to provide good control of all storage insect pests including the LGB (Giles and Leon, 1974). But the high initial cost of drums in some areas and the tendency for people to use them for other purposes such as water storage, limits their use in rural grain storage. Plastic bags provide a cheaper alternative but insects tend to perforate the bags, even if the grain is fumigated initially (Giles and Leon, 1974). As hermetic storage works on the principle of insects using up the available oxygen in an airtight container, considerable damage may already be caused by LGB before the pests die.

#### **2.1.8.7 Host Plant Resistance**

Host plant resistance to storage insects could be of immense value in rural storage systems as a factor which could compliment other pest control measures. Mechanisms of resistance of grain to *Sitophilus spp* are more understood than those relating to *P truncatus* (Philogene et al., 1989). In the case of the LGB the phenolic acid content of maize grain, especially that of para-coumaric acid has been shown to be important (Conilh de Beyssac, 1990). If specific factors conferring resistance to storage pests can be identified, these may readily be included in breeding programmes than those which involve more general changes such as grain hardness or endosperm type.

#### 2.1.8.8 Biological Control

There has been increased interest in the possibility of the biological control of the LGB. Classical biological control involves the permanent establishment of introduced natural enemies, which may either be predators, parasitoids or pathogens. It has the advantage of requiring little or no change in storage practices on the part of farmers. It therefore needs little intervention from extension services. This would circumvent two limitations (need for change in storage practices and intervention from extension services) frequently encountered on the introduction of other non-traditional technologies (Markham, 1990).

(i) Predators: The first indication that the LGB might be subject to control by natural enemies came from identification records of the predatory beetle *Teretriusoma nigrescens* (Lewis) (Col.:Histeridae), in association with the pest in maize samples from Mexico (Haines, 1981). Two predators, *Calliodis* spp. and *T. nigrescens* were encountered attacking LGB in Costa Rica but not in Africa (Boeye, 1988). *Calliodis* spp., an anthocorid was not considered for introduction into Africa on account of its comparative fragility and inability to survive without hosts in the desiccating conditions of grain stores (Boeye, 1990). *T. nigrescens* in contrast was able to survive for at least 3 months on maize without prey (Leliveldt and Laborious, 1990). *T. nigrescens* is a voracious predator of LGB capable of suppressing populations of the pest, both alone and with other storage pests, on shelled maize and on cobs (Rees, 1991). But experience shows it is unable to provide a complete control of LGB under ambient conditions in grain stores (Helbig, 1993).

(ii) Pathogens: Comparative studies of micro-organisms pathogenic to *P. truncatus* in Tanzania and Central America were also made (Boeye et al., 1988). Seven out of 23 fungal isolates and two out of 14 bacterial isolates from Central America were found to be somewhat pathogenic to LGB. Unfortunately, the most pathogenic fungi were *Aspergillus spp.* whose use as control agents in rural stores can be discounted in view of their toxic metabolites (Burde, 1988). The protozoa *Nosema pleistophora* (L.) and *Mattesia spp.* were isolated from LGB in Central America (Burde, 1988). Laboratory studies showed that *Mattesia spp.* infection could kill up to 90% of first instar LGB larva and reduced the egg production of adult females without affecting *T. nigrescens* (Leliveldt, 1990). Trials of practical application of protozoa for control of LGB in rural stores have recently been carried out in Togo (Laborious, 1990).

(iii) Parasitoids: Among insect natural enemies, two pteromalids, *A. calandrae* (Howard) and *Chaestospila elegans* Westwood, were found to attack LGB in Costa Rica (Boeye, 1988). Both were found to be native to Africa, as parasitoids of various storage pests.

In the light of this, it was important to investigate the occurrence of hymenopterous parasitoids in Ghana, and their possible controlling effect on *P. truncatus*. The present study was therefore embarked upon to search for parasitoids and to assess the effectiveness of these parasitoids in the control of the LGB

## **2.2 The Predator, *Teretriosoma nigrescens* Lewis (Coleoptera: Histeridae):**

### **2.2.1 Taxonomy and description**

The predator, *T. nigrescens* was first described by Lewis (1891). It belongs to the family Histeridae, which has over 3700 species. However, Hinton (1945) identified only fourteen species as being associated with stored products worldwide. Until recently, evidence of the presence of *T. nigrescens* could be found only in Mexico and Central America (Haines, 1981; Rees et al., 1990). It occurred in association with *P. truncatus*, a pest of erratic importance on farm stored maize (Wright, 1984). According to Leliveldt (1990), *T. nigrescens*, like all other histerid beetles is about 2.3mm in size. Partial cover-up of the abdomen by the hard elytra allow for the exposure of two abdominal segments. The jointed antennae thicken up toward the tip, forming a club-like structure. Tibia of the first pair of legs are toothed, a feature important in defining the species (Poschko, 1994). Due to lack of obvious external dimorphism, sex determination in *T. nigrescens* is only possible after dissection.

To date, *T. nigrescens* has been introduced into Tanzania, Togo (Rees, 1991), Benin, and Ghana to augment the biocontrol efforts against *P. truncatus* in Africa.

### **2.2.2 Biology and Ecology**

Investigations by Rees (1985) into the development cycle of *T. nigrescens* revealed that the development time from egg to adult is 56 days at 26°C, 70% r.h.. Leliveldt and Laborius (1990) however, observed complete development time of less than 50 days at 30°C and 70% r.h. More recently Oussou et al (1995) reported that *T. nigrescens* completed development in 23.5 days at 30°C and 70% r.h.. The relatively large eggs (1.1x0.5mm) laid singly amongst the

commodity, hatch in about seven days at 27°C (Rees, 1985). The larvae are campodeiform, 2 - 3mm long on eclosion, with flattened head bearing large sickle-shaped mandibles. The head and prothorax are heavily sclerotized. There are two larval instars which last between 12 days (Oussou et al, 1995&1999) and 26 days (Leliveldt, 1990), these being at 30°C, 70% r.h and 30°C, 75% r.h respectively. It has been observed by Rees (1985) that the fully grown larva, 1.0 - 1.2cm long, pupates within a chamber in a presumably already damaged grain, fashioned with its mandibles. Pupation is completed between 11 and 18 days at 30°C (Leliveldt and Laborius, 1990). *T. nigrescens*, being a long-lived insect, can reach an age of over 20 months, and still able to reproduce after 16.5 months of reaching the adult stage (Poschko, 1994).

Amongst a list of preys, *T. nigrescens* has shown a distinct preference for *P. truncatus*. It is able to reproduce on two species of *Dinoderus*, on *Sitophilus spp*, *Rhyzopertha dominica* (Fabricius) and *Tribolium castaneum* (Herbst) (Rees, 1987 and Poschko, 1994). Like other histerids, *T. nigrescens* hunts aggressively for its prey. In maize field traps baited with *Prostephanus* pheromone, large numbers of adult *T. nigrescens* have been caught, indicating the ability of this predator to locate *P. truncatus* over much greater distances (Boeye, 1990). Although *T. nigrescens* can also make use of plant food, the fear that it could be a pest on stored food is unfounded, since losses to plant materials are negligible (Poschko, 1994). Indeed there is evidence (Helbig, 1993), that when *T. nigrescens* was kept on maize for 12 weeks no loss was recorded at all.

### 2.2.3 Classical Biological Control of *P. truncatus* using *T. nigrescens*

The conventional response to the outbreak of *P. truncatus*, orchestrated by the Food and Agriculture Organization of the United Nations (FAO), and the Natural Resources Institute (NRI), has gone through an expected cycle, beginning with attempted eradication, through containment, by statutory and other measures, to the testing of insecticide-based strategies for longer term management of the pest (Golob, 1988a). In East Africa, considerable success was reported for a strategy based on a modification of traditional practices involving shelling the grain, modifying storage structures and applying a binary insecticide (Golob, 1988a). In West Africa, similar binary products, comprising a synthetic pyrethroid to control *P. truncatus* and an organophosphate for controlling more familiar pests have been recommended. But the humid conditions in much of the outbreak area have limited prospects of modifying storage practices. Shelling has proved less applicable, and rapid breakdown of insecticides applied to cobs has been frustrating (Golob, 1988b).

Classical biological control was clearly an appealing alternative. Amongst the limited arthropod natural enemies of *P. truncatus*, *T. nigrescens* became the best candidate. It is similar in dimensions and environmental requirements with the pest and was more adapted to the habits and habitat of *P. truncatus*. Additionally, it was shown in studies at NRI that the predator was not only attracted from a distance by the aggregation pheromone; it also responded to shorter range chemical stimuli left on the grain by *P. truncatus* (Rees, 1990).

In laboratory studies *T. nigrescens* larvae proved to be voracious predators of the larger grain borer, especially its immature stages. The predator's consumption rate was estimated by NRI

researchers at up to 3.5 prey larvae per day (Rees, 1985) and in German Technical Co-operation (GTZ) studies at 5.7 eggs or 4.9 larvae per day, when the predator foraged in continual darkness (Leliveldt and Laborius, 1990). Rees (1985), in an experiment on maize in jars in the laboratory, observed that a predator-prey ratio of 1 : 10 was effective in regulating *P. truncatus* populations. Boeye (1988), in Costa Rica, reported a decline of 87% of *P. truncatus* population on shelled maize by the predator after 110 days, as compared to the control. In a corresponding study using maize cobs, the larger grain borer population 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 cob caused by *P. truncatus* was reduced by 47% and 21% respectively (Boeye, 1988).

*T. nigrescens* was readily maintained in the laboratory, where it proved hardy and long-lived. It was felt that voracious predation by both adults and larval *T. nigrescens* would outweigh any disadvantage from the predator's somewhat slow development rate and low reproductive rate. In summary, the potential of *T. nigrescens* as a control agent looked sufficiently promising to justify field releases that have taken place in Togo and Benin (Markham et al., 1994b) and of late in Ghana. These field releases, in the end provide one of the best components of an integrated control of *P. truncatus*.

## **2.3 Hymenopterous Parasitoids in the Stored Product system**

### **2.3.1 A general overview**

Although many species of parasitic wasps have been recorded in association with beetle and moth pests of stored products, most of these are only rare or occasional (Haines, 1981). The great majority of records from tropical stores refer to only 12 common species in three easily recognizable families viz: Braconidae (with one common species), Pteromalidae (with five common species), and Bethyridae (with six common species). Further more, only a few other species in these and five related families account for most of the remaining records (Haines, 1981).

### **2.3.2 Braconid parasitoids in storage**

In the Braconidae, the only common storage wasp is *Bracon hebetor* Say, which is a parasitoid of pyralid warehouse moths (*Corcyra cephalonica* (Stainton), *Ephestia* spp, and *Plodia interpunctella* (Hubner) ) throughout the tropics and subtropics (Benson, 1973). There are occasional records of the closely related species, *B. brevicomis* Wesmael from storage. Other braconids (usually *Apanteles* spp) are rarely found in storage (Benson, 1973).

### **2.3.3 Pteromalid parasitoids in storage**

The family Pteromalidae contains the commonest of all the parasitic wasps found in tropical stores: *Anisopteromalus calandrae* (Howard), which is apparently associated with many beetle (and moth) storage pests, especially *Sitophilus* spp., *Lasioderma serricone* (F.) and *Callosobruchus* spp.. is often found in large numbers (Haines, 1981). The distinctive

*Chaestospila elegans* Westwood , another common pteromalid, is frequently found with *A. calandrae*, though in smaller numbers, and also parasitizes several storage pests (Haines, 1974). *Dinarmus basalis* (Rondani), a parasitoid of Bruchidae in stored produce, occurs in many parts of the tropics, attacking especially *Callosobruchus* spp.. *Pteromalus semotus* (Walker) is of cosmopolitan distribution, usually associated with the grain moth *Sitotroga cerealella* (Olivier). *Lariophagus distinguendus* (Foester), a parasitoid of various stored product beetles is not frequent or numerous in tropical stores. Other pteromalids such as *Dinarmus colemani* (Crawford) are rarely found (Haines, 1981).

#### **2.3.4 Bethylid parasitoids in storage**

The Bethylidae, although also common in tropical storage, are often overlooked because of their small size and slender shape (Haines, 1981). *Holepyris sylvanidis* (Brethes) is mainly a parasitoid of *Tribolium* spp.. *Holepyris hawaiiensis* (Ashmead) is a widespread parasitoid of *Ephestia* spp. and *Plodia interpunctella* (Huhner). Among the rarer species of bethylid, *Cephalonomia gallicola* (Ashmead) is the only one specifically associated with storage, as a parasitoid of the anobiids *Lasioderma serricone* (F.) and *Stegobium paniceum* (L.) (Haines, 1981).

#### **2.3.5 Other less represented parasitoids in storage**

According to Richards (1949), species of Ichneumonidae, especially *Venturia cariescens* (Gravenhorst) and *Diadegma chrysostictos* (Gmelin) , are parasitoids of storage moth larvae but are generally much less common in tropical storage than in temperate climates. Wasps of the family Chalcididae are only occasionally found in small numbers in stores (Haines, 1981). The

tiny wasps of the family Trichogrammatidae, which are egg parasites, are sometimes found to parasitize some storage pests, but are rarely recorded from stores because of their very small size (Richards, 1949). Members of the family Encyrtidae are uncommon in stores, but four species of *Zeteticontus* have been recorded, of which *Z. utilis* Noyes is known to parasitize the larvae of *Carpophilus hemipterus* (L.) (Subra Rao, 1972).

Since a number of parasitoids are already present in the tropics, there is the need to examine the effect these are likely to have on the new pest, *Prostephanus truncatus* (Horn), introduced into Africa . Indeed the effect of some of these on *P. truncatus* have been examined in Central America, but no similar work has been carried out in Ghana.

### **3.0 MATERIALS AND METHODS**

#### **3.1 The search for parasitoids**

##### **3.1.1 Stored-product sampling**

Stored products, especially maize and cowpeas in market stores were sampled to find out which hymenopterous parasitoids were present. It was also to discover which stored product pests the parasitoids were associated with. The various market stores visited were at the Madina , Kaneshie, Alajo and Makola markets, all in Accra. Other samples were taken from the University of Ghana farmstore, as well as from the Kpeve market in the Volta region. At each market place, two margarine tins, one full of maize and the other cowpea, were bought from each of three randomly selected sellers. Each separate sample was immediately placed in a polythene bag and labelled to show date of collection, place of collection, and product collected. Any parasitoids seen in the produce at the time of sampling were collected into a vial using an aspirator. Each vial was also labelled accordingly. The samples were then carried to the laboratory for subsequent incubation and identification.

##### **3.1.2 Rearing out of parasitoids and hosts**

In the laboratory, each sample was placed in a one-litre Kilner jar. Emerged insects were collected once a week by means of an aspirator. Collection continued for 8 weeks. Parasitoids and insect pests collected were preserved in 70% ethanol for subsequent identification.

##### **3.1.3 Identification of insects**

The parasitoids and insect hosts were identified by using available identification keys, developed

by Dobie et al. (1991) of the Natural Resources Institute (NRI) of the United Kingdom. These identifications were confirmed by the Plant Health Management Division of the International Institute of Tropical Agriculture (IITA) at Benin.

The parasitoid, *Anisopteromalus calandrae* (Howard) (Hymenoptera: Pteromalidae) was associated with *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) in maize. The same parasitoid was also associated with *Callosobruchus maculatus* (Fabricius) (Coleoptera: Bruchidae) in cowpeas, *Vigna unguiculata* Walp. *Dinarmus basalis* (Rondani), a bruchid parasitoid was associated with *Callosobruchus maculatus* in cowpeas. Also, *C. maculatus* was parasitized by *Eupelmus vuilleti* Crawford (Hymenoptera: Pteromalidae), in cowpeas. The parasitoid, *Holepyris sylvanidis* (Brethes) (Hymenoptera: Bethyridae) was associated with *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae), in maize.

#### 3.1.4 Selection of parasitoids for study

Of the four parasitoids encountered during the sampling and laboratory studies, two were selected for the present study. *A. calandrae* and *D. basalis*, both pteromalid parasitoids, were the most abundant and most frequent (see Table 1). Of the remaining two parasitoids, *E. vuilleti* (?), also a pteromalid was in extremely low numbers. Also, it could not be positively identified by the IITA taxonomist for lack of a female specimen. So its use for this study was therefore discounted. *H. sylvanidis*, a bethyrid parasitoid, in addition to its low numbers, was observed to be able to escape from the study chambers due to its slender shape. For this reason it was also not suitable for use in the study.

Thus, only *A. calandrae* and *D. basalis* were used in the laboratory study to find out about their possible controlling effect on the larger grain borer, *P. truncatus*.

**Table 1 : The frequency and abundance of Parasitoids obtained from sampled stored products.**

Stored Product	Parasitoid	Host Insect	Frequency (%)**	Abundance per one litre jar
Maize	<i>A. calandrae</i>	<i>S. zeamais</i>	42.6	Up to 40 insects
Maize	<i>H. sylvanidis</i>	<i>T. castaneum</i>	4.4	Up to 10 insects
Cowpeas	<i>A. calandrae</i>	<i>C. maculatus</i>	9.3	Up to 20 insects
Cowpeas	<i>D. basalis</i>	<i>C. maculatus</i>	40.7	Up to 60 insects
Cowpeas	<i>E. vuilleti</i>	<i>C. maculatus</i>	3.0	Up to 10 insects

\*\*Frequency (%) =  $\frac{\text{Number of samples in which parasitoid occurred}}{\text{Total number of samples}} \times 100$

### **3.2 Rearing *Sitophilus zeamais***

Maize was sterilized by placing in an oven at 80°C for four hours. This was to kill any insects and mites present. Grain was then allowed to cool to 27°C before use. Moisture content of grain at time of use was 12.5%. About 200g of the sterilized maize was placed in each of 10 rearing jars. One hundred unsexed adult *S. zeamais* were introduced into each jar for oviposition. After one week, all adults were removed from all the jars by using an aspirator. The *S. zeamais* that were subsequently obtained from these cultures were used for the various experiments in the study.

### **3.3 Rearing *Callosobruchus maculatus***

Cowpea was sterilized by placing in an oven at 50°C for two hours. This was allowed to cool to room temperature before use. About 200g of the sterilized cowpeas were weighed out into each of 10 rearing jars. One hundred unsexed adult *C. maculatus* were introduced into each jar for oviposition. All adult insects were removed after a week using an aspirator. The *C. maculatus* that were subsequently obtained from these cultures were used for the various experiments in the study .

### **3.4 Rearing *Prostephanus truncatus* (LGB)**

LGB was reared on maize. The maize was sterilized as described above in Section 3.2 and 200g of the sterilized maize were placed in each of 20 jars. Twenty unsexed adult *P. truncatus* were introduced into each jar for oviposition. All adult LGB were removed after 2 weeks. The *P. truncatus* obtained from these cultures were then used for the various experiments in the study.

### 3.5 Rearing of Parasitoids

These parasitoids were obtained live from market stores and reared on their respective host insects. Ten pairs of each parasitoid were introduced into each rearing chamber when the host cultures were about 3 weeks old. *A. calandrae* was reared on *S. zeamais*, in maize and *D. basalis* on *C. maculatus* in cowpeas. When adult parasitoids began to emerge, the culture jars were examined daily so that adults of a desired age could be used for the experiments.

### 3.6 Damage and Dry-weight Loss assesment

Damage was assessed on the grain in each jar. Initially, grain in each jar was poured separately into a plastic tray. Each grain was then assessed singly by separating and counting damaged and undamaged grains. Grains with any kind of insect exit holes were regarded as damaged. The percentage of damaged grains out of the total number of grains was recorded.

The standard count-and-weigh technique (Boxall, 1986), was used in all cases to determine dry-weight loss, with the exception of experiments involving the LGB. In this technique, the grain sample in each jar was separated into damaged and undamaged grains. Both the damaged and undamaged grains were counted with a hand tally counter and weighed with an OHAUS mechanical weighing scale.

The percent dry-weight loss was calculated using the following equation (Boxall, 1986):

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

Nd = number of damaged grains.                      Nu = number of undamaged grains.

D = weight of damaged grains.                      U = weight of undamaged grains.

In the experiments involving the LGB, the standard count and weigh method could not be used in determining the losses. This was so because at the end of the experiments, most of the damaged grains had been converted into powder from LGB feeding. Individual whole grains could not therefore be identified. The Sample-Weight-Method (Pantenius, 1988), was therefore used. The grain in each jar was sieved and the grain left behind was then weighed. This was then related to the weight of grain initially put in each jar. Loss was thus expressed as a percentage of initial grain weight.

### 3.7 Analysis of Results

Microsoft Excel 4.0 package was used for all statistical calculations. Analyses were all based on the mean separation procedures of **Steel and Torrie, 1980**. The data were analysed after the following transformations were made :  $\text{Log}_{10} (x + 1)$  for all adult insect numbers, and  $\text{arcsin} ( (x + 1)^{1/2} )$  for grain dry-weight loss.

## 4.0 DESCRIPTION OF EXPERIMENTS

### 4.1 The effect of *A. calandrae* on *S. zeamais* population and activity

#### 4.1.1 Introduction

*A. calandrae* (Howard) is a parasitic wasp that attacks numerous Coleopteran hosts (Ghani & Sweetman, 1955). It has worldwide distribution and is a common parasitoid of the larvae and pupae of many beetles found within stored grain kernels (Ghani & Seweetman, 1955; Okamoto, 1971). Its potential for artificially induced control is enhanced because it has a high fecundity (Sweetman, 1958) and is a strong flyer that distributes itself well (Bare, 1942; Cline et al., 1983). Laboratory tests have demonstrated that *A. calandrae* has the potential to control the maize weevil in corn (William & Floyd, 1971).

The present study was carried out to assess the level of control *A. calandrae* would have on laboratory cultures of the maize weevil, *S. zeamais*, so as to compare it with the level of control the parasitoid would have on laboratory cultures of the larger grain borer, *P. truncatus* under local ambient conditions. This would help to assess the comparative efficiency of the parasitoid in controlling the two pests.

#### 4.1.2 Materials and Methods

The maize weevils were originally collected from maize on sale at the Kpeve market in the Volta Region. They were reared in the laboratory for three generations on corn. Maize weevil adults, about four weeks old, were used to carry out the experiment. The study covered a period of about 21 weeks, from January to June, 1997, at the Kpeve LGB Research Laboratory.

One-litre size Kilner jars with wire mesh covers were used as storage containers for the test. Each jar was filled with 200g of maize which had been cleaned and disinfested by keeping in an oven at 80°C for four hours. The maize was then equilibrated to ambient laboratory temperature of about 27°C for two days. The moisture content of the maize after equilibration was 14.5 %. Thirty unsexed adult maize weevils of about four weeks old were added to each jar using an aspirator. Each jar was then covered with a wire mesh top.

Five weeks after maize weevil infestation, 0 - 2 day old *A. calandreae* were aspirated from stock cultures and introduced into the test jars. Two pairs of parasitoid were released per jar. There were six replicates, each jar having a corresponding control without parasitoid.

A census of each insect population was taken 12 weeks after introduction of the parasitoids. One at a time, the contents of each test jar was sifted over a sieve of mesh size 4.75mm in diameter and dust and insects were removed. Live and dead maize weevil adults and live parasitoid adults were counted. The maize samples were each returned to the respective jars and incubated for four more weeks. During the incubation, the samples were sifted weekly to remove and count emerged maize weevils and parasitoids. Total counts were then computed for each jar. The contents of each test jar were then weighed to assess direct insect damage to maize from feeding of the maize weevil. The standard count-and-weigh method described in Section 3.6 above was used to determine dry-weight loss.

Insect numbers were transformed to logarithms before being analysed for statistical significance. All loss parameters expressed as percentages were transformed to  $\arcsin (x+1)^{1/2}$  before being

analysed for statistical significance. In all pairwise comparisons, (Student's t-Test) was used. Linear correlation tests were also performed to investigate extent of relationships between selected parameters. All figures used in the discussion were backtransformed before use.

### **4.1.3 Results and Discussion**

#### **4.1.3.1 *S. zeamais* density**

The mean *S. zeamais* density per replicate in the parasitoid-free culture was 457.1 as against 239.9 in the mixed culture, in which *A. calandreae* was introduced (see Table 2). This showed a suppression level of 47.5% under the influence of the parasitoid. The mean number of live parasitoids in the mixed culture at the time of taking data was 25.5. There were significantly more *S. zeamais* in the parasitoid-free cultures than the mixed cultures at ( $P < 0.05$ ). Even though the parasitoid and maize weevil numbers were positively correlated, the relationship was not very strong (see Table 3). The parasitoid alone could thus not account for the lower host numbers in the treatment.

In a similar experiment, Helbig (1993), working in Togo found that *S. zeamais* population was not significantly affected by *A. calandreae*. Conversely however, Williams and Floyd (1971) recorded significant suppression levels of more than 70% under the influence of *A. calandreae*. Cline et al. (1985), have shown that the same parasitoid could suppress *S. oryzae* (L) population by 76.1%. It would appear that experimental conditions greatly affect the performance of the parasitoid. While Helbig (1993) carried out his studies under ambient environmental conditions, Williams and Floyd (1971), and Cline et al (1985) operated under controlled conditions.

Compared to the results of Williams and Floyd (1971) and Cline et al. (1985), the lower suppression may be due to the ambient conditions of this experiment.

#### **4.1.3.2 Loss and Damage**

Mean grain damage was 61.8% for the parasitoid-free culture as against 78.3% in the mixed culture (see Table 2 next page). These were significantly different from each other at ( $P < 0.05$ ). This difference was due to differences in host densities attributable to the effect of the parasitoid. There was positive but weak correlation between parasitoid numbers and damage levels (see Table 3). Visual inspection did not show obvious differences in damage levels.

The mean grain dry-weight loss of 3.6% in the parasitoid-free culture was significantly higher than that of the treatment value of 2.5% ( $P < 0.05$ ) (see Table 2). For quantities of grain in warehouse storage, this would translate into loss reduction of economic proportions. It is notable therefore that *A. calandrae* can effect reduction in grain loss and damage at a significant level on *S. zeamais* under local ambient conditions.

**Table 2 : The effect of *A. calandrae* on *S. zeamais* numbers, damage and loss.**

	<i>A. calandrae</i>	<i>S. zeamais</i>	%Damage	%Loss
*Control	: -	457.1±24.2 a	78.3±0.8 a	3.6±0.3 a
*Treatment	: 25.5	239.9±16.8 b	61.8±0.4 b	2.5±0.1 b
Percentage suppression :		47.5%		

Means ± S.E followed by the same letter in a column are not significantly different from each other ( $P > 0.05$ ) by t-Test. Insect numbers were determined from 200g of maize test medium.

Each value is a mean of six replicates±S.E.

\*Control = Parasitoid-free cultures.

\*Treatment = Mixed cultures.

**Table 3 : Correlation coefficients of pairs of parameters**

<i>A. calandrae</i> & <i>S. zeamais</i>	<i>A. calandrae</i> & % Loss	<i>A. calandrae</i> & % Damage	<i>S. zeamais</i> & % Loss	<i>S. zeamais</i> & % Damage
0.331	0.129	0.313	0.537	0.441

r values > 0.754 have  $P < 0.05$  . Six observations were used in this computation.

## **4.2 The effect of *A. calandrae* on *P. truncatus* population and activity**

### **4.2.1 Introduction**

The potential of *A. calandrae* for artificially induced control is enhanced by its high fecundity (Sweetman, 1958) and great strength for flight which enables it distribute itself well (Bare, 1942; and Cline et al., 1983). Studies at the Colegio de Pogradados in Mexico, in collaboration with the International Institute of Tropical Agriculture have indicated that *A. calandrae*, in laboratory tests seemed to show a behavioural preference for *P. truncatus* over *S. zeamais* (C.Martinez, unpublished data).

With *A. calandrae* present in the country, there is a need to assess the prospects of using it as a component of an integrated control strategy of the larger grain borer in Ghana. This need is strengthened by the observation that the predator, *T. nigrescens* does not provide complete and satisfactory control over the LGB when used alone (Helbig, 1993). This study therefore sought to establish, to what extent *A. calandrae* could be used to control LGB populations in the laboratory.

### **4.2.2 Materials and Methods**

*P. truncatus* specimens used in this study were originally obtained from stock cultures, maintained at the Kpeve LGB research laboratory over two years. They were cultured on maize. Stock cultures of *A. calandrae* were maintained in the same laboratory on the maize weevil, *S. zeamais*, reared on maize for three generations. The study was conducted at the Kpeve laboratory from January to June, 1997.

One- litre size Kilner jars were used as test chambers. Using an "OHAUS" weighing scale, 200g of previously disinfested maize were measured into each of 12 test jars. Twenty unsexed adult *P. truncatus* of about four to five weeks old were obtained from the cultures by means of an aspirator and added to each jar. Each jar was fitted with wire mesh top. The moisture content of the maize at the time of use, as measured by the "DOLE" moisture meter was 12.5%.

Five weeks after introduction of LGB, *A. calandrae* adults were first introduced into six of the jars. The other six remaining jars served as controls. Two pairs of 0-2 day old parasitoids were released into each jar. A census of each insect population was taken 12 weeks after the introduction of the parasitoids.

The census was taken for pairs of one test jar and its control at any one time. One at a time, the contents of each jar was sifted over a sieve of 4.75mm diameter. In this way dust and insects were removed. Live and dead LGB and live parasitoids were removed and counted. The resulting maize samples were returned to their respective jars and incubated for four more weeks. During the incubation, the samples were sifted weekly to remove and count emerged LGB and parasitoid adults. The contents of each jar were then examined to assess direct insect damage and to determine grain dry-weight loss using the Sample-Weight-Method (Pantenius, 1988).

Data were analysed using t-test for all pairwise comparisons. Insect numbers were transformed to logarithms, and all percentages transformed to  $\arcsin(p)^{1/2}$  before analyses. Linear correlation tests were performed between selected parameters to find out the strengths of any possible

relationships. All previously transformed figures were backtransformed for use in the following discussions.

### 4.2.3 Results and Discussion

#### 4.2.3.1 Larger grain borer numbers

The mean LGB number per replicate in the parasitoid-free culture was 1072 insects. This was significantly higher than that of the mixed culture with mean of 603 ( $P < 0.05$ ). Under the influence of *A. calandrae*, there was therefore a suppression of the *P. truncatus* population by 43.8% (see table 4 on page 39). The mean number of parasitoids in the treatment set-up was 20.2 (Table 4). There was also a significantly high positive correlation between *A. calandrae* and *P. truncatus* numbers (see Table 5). The observed suppression in the LGB numbers in the treatment could thus be largely attributed to the action of the parasitoid. Comparatively, the level of suppression caused by the parasitoid in the case of the observed indigenous host, *S. zeamais*, of 47.5% was thus a little higher than with *P. truncatus*. It has earlier on been observed by Helbig (1993), that *A. calandrae* thrives better on *S. zeamais* than on *P. truncatus*.

Helbig (1993), carrying out similar studies in Togo, achieved a 70% suppression using *A. calandrae* against *P. truncatus* within a shorter period of 8 weeks as compared to the present study which spanned 16 weeks. In the Togo study however, 5 pairs of parasitoid were added weekly which helped to boost up the numbers and thereby provided better control. In the present study, in which only two pairs of *A. calandrae* were added, and once for 16 weeks, the 43.8% suppression points to an appreciable control. *A. calandrae* therefore has the potential to

contribute to the integrated control of *P. truncatus* in Ghana. Studies by Murphy and Cross (1990), under the International Institute of Biological Control (IIBC)[now CABI-BIOSCIENCES] LGB screening programme for beneficial insects have shown that *T. nigrescens*, the predatory beetle, does not pose a threat to the parasitoid populations whether in the presence or absence of *P. truncatus*. *A. calandreae* can therefore compliment *T. nigrescens* control when these are used together.

#### 4.2.3.2 Damage and Loss

In the presence of *A. calandreae*, weight loss of 33.8% in the mixed culture was significantly lower than the 49.7% observed in the parasitoid-free cultures (see Table 4) ( $P < 0.05$ ). There was therefore a reduction of 32% in the weight loss under the influence of the parasitoid. The difference in loss could also be explained by the different LGB numbers in the mixed and parasitoid-free cultures.

The parasitoid did not significantly affect the levels of damage in the mixed cultures as against the parasitoid-free cultures. The damage level of 87.2% in the treatment was not significantly different from the 89.5% in the parasitoid-free cultures ( $P > 0.05$ ) (see Table 4) Correlation between the parasitoid numbers and damage level was strong but not significant (see Table 5 on page 39). So in the event that *A. calandreae* is used in the integrated control of *P. truncatus*, any reduction in grain damage level observed could not be attributed to the parasitoid.

**Table 4 : The effect of *A. calandrae* on *P. truncatus* numbers, damage and loss of maize.**

	Mean number of <i>A. calandrae</i>	Mean number of <i>P. truncatus</i>	% Damage	% Loss
*Control	-	1071.5±35.3 a	89.5±1.2 a	49.7±1.7 a
*Treatment	20.2±3.2	602.6±33.6 b	87.2±1.3 a	33.8±0.8 b
Percentage suppression : 43.8%.				

Means ± S.E. followed by the same letter in a column are not significantly different from each other (  $P > 0.05$  ) by t-Test. Insect numbers determined from 200g maize test medium. Each value is a mean of six replicates.

\*Control = Parasitoid-free cultures.

\*Treatment = Mixed cultures

**Table 5 : Correlation coefficients of selected pairs of parameters.**

<i>A. calandrae</i> & <i>P. truncatus</i>	<i>A. calandrae</i> & % Damage	<i>A. calandrae</i> & % Loss	<i>P. truncatus</i> & % Damage	<i>P. truncatus</i> & % Loss
0.946*	-0.752	0.013	0.145	0.116

r values > 0.754 have  $p < 0.05$ . Six observations were used in this computation.

### **4.3 The acceptability and suitability of different *P. truncatus* larval instars for the development of *A. calandreae*.**

#### **4.3.1 Introduction**

The larger grain borer, *P. truncatus*, has three larval instars, a determination based on the greatest distance between the ventrally sclerotized lateral structures of the frontoclypeus (Subramanyam et al., 1985). Parasitic hymenoptera associated with the larger grain borer in its country of origin usually show a preference for certain ages (sizes) of the host (Brower, 1992).

In this experiment therefore, the aim was to investigate whether *A. calandreae* will show any preference for specific age classes or sizes of *P. truncatus*. This information will be vital in future for mass rearing of *A. calandreae* for biological control of *P. truncatus*.

#### **4.3.2 Materials and Methods**

*A. calandreae* and *P. truncatus* used for this study were obtained from stock cultures maintained at the Kpeve LGB research laboratory. To obtain LGB larvae, maize biscuits were offered for egg laying. Maize biscuits were prepared according to the procedure of Vowotor et al., 1997, by mixing 300g of maize flour, 100g of corn starch and 500cm<sup>3</sup> of water. The mixture was then pressed into rectangular blocks measuring 2.0cm x 1.0cm x 0.5cm. They were then removed from the mould and allowed to dry for 72 hours in a tray. Ten unsexed adult LGB were put into petri dishes each containing maize biscuits. They were removed after a week during which oviposition would have taken place. Incubation was done under ambient laboratory conditions.

Larval instars were determined by using their ages as described by Subramanyam et al., 1985 ; 1st instar, 0 - 6 days old; 2nd instar, 7 - 14 days old; and 3rd instar, 15 - 27days old. Following this regime, 6 days old, 10 days old, and 20 day old larvae were assumed to be 1st, 2nd and 3rd instars respectively.

**Test 1:** To test the acceptability and suitability of different LGB larval instars for the development of *A. calandreae*, 10 host larvae of a given instar were placed in a vial (6x2cm) and a single 0 - 2 days old female parasitoid placed into it. There were four replicates. During a maximum observation period of 5 minutes, no oviposition behaviour could be observed in any of the instars. Each set was therefore left for 24 hours after which the parasitoids were removed. All exposed larvae were supplied with maize flour and reared to pupation. Individual pupae were then kept in glass vials till adult emergence. Compaction of the flour was achieved by tapping the bottom of of each vial 4 - 5 times on the laboratory bench. This was vital for the development of the LGB larvae.

**Test 2 :** To test the preference of *A. calandreae* for the different LGB larval instars, 5 each of 1st , 2nd and 3rd larval instars were placed together in a vial. Two 0 - 2 days old female parasitoids were released into each vial and removed after 24 hours. There were three replicates. After removal of the parasitoids, the different instars were then isolated from each other. All exposed larvae were supplied with maize flour, in which compaction was achieved by tapping the bottom of the vial 4 - 5 times against the bench. Individual pupae were then kept in glass vials till adult emergence.

Data was analysed by One-way Analysis of Variance (ANOVA) to test for statistical significance of observations. All host and parasitoid emergence, expressed as percentages, were transformed to square roots before analyses. Fisher's Protected LSD was used for all mean separations. All values presented in the results and discussion are backtransformed values.

### **4.3.3 Results and Discussion.**

#### **4.3.3.1 Host instar preference, acceptability and suitability**

**Results of Test 1 :** *A. calandrae* apparently prevented more of the 3rd instar LGB larvae from developing into adulthood than it did for the other instars (see Table 6 on page 44). Only 10.0% of the 3rd instars emerged as adults. Of the 2nd instars, 20.0% emerged as adults, and 42.5% of the 1st instars emerged as adults. All these values were significantly different from each other ( $P < 0.05$ ). Thus significantly more 3rd instar LGB larvae were attacked than the other instars (Fisher's Protected LSD:  $F = 9.16$ ,  $df = 2,9$ ,  $P = 0.0073$ ). This was confirmed in the proportion of each instar yielding parasitoids (see Table 6). Significantly higher number of *A. calandrae* emerged from the 3rd instar than the other instars ( $P < 0.05$ ). In the 3rd instar, emergence of parasitoid was 30.6%; 13.6% in the 2nd and 6.1% in the 1st instars. All these were significantly different from each other (Fisher's Protected LSD:  $F = 10.66$ ,  $df = 2,9$ ,  $P = 0.0001$ ).

The conclusion is that 3rd instar LGB larvae are more suitable for the development of *A. calandrae*. Also, the development time of the parasitoid was 13.4 days in the 3rd instar, which was the shortest ( see Table 6). It took as long as 17.0 days for the parasitoid to emerge from the 1st LGB instar.

All larval LGB instars are therefore acceptable for oviposition, but the 3rd instar is the most suitable for the development of *A. calandrae*. These findings agree with the observations of Brower (1992), in which various parasitoids, including *A. calandrae* were found to thrive better on older and larger immature stages of *P. truncatus*.

**Results of Test 2 :** Significantly higher proportion of 3rd instar LGB larvae were successfully parasitized by *A. calandrae* (see Table 7 overleaf). No 1st instar larva was parasitized, as against 11.5% of the 2nd instars which yielded parasitoids. Of the 3rd instars, *A. calandrae* successfully parasitized 20.9%. In the absence of other instars, *A. calandrae* will therefore attack 1st instar host larvae, but the preferred host size (age) is the 3rd instar. The observed levels of successful parasitization, that is, emergence of live parasitoids, were significantly higher in the 3rd instars than the 1st and 2nd instars (Fisher's Protected lsd:  $F = 8.89$   $df = 2,6$  ,  $P = 0.0005$ ) (see appendix 7).

**Table 6 : Host fate after parasitization by *A. calandrae***

LGB Instar	<i>A. calandrae</i> : mean	<i>P. truncatus</i> : mean	Parasitoid development
	percentage emergence	percentage emergence	time (in days)
I	6.1 ± 4.8 c	42.5 ± 6.3 a	17.0 a
II	13.6 ± 5.0 b	20.0 ± 4.1 b	15.5 b
III	30.6 ± 4.8 a	10.0 ± 4.1 c	13.4 c

Means ± S.E. followed by the same symbol in a column are not significantly different from each other (  $p > 0.05$ ) by Fisher's Protected LSD. LGB emergence:  $F = 9.16$ ;  $df = 2,9$ ;  $P = 0.0073$ .

*A. calandrae* emergence:  $F = 10.66$ ;  $df = 2,9$ ;  $P = 0.0001$ .

**Table 7 : Preference shown by *A. calandrae* for diferent LGB larval instars in a mixture of all three larval instars.**

Mean percentage successful parasitization by <i>A. calandrae</i> *	
LGB Instar	
I	0.00 ± 0.00 a
II	11.5 ± 5.8 b
III	20.9 ± 5.0 c

\* Means ± S.E. followed by the same letters in a column are not significantly different from each other (  $P > 0.05$ ) by Fisher's Protected LSD:  $F = 8.89$ ;  $df = 2,6$ ;  $P = 0.0005$ .

#### **4.4 The effect of *D. basalis* (Rondani) on *C. maculatus* Population and activity**

##### **4.4.1 Introduction**

*D. basalis* larva is an external parasite of mature larvae and pupae of bruchid hosts (Verma, 1991). The parasitoid shows marked preference for *C. maculatus* host over other bruchid hosts (Verma, 1991).

During the parasitoid search, *D. basalis* was found associated with *C. maculatus* in market stores. For its widespread occurrence and high numbers, it was necessary to evaluate its controlling effect on the host, *C. maculatus*, for subsequent comparison with its possible effect on *P. truncatus* population.

##### **4.4.2 Materials and Methods**

*C. maculatus* was cultured on stored cowpeas (*V. unguiculata*) while *D. basalis* was cultured on *C. maculatus* in stored cowpeas. The study, which covered a period of about 16 weeks, was carried out at the Kpeve Agricultural Research laboratory. One-litre size Kilner jars with wire mesh tops were used as test chambers. Twelve jars were each filled with 200g of previously disinfested cowpeas. Disinfestation of cowpeas involved heating in an oven at 50°C for two hours. The cowpeas was then equilibrated to ambient laboratory temperature of 28°C for two days.

Thirty unsexed adult *C. maculatus*, of 1-2 days old were then added to each jar. These were left for two weeks during which oviposition would have taken place. All *C. maculatus* were then

removed from the jars by aspiration. Two pairs of 0 - 2 day old *D. basalis* adults were added to each of six jars, with six other jars as control without parasitoid.

A census of each insect population was taken 12 weeks after the introduction of parasitoids. Once at a time, the contents of each test jar, followed by that of its control was sifted over a 4.75mm mesh sieve to remove dust and insects. Live adult *C. maculatus* and parasitoids were counted with the aid of a tally counter. The cowpea samples were then incubated for four more weeks. Sifting was done weekly to remove and count emerged bruchids and parasitoids. The contents of each test jar were then examined to assess level of grain damage from bruchid activity. The count-and-weigh method (Boxall, 1986), was used to assess dry-weight loss.

Insect numbers were transformed to logarithms before statistical analysis. All loss and damage levels, expressed as percentages were transformed to  $\arcsin (P)^{1/2}$  before being analysed for statistical significance. In all pairwise comparisons between treatment and control means, (Student's t-Test) was used. All figures used in the results and discussion were backtransformed.

### **4.4.3 Results and Discussion**

#### **4.4.3.1 Insect numbers**

At the time of final observation, there was a mean of 49.5 live *D. basalis* per replicate in the treatment set up (see Table 8 on page 49). Mean live *C. maculatus* adults in the control was 1288.2; while in the mixed cultures it was 208.9 *C. maculatus* adults (see Table 8). These treatment and control values were significantly different from each other ( $P > 0.05$ ). The

suppression level of the *C. maculatus* population under the influence of *D. Basalis* was 83.8%.

#### 4.4.3.2 Loss and Damage

There was a significant difference in the weight loss between the mixed culture and parasitoid-free culture ( $P < 0.05$ ). The mean percentage weight loss of cowpeas in the control was 54.7% and 44.5% in the mixed culture (see Table 8). The reduction in weight loss under the influence of *D. basalis* was therefore 18.6%.

The mean percentage grain damage was 79.4% in the control and 75.1 in the mixed culture (see Table 8). These were significantly different from each other ( $P < 0.05$ ). The reduction in damage level by 4.3% in the treatment could thus be attributed to the parasitoid.

**Table 8 : The effect of *D. basalis* on *C. maculatus* numbers, damage and loss of cowpeas**

	Mean number of <i>D. basalis</i>	Mean number of <i>C. maculatus</i>	% Damage	% Loss
*Control		1288.2±179.1 a	79.4±1.3 a	54.7±0.3a
*Treatment	49.5	208.9±29.9 b	75.1±1.5 b	44.5±1.5b
% suppression: 83.8%				

Means ± S.E. followed by the same letter in a column are not significantly different from each other ( $P > 0.05$ ) by t-Test. Each value is a mean of six replicates.

\* Control = Parasitoid-free culture      \*Treatment = Mixed culture

## **4.5 The effect of *D. basalis* on *P. truncatus* population and activity**

### **4.5.1 Introduction**

*D. basalis* , found in association with *C. maculatus* during the parasitoid search, was one of the most frequent and most abundant encountered. It is a parasitoid of immature bruchid hosts, especially *C. maculatus* (Verma, 1991).

The present investigation was conducted to find out whether *D. basalis* will attack *P. truncatus* , and what level of control it might have on the host population.

### **4.5.2 Materials and Methods**

*P. truncatus* and *D. basalis* species used for the study were obtained from stock cultures maintained in the laboratory. As before, one-litre size Kilner jars were used as observation chambers. The jars were each filled with 200g of previously disinfested maize. Twenty unsexed adult *P. truncatus* of about 5 weeks old were added to each jar.

Two pairs of 0 - 2 day old *D. basalis* adults were first introduced into six of the jars 5 weeks after infestation with LGB. Six others served as control without parasitoids. A census of each insect population per jar was taken 12 weeks after the introduction of the parasitoids. The procedure was as described in Section 4.4.2 above. After this, the maize samples in each jar were further incubated for 4 weeks. At weekly intervals each sample was sifted to remove and count emerged LGB and live parasitoids. The contents of each jar were then examined by the Sample-Weight-Method ( Pantenius. 1988), to assess grain loss from *P. truncatus* activity. Levels of grain

damage were assessed by examining individual grains for presence or absence of insect bore holes. Damage was expressed as percentage of number of grains present in each jar.

Data were analysed using (Student's t-Test) for all pairwise comparison to establish statistical significance of observed means. Insect numbers were transformed to logarithms and all proportions expressed as percentages were transformed to  $\arcsin(P)^{1/2}$  before analyses. Figures used in the results are backtransformed values.

### 4.5.3 Results and Discussion

#### 4.5.3.1 Insect counts

The mean density of *P. truncatus* of per replicate in the Parasitoid-free culture was 891.3 and 870.9 in the mixed culture (see table 9 on page 52). These were not significantly different from each other ( $P > 0.05$ ). Above all else, there was no increase in *D. basalis* population. All introduced parasitoid specimens died within a week of introduction. Two weeks afterwards however, no parasitoids could be seen emerging. Further examination after two more weeks lead to the conclusion that *D. basalis* did not attack *P. truncatus*.

In a follow-up test, one adult *D. basalis* female was introduced to one 3rd instar LGB (10 replicates). No new parasitoids emerged after 3 weeks of observation. The development time of *D. basalis* is about 14 days (Verma, 1991). Since the parasitoid did not emerge after this period, it was seen as an affirmation of the earlier observation that *D. basalis* does not attack *P. truncatus*. Apparently *D. basalis* is restricted to the bruchids in its parasitism (Verma, 1991).

#### 4.5.3.2 Grain dry-weight loss

From the observation that *P. truncatus* was not attacked by *D. basalis*, only the weight loss was examined leaving out grain damage. The mean percentage weight loss of 32.2% in the control was not significantly different from the 31.8% obtained for the treatment ( $P > 0.05$ ) (see Table 9). The observed difference in the weight loss between the treatment and control was therefore not due to the parasitoid.

It could be firmly concluded from this study that *D. basalis* has no potential for the control of *P. truncatus*.

**Table 9 : The effect of *D. basalis* on *P. truncatus* numbers, and loss of maize.**

	Mean number of <i>D. basalis</i>	Mean number of <i>P. truncatus</i>	% Loss
Parasitoid-free culture	-	891.3 ± 31.2 a	32.2 ± 1.0 a
Mixed culture	0.0	870.9 ± 24.8 a	31.8 ± 1.2 a

Means ± S.E. followed by the same letter in a column are not significantly different from each other ( $P > 0.05$ ) by t-Test. Insect numbers determined from 200g maize test medium.

Each value is a mean of six replicates.

## 5.0 SUMMARY AND CONCLUSION

A study was conducted as to the possibility of identifying indigenous parasitoids in the stored product system for the control of the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) in Ghana. A search was made for parasitoids associated with various stored product pests in selected market stores in the Greater Accra Region, and Kpeve in the Volta Region. The parasitoids were identified with assistance from the International Institute of Tropical Agriculture (IITA) in Benin. Each parasitoid was reared on its respective host in a culture maintained at the Kpeve Agricultural Research laboratory. Based on the frequency of occurrence and abundance of the parasitoids, two were chosen for study as to their possible controlling effect on *P. truncatus*.

The level of suppression of the natural host population as against that of *P. truncatus* was investigated in each case. The effect of each parasitoid on the losses and damage levels was also investigated.

From the study, the following results can be summarised:

(1) Four parasitoids were obtained from the search as follows: *Anisopteromalus calandrae* (Howard) (Hymenoptera: Pteromalidae) was associated with *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) in maize. The same parasitoid was also associated with *Callosobruchus maculatus* (Fabricius) (Coleoptera: Bruchidae) in cowpeas, *Vigna unguiculata* Walp. *Dinarmus basalis* (Rondani) (Hymenoptera: Pteromalidae), a bruchid parasitoid, was associated with *Callosobruchus maculatus* in cowpeas. Also, *C. maculatus* was parasitized by

*Eupelmus vuilleti* Crawford (Hymenoptera.: Pteromalidae) in cowpeas. The parasitoid, *Holepyris sylvanidis* (Brethes) (Hymenoptera.: Bethylidae) was associated with *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) in maize.

(2) *Anisopteromalus calandrae*, and *Dinarmus basalis* were the most frequent and most abundant, with *H. sylvanidis* and *E. vuilleti* occurring in extremely low numbers. Thus only *A. calandrae* and *D. basalis* were used in the study.

(3) While *A. calandrae* caused a 47.5% suppression in *S. zeamais* population, it reduced *P. truncatus* population by 43.8%. *A. calandrae* therefore significantly reduced the two host populations. There was also a significant reduction in the loss and damage suffered by maize from *S. zeamais* and *P. truncatus* activity due to the presence of this parasitoid.

(4) The suitability of different LGB larval instars for the development of *A. calandrae* was investigated. All three LGB larval instars were observed to support the development of the parasitoid. The third instar was however the most suitable because a higher proportion of *A. calandrae* adults emerged from these. In a choice test, *A. calandrae* showed a marked preference for 3rd instar larvae.

(5) *D. basalis* caused a 83.8% suppression in *C. maculatus* population. It also caused a significant reduction in the loss suffered by cowpeas from *C. maculatus* activity. But there was no significant reduction in the damage suffered by cowpeas under the influence of the parasitoid.

It was also discovered that *D. basalis* did not attack *P. truncatus* and therefore could not affect the loss and damage suffered by maize from *P. truncatus* activity.

From these results it can be observed that *A. calandrae* has the potential to control *P. truncatus* population. It can therefore contribute positively to an integrated control of *P. truncatus*. On the other hand, *D. basalis* has no contribution to make towards the eventual control of the larger grain borer. It is however important to mention that both parasitoids have a great potential for contributing to the control of the host insect pests on which they were found during the parasitoid search, especially *D. basalis* against *C. maculatus*.

## 6.0 LITERATURE CITED

- Addo, S. (1994) Tolerance of different maize varieties and wood species used in maize storage structures in the Volta Region, Ghana, to the larger grain borer, *Prostephanus truncatus* (Horn). M.Phil. Thesis, University of Ghana, Legon-Accra, Ghana.
- Al-Sousi, A.J., H.El-Haidari & J.I. Al-Ani. (1970) Outbreaks and new records.Iraq. Larger grain borer on maize. FAO Plant Protection Bulletin 18 (4) 93.
- Ayertey, J.N. & Brempong-Yeboah, C.Y. (1991) A survey of the larger grain borer, *Prostephanus truncatus* (Horn) in some areas in Ghana. In: Ndoye, M.(ed.) Exotic pests in Africa, Prevention and control. Proc. Symposium, 9th Scientific Conference. African Association of Insect Scientists, Accra, Ghana, Sept., 1991. pp59-66.
- Back, E.A., & R.T. Cotton. (1922) Stored-grain pests. U.S. Department of Agriculture, Farmers Bulletin No. 1260. 47pp.(Editions: 1922, 1927, 1930, 1931, 1938, 1940).
- Bare, C.O. 1942. Some natural enemies of stored-tobacco insects, with biological notes. J.Econ. Entomol. 35: 185-189.
- Bell, R.J., & F.L. Watters. (1982) Environmental factors influencing the development and rate of increase of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) on stored maize. Journal of Stored Products Research 18: 131-142.
- Benson, J.F. (1973) Intraspecific competition in the population dynamics of *Bracon hebetor* Say (Hymenoptera: Braconidae). Journal of Animal Ecology, 42, 105-124.
- Boateng, B.A. (1997) Effects of maize variety and season on population dynamics of the larger grain borer, *P. truncatus* (Horn) and the maize weevil, *Sitophilus zeamais* Motschulsky, and grain losses in the traditional 'Ewe' storage barn in Ghana. M.Phil. Thesis. University

of Ghana, Legon-Accra, Ghana.

Boeye, J. (1988) Autecological investigations on the behaviour of the larger grain borer,

*Prostephanus truncatus* (Horn) (Coleoptera:Bostrichidae) in Costa Rica.Doktorarbeit,

Institut fur Phytopathologie der Christian-Albrechts-Universitat zu Kiel.xiii + 195pp.

Boeye, J. (1990) Ecological aspects of *Prostephanus truncatus* (Horn) (Coleoptera:Bostrichidae)

in Costa Rica, pp.73-86. In:R.H.Markham & H.R. Herren (eds.) Biological control of the

larger grain borer. Proceedings of an IITA/FAO coordinating meeting, Cotonou, Republic

of Benin, 2-3 June 1989. International Institute of Tropical Agriculture, Ibadan, Nigeria,

viii + 171pp.

Boeye, J., S. Burde, H. Keil, G.-A. Laborius & F.A. Schulz. (1988) The possibilities for

biologically integrated control of the larger grain borer (*Prostephanus truncatus* [Horn]) in

Africa, 110-139. In G.G.M. Schulten & A.J. Toet (eds.) Workshop on the containment

and control of the larger grain borer, Arusha, Tanzania, [16-21 May 1988]. Ministry of

Agriculture and Livestock development [Tanzania] with assistance from Food and

Agriculture Organization of the United Nations, [Rome, Italy], Report II Technical papers

presented at the workshop [unpublished]. ii + 209pp.

Boxall, R. A. (1986) A critical review of the methodology for assessing farm-level grain losses

after harvest. Report of the Tropical Development and Research Institute, G191,

viii + 139pp.

Brower, J.H. (1992) Biological control of *Prostephanus truncatus* (Horn) with parasitic

hymenoptera In:Fleurat-Lessad,F.,and Ducom,P., eds, Proceedings of the Fifth

International Working Conference on Stored-product Protection, Bordeaux, France,

September, 1990, 2, 1257-1258.

- Burde, S. (1988) Microbial antagonists of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae)-basis for a biological treatment in tropical store protection. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, Hamburg. 97pp.
- Calderon, M., & E. Donahaye. (1962) Israel. First record of *Prostephanus truncatus* in stored grain. FAO Plant Protection Bulletin 10: 43-44.
- Chittenden, F.H. (1911) Papers on insects affecting stored products. The larger grain borer. U.S. Department of Agriculture, Division of Entomology, Bulletin No. 96: 48-52.
- Cline, L.D., J.W. Press, & B.R. Flaherty. (1983) Response of selected parasitoids, and predators of stored-product insects to whitelight and blacklight traps. Ibid. 76: 298-301.
- Cline, L.D., J.W. Press, & B.R. Flaherty. (1985) Suppression of the rice weevil, *Sitophilus oryzae* (Coleoptera: Curculionidae), inside and outside of burlap, woven polypropylene, and cotton bags by the parasite wasp, *Anisopteromalus calandrae* (Hymenoptera: Pteromalidae). J. Econ. Entomol. 78:835-838.
- Conilh de Beyssac, B. (1990) Analysis of the susceptibilities of seven maize cultivars to attack by the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). Master of Science thesis, University of Ottawa, Canada. 130pp.
- Cotton, R.T., & N.E. Good. (1937) Annotated list of the insects and mites associated with stored grain and cereal products, and of their arthropod parasites and predators. U.S. Department of Agriculture, Miscellaneous Publication No. 258. 81pp.
- Cowley, R.J., D. C. Howard, & R.H. Smith. (1980) The effect of grain stability on damage caused by *Prostephanus truncatus* (Horn) and three other beetle pests of stored maize.

Journal of

Stored Products Research. 16: 75-78.

Delgado M. N., & R. Hernandez Luna. (1951) Control of the maize seed weevil (= larger grain borer) (*Prostephanus truncatus* [Horn]), pp.26-29. In Primera Asamblea Latinoamericana de Fitoparasitologia. Secretaria de Agricultura y Granaderia, Oficina de Estudios Especiales, Mexico, Folleto Miscelaneo No. 4. 426pp.

Detmers, H.-B. (1990) Response of the larger grain borer *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) to methyl bromide, p.90. In 5th International Working Conference on Stored-product Protection, Bordeaux, France, September 9-14, 1990. Abstract volume. 264pp.

Dick, K.M., D.P. Rees, K.K. Lay & A. Ofofu. (1989) Occurrence of larger grain borer *Prostephanus truncatus* (Horn), in Ghana. FAO Plant Protection Bulletin 37(3): 132.

Dobie, P., Haines, C.P., Hodges, R.J., Prevet, P.F., Rees, D.P. (1991) Insects and Arachnids of Tropical Stored Products: A Training manual, Second edition(Edit. C.P. Haines) Natural Resources Institute, ODA, 246pp.

Fisher, W.S. (1950) A revision of the North American species of beetles belonging to the family Bostrichidae. USDA. Miscell. Publication No. 698.157pp.

Ghani, M.A.. & H.L. Sweetman. (1955) Ecological studies on the granary weevil parasite, *Aplastomorpha calandrae* (Howard). Biologia 1:115-139.

Giles, P.H. (1975) Annual Report 1974 on the activities of SERPAL and the Grain Storage Extension Group. Seccion de Productos Almacenados (SERPAL), Ministerio de Agricultura y Ganaderia, Managua, Nicaragua. 10pp.

- Giles, P.H., & O. Leon V. (1974) Infestation problems in farm-stored maize in Nicaragua. pp. 68-76. In Proceedings of the first International Working Conference on Stored-Product Entomology, Savanna, Georgia, U.S.A., October 7-11, 1974. 705pp.
- GLGBP. (1993) Field studies in the Volta Region. MoFA/ODA (U.K) , Ghana LGB Project, Quarterly Report 2, April-June, 1993.
- Golob, P. & R. Hodges. (1982) Study of an outbreak of *P. truncatus* (Horn) in Tanzania. Report of the Tropical Products Institute, G164. 23pp.
- Golob, P. (1988a) Chemical control of the larger grain borer, pp53-69. In G.G.M. Schulten & A.J. Toet (eds.) Report II Technical papers presented at the workshop. Workshop on the containment and control of the larger grain borer, Arusha, Tanzania, [16-21 May 1988]. Pest control services, Ministry of Agriculture and Livestock Development [Tanzania] and Food and Agriculture Organization of the United Nations, [Rome, Italy] [Unpublished]. ii + 209pp.
- Golob, P. (1988b) Current status of the larger grain borer *Prostephanus truncatus* (Horn) in Africa. Insect Science and its Application. 9(6): 737-745.
- Golob, P., P. Changjaroen, A. Ahmed, & J. Cox. (1985) Susceptibility of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) to insecticides. Journal of Stored Product Research. 21: 141-150.
- Golob, P., & C. Hanks. (1990) Protection of farm stored maize against infestation by *Prostephanus tuncatus* (Horn) and *Sitophilus* spp. In Tanzania. Journal of Stored Products Research 26 (4) : 187-198.
- Golob, P., P. Broadhead & M. Wright. (1990a) Susceptibiity of *Teretriosoma nigrescens* Lewis

(Coleoptera: Histeridae) to insecticides, p. 150. *In* Abstract volume, 5th International Working Conference on Stored-Product Protection, Bordeaux, France, September 9-14, 1990. 264pp.

Golob, P., P. Broadhead & M. Wright. (1990b) Development of resistance to insecticides by *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae), p. 118. *In* Abstract volume, 5th International Working Conference on Stored-Product Protection, Bordeaux, France, September 9-14, 1990. 264pp.

Haines, C.P. (1974) Insects and arachnids from stored products : A report on specimens received by the Tropical Stored Products Centre 1972-1973. Report of the Tropical Products Institute, L39. 22pp.

Haines, C.P. (1981) Insects and arachnids from stored products : A report on specimens received by the Tropical Stored Products Centre 1973-1977. Report of the Tropical Products Institute, L54. 73pp.

Harnisch, R., & S. Krall. (1984) Togo: Further distribution of the larger grain borer in Africa. *FAO Plant Protection Bulletin* 32:113-114.

Haskem, M.Y., & C. Reichmuth. (1989) The efficiency of phosphine against eggs of lesser grain borer, *Rhyzopertha dominica* (Fab.) and larger grain borer *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). *Nachrichtenblatt des Deutschen Pflanzenschutzdienstes* (Braunschweig) 41 (10) :159-163.

Helbig, J. (1993) The ecology of *Prostephanus truncatus* in Togo with particular emphasis on interaction with the predator, *Teretriosa nigrescens*. Deutsche Gesellschaft Zusammenarbeit (GTZ) GmbH, Hamburg. 133pp.

- Hell, K. (1988) Influence of insect growth regulators on *Prostephanus truncatus* and *Teretriosoma nigrescens* as storage beetles, pests of maize. Mededelingen van de Faculteit Landbouwwentenschappen, Rijksuniversiteit Gent, 52 (2a) : 241-246.
- Hinton, H.E. (1945) The Histeridae associated with stored products. Bull. Entomol.Res.35 : 309-340.
- Hodges, R.J. (1982) A review of the biology and control of the larger grain borer, *P. truncatus* (Horn) (Coleoptera:Bostrichidae). Tropical Stored Products Information 43 : 3-9.
- Hodges, R.J. (1984) Field ecology and monitoring of *Prostephanus truncatus* (Horn) (Coleoptera:Bostrichidae), pp.32-48. In : The larger grain borer, *P. truncatus* (Horn). GASGA Workshop, Tropical Products Institute storage Department, Slough,24-25 February, 1983. Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GmbH, Eschborn, Federal Republic of Germany.139pp..
- Hodges, R.J., W.R.Dunstan, I. Magazini, & P.Golob. (1983a) An outbreak of *Prostephanus truncatus* (Horn) (Coleoptera:Bostrichidae) in East Africa. Protection Ecology 5:183-194.
- Hodges, R.J., W.R.Dunstan, I. Magazini, & P.Golob. (1983b) Responses of *Prostephanus truncatus* to components of the aggregation pheromone of *Rhyzopertha dominica* in the laboratory and field.Entomologia experimentalis et applicata 34 (3) : 266-272.
- Hodges, R.J., A.Cork, & D.R.Hall. (1984) Aggregation pheromones for monitoring the larger grain borer, *Prostephanus truncatus*. British Crop Protection Conference-Pests and Diseases 4A-3 : 255-259.
- Hodges, R.J., & J. Meik. (1984) Infestation of maize cobs by *Prostephanus truncatus* (Horn)

- (Coleoptera:Bostrichidae)- aspects of biology and control. *Journal of Stored Products Research* 20(4): 205-213.
- Hodges, R.J., J. Meik, & H. Denton. (1985) Infestations of dried cassava (*Manihot esculenta* Cranz) by *Prostephanus truncatus* (Horn) (Coleoptera:Bostrichidae). *Journal of Stored Products Research*. 21 : 73-77.
- Horn, G.H. (1878) Revision of the Bostrichidae of the United States. *Proceedings of the American Philosophical Society* 17:540-555.
- Howard, D.C. (1983) The population biology of the greater grain borer, *Prostephanus truncatus* (Horn). Ph.D. Thesis, University of Reading, U.K.
- Howard, D.C. (1984) The ability of *Prostephanus truncatus* (Horn) to breed on different maize varieties. *Proc.GASGA Workshop on the larger grain borer, Prostephanus truncatus*, 24-25 February, 1983, TPI, Slough Publ.GTZ, Eschborn, pp17-31.
- Kega, V.K., & C.W. Warui. (1983) *Prostephanus truncatus* in Coast Province, Kenya. *Trop. Stored Prod. Inf.* 46,2.
- Kingsolver, J.M. (1971) Key to the genera and species of Bostrichidae commonly intercepted in USDA quarantines inspections. U.S. Dept of Agriculture, Agricultural Quarantine Inspection Memorandum No. 697 (Unpublished).11pp. (P6).
- Krall, S. (1984) A new threat to farm stored maize in West Africa: *Prostephanus truncatus* (Horn) (Coleoptera:Bostrichidae). *Tropical Stored Products Information* 50 : 26-31.
- Krall, S. (1987) Experience with a new stored grain pest in Togo and Benin:the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera:Bostrichidae), pp623-629. In : E. Donahaye & S. Navarro (eds.): *Proceedings of the fourth int.working conference on*

stored-product Protection, Tel-Aviv, Israel, 21-26 Sept., 1986. 668pp.

Laborius, G.A. (1990) Biologically-integrated control of the larger grain borer. GTZ project research programme, pp16-24. In: R.H. Markham and H.R. Herren (eds.) Biological control of the larger grain borer, *Prostephanus truncatus* (Horn). Proceedings of an IITA/FAO coordinating meeting, Cotonou, Republic of Benin, 2-3 June 1989. International Institute of Tropical Agriculture, Ibadan, Nigeria. viii+171pp.

Leliveldt, B. (1990) Antagonisten von *Prostephanus truncatus* (Horn) (Coleoptera:Bostrichidae) [Natural enemies of *Prostephanus truncatus* (Horn) (Coleoptera:Bostrichidae)]. Doktorarbeit freie Universitat Berlin. ix+ 215pp.

Leliveldt, B. & G.A. Laborius. (1990) Effectiveness and specificity of the antagonist, *Teretriosoma nigrescens* Lewis (Coleoptera:Histeridae) on the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera:Bostrichidae), pp87-102. In: R.H. Markham and H.R. Heren (eds.) Biological control of the larger grain borer. Proceedings of an IITA / FAO coordination meeting, Cotonou, Republic of Benin, 2-3 June, 1989. International Institute of Tropical Agriculture, Ibadan, Nigeria. viii+171pp.

Lesne, P. (1897) Revision des coleopteres de la famille des Bostrychides (Revision of beetles of the Bostrichid family). Annales de la societe Entomologique de France 66: pp319-350.

Lewis, G. (1891) On the two new species of Mexican Histeridae. Ent. Monthly Magazine 2 (2), pp106-107.

Makundi, R.H. (1986) The toxicity of deltamethrin and cyfluthrin to the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera:Bostrichidae). International Pest Control 28 (3) : 79-81.

- Markham, R.H. (1990) The role of quantitative ecology and systems analysis in the biological control of the larger grain borer, pp 35-50. *In*: R.H.Markham and H.R.Herren (eds.). Biological control of the larger grain borer.Proceedings of an IITA/FAO coordination meeting , Cotonou, Rep. Of Benin, 2-3 June, 1989. International Institute of Tropical Agriculture. Ibadan, Nigeria.171pp.
- Markham, R.H., Bosque-Perez, N.A., Borgmeister, C. & Meikle, W.G. (1994a) Developing pest management strategies for *Sitophilus zeamais* and *Prostephanus truncatus* in the tropics. *FAO Plant Prot. Bull.* 42 (3) 97-116.
- Markham, R.H., Borgmeister, C & Meikle, W.G. (1994b) Can biological control solve the larger grain borer crisis? *In* : E.Highly, E.J Wright, H.J.Banks and B.R.Champ (eds.). Proc.6th Int. Wkg Conf. Stored-Prod. Prot.17-23 April, 1994, Canberra, Australia Vol. 2 : 1087-1097.
- Markham, R.H., Wright, V.F & Rios Ibarra, R.M. (1991) A selective review of research on *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) with an annotated and updated bibliography. *CEIBA.* 32 (1) 90pp.
- McFarlane, J.A. (1988) Pest management strategies for *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) as a pest of stored maize grain:present status and prospects.*Tropical Pest Management.* 34 (2) : 121-132.
- McFarlane, J.A. (1989) Preliminary experiments on the use of solar cabinets for the disinfestation of maize cobs and some observations on heat tolerance in *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). *Tropical Science.* 2 (2) : 75-89.
- McGuire, J.U. & B.S. Crandall. (1967) Survey of insect pests and plant diseases of selected food

crops of Mexico. Central America and Panama. U.S. Department of Agriculture. 157pp.

Murphy, S.T. & A.E. Cross. (1990) The IIBC LGB screening programme for beneficial insects:

Summary of results. In: BOEYE, J., WRIGHT, M. & LABORIUS G.-A. (Eds.):

Implementation of and further research on biological control of the Larger Grain Borer.

Proceedings of FAO/GTZ Coordinating Meeting , Lome, Togo. 104-109.

Nyakunga, Y.B. (1982) The biology of *Prostephanus truncatus* (Horn) (Coleoptera:

Bostrichidae) on cassava. Master of Science thesis, University of Reading. England. 76pp.

Okamoto, K. (1971) The synchronization of the life cycles between *Callosobruchus chinensis* (L)

and its parasite *Anisopteromalus calandrae* (Howard). Jpn. J. Ecol.. 20: 233-237.

Oussou, R.A., Meikle, W.G., Borgemeister, C., Markham, R.H., Deygbey, P., Adda, C.,

Djomanou, B., Azoma, K. & Bonou, C.A. (1995) Growth and development of

*Tretriosoma nigrescens* Lewis (Coleoptera: Histeridae) under different humidity

regimes. Conf. Association of African Insect Scientists (AAIS), on the theme

Management of insects for better health and Natural Resource Management. 6-11 Aug.,

1995. Yamoussoukro, Cote d'Ivoire.

Oussou, R.A., Meikle, W.G., Markham, R.H. (1999) Factors affecting development and

survivorship of larvae of *Tretriosoma nigrescens* Lewis. Insect Science and its

Application 18 (1): 53-58.

Pantenius, C.U. (1988) Storage losses in traditional maize granaries in Togo. Insect Science and

its Application. 9, 725-735.

Philogene, B.J.R., R.T. Arnason & J.D.H. Lambert. (1989) Factors contributing to the protection

of maize against attacks of *Sitophilus* spp. and *Prostephanus truncatus*. pp141-149. In:

- Cereales en regions chaudes: Conservation et transformation. Colloque international de Technologie. Centre universitaire de N'Gaoundere, Cameroun. 22-26 Fevrier, 1988.
- Posada, O.L., I.Z.de Polania, I.S. de Arevalo, A. Saldarringa V., F.Garcia R. & R.Cadenas M. (1976) List of harmful insects and other pests in Colombia. Instituto Colombiano Agripecuario, Program de Entomologia, Boletin Tecnico No. 43. 484pp.
- Poschko, M. (1994) Research into the biology and host specificity of *Teretriosoma nigrescens*, a potential predator of *Prostephanus truncatus*. Ph.D Thesis. Univ. of Berlin. GTZ, Eischborn, Germany.
- Quintana, R., D.A. Wilbur & W.R. Young. (1960) Stored grain insects that infest maize in the field. *Agricultura Technica en Mexico* 10: 40-43.
- Rees, D.P. (1985) Life history of *Teretriosoma nigrescens* Lewis (Coleoptera: Histeridae) and its ability to suppress populations of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). *J. Stored Prod. Res.* 21:115-118.
- Rees, D.P. (1987) Laboratory studies on predation by *Teretriosoma nigrescens* Lewis (Coleoptera: Histeridae) on *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) infesting maize cobs in the presence of other maize pests. *J. stored Prod. Res.* 23: 91-195.
- Rees, D.P. (1990) *Teretriosoma nigrescens* Lewis (Coleoptera: Histeridae), a predator of the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae): Current status of knowledge, pp.103-111. In R.H. Markham & H.R. Herren (eds.) Biological control of the larger grain borer. Proceedings of an IITA / FAO coordination meeting.
- Rees, D.P. (1991) The effect of *Teretriosoma nigrescens* Lewis (Coleoptera: Histeridae) on

three species of storage Bostrichidae infesting shelled maize. *Journal of Stored Products Research*. 27 (1) : 83-86.

Rees, D.P., R.Rodriguez Rivera & F.J.Herrera Rodriguez. (1990) Observations on the ecology of *Teretriosoma nigrescens* Lewis (Coleoptera: Histeridae) and its prey *P. truncatus* (Horn) (Coleoptera:Bostrichidae) in the Yucatan peninsula, Mexico. *Tropical Science* 30(2):153 - 165.

Richards, O.W. (1949) Parasitic Hymenoptera found in British houses, warehouses and ships. *Proceedings of the Royal Entomological Society of London*, **18**, 19-35.

Rodriguez Rivera, R. (1990a) Perspectives of entomological research in stored products in southern zone of Mexico, pp.43-51. *In* L.J. Gutierrez Diaz & N. Contreras Moreno (eds.) "Perspectivas de la investigacion en Mexico" II Simposia nacional de Entomologia, Oaxaco, Oaxaco [Mexico], 14 mayo 1990. Sociedad Mexicana de Entomologia. 110pp.

Rodriguez Rivera, R. (1990b) The on-farm storage of maize and pest status of the larger grain borer in southern Mexico, pp.25-29. *In* : R.H.Markham and H.R.Herren (eds.) Biological control of the larger grain borer. *Proceedings of an IITA/FAO coordination meeting*, Cotonou, Rep. Of Benin, 2-3 June 1989. International Institute of Tropical Agriculture, Ibadan, Nigeria. viii + 171pp.

Schulz, F.A., & G.A Laborius. (1987) Strategy for bio-integrated control of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae), pp497-503. *In*:E.Donahaye and S.Navar (eds.). *Proceedings of the fourth International Working Conf. On Stored Prod. Protection*, Tel-Aviv, Israel, 21-26 Sept., 1986. 668pp.

Shires, S.W. (1977) Ability of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae)

to damage and breed on several stored food commodities. *Journal of Stored Products Res.* 13: 205-208.

Shires, S.W. (1979) Influence of temperature and humidity on survival, development period and adult sex ratio in *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). *Journal of Stored Prods. Research.* 15:5-10.

Shires, S.W. (1980) Life history of *Prostephanus truncatus* (Horn) (coleoptera: Bostrichidae) at optimum conditions of temperature and humidity. *Journal of Stored Products Research.* 16:149-150.

Shires, S.W. & S. McCarthy. (1976) A character for sexing live adults of *P. truncatus* (Horn) (Coleoptera: Bostrichidae). *Journal of Stored Products Research.* 12:273-274.

Spilman, T.J. (1984) Identification of larvae and pupae of the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera:Bostrichidae), and the larger black flour beetle, *Cynaesus angustus* (Coleoptera:Tenebrionidae), pp. 44-53. In Proceedings of the third international Working conference on Stored-Product Entomology, Kansas State University, Manhattan, Kansas, USA, October 23-28, 1983. 726 + 7pp.

Steel, R.G.D. & J.H. Torrie. (1980) Principles and Procedures of Statistics: A Biometrical Approach. pp633. Second Edn., McGraw-HILL, INC., NEW YORK, 1980.

Subra Rao, B.R. (1972) On *Zeteticontus silvestri*, with descriptions of three new species (Hymenoptera: Encyrtidae). *Entomophaga*, 17, (2), 179-195.

Subramanyam, Bh., L.K. Cutkomp, & B.A.Darveaux. (1985) A new character for identifying larval instars of *Prostephanus truncatus* (Horn) (Coleoptera:Bostrichidae). *Journal of Stored Products Research.* 21 (2) : 101-104.

- Sukprakarn, C. (1976) Insect pests of stored products found in Thailand. *Journal of Agricultural Science*. 1:501-504.
- Sweetman, H.L. (1958) *The principles of biological control*. Wm. C. Brown and Co., Dubuque.
- Verma, R. (1991) Life history and some aspects of biology of *Dinarmus basalis* (Hymenoptera, Pteromalidae), a parasite of stored legume bruchids. *Acta Entomol. Bohemslov.*, **88**: 359-366.
- Vowotor, K.A., Boateng, B.A., Ayertey, J.N., Oussou, R.D., Meikle, W.G., Borgemeister, C. and Markham, R.H. (1995) Controlling the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) in maize using host-plant resistance and biological control techniques. Paper presented at CTA/IIBC Conference, Addis Ababa, 9-14th October, 1995.
- Williams, R.N., & E.H. Floyd. (1971) Effect of two parasites, *Anisopteromalus calandrae* and *Chaestospila elegans*, on populations of the maize weevil under laboratory and natural conditions. *J. Econ. Entomol.* 64: 1407-1408.
- William, H.J., Silverstein, R.M, Burkholder, W.F & A. Korramshahi. (1981) Dominicalure 1 and 2: components of aggregation pheromone from male lesser grain borer, *Rhyzopertha dominica* (F.) (Coleoptera:Bostrichidae). *J.Chem.Ecol.*7:759-781.
- Wright, V.F. 1984. World distribution of *Prostephanus truncatus*. pp.11-16. In : The larger grain borer, *Prostephanus truncatus* (Horn). GASGA Workshop, Tropical Products Institute Storage Department, Slough, 24-25 February, 1983. Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GmbH, Eschborn, Federal Republic of Germany. 139pp.
- Young, W.R., D. Candia, Z.D. Barnes & D.L. Smith. (1962) *Storage of maize in the tropics*

Young, W.R., D. Candia, Z.D. Barnes & D.L. Smith. (1962) Storage of maize in the tropics under different moisture levels. *Agricultura Tecnica en Mexico* 12: 13-16.

Zacher, F. (1954) The importation of storage pests to Germany. pp50-55. In : *Verhandlungen der Deutschen Gesellschaft für angewandte Entomologie e.V. auf der zwölften Mitgliederversammlung zu Frankfurt am Main, 27-29 October, 1952.* [Importation,p53].

Reprinted pp56-61, in H.Weider (1963) *Friedrich Zacher; Vierzig Jahre Vorratsschutz in Deutschland; eine Auswahl aus Zeitschriftenaufätzen und Tagungsvortragen.* Ducker & Humboldt, Berlin. pp143.

**APPENDIX****APPENDIX 1**

**The effect of *A. calandrae* on *S. zeamais* population and activity on maize.**

<b>TREATMENT</b>				
Replicate	<i>S. zeamais</i> nos.	<i>A. calandrae</i> nos.	% grain damage	%dry-weight loss
1	275	25	62.4	2.7
2	198	19	60.5	2.6
3	302	21	61.9	2.1
4	243	31	59.8	2.5
5	224	25	62.5	2.6
6	203	32	60.7	2.4
Mean	240.8	25.5	61.3	2.5
St. Dev.	41.1	5.2	1.1	0.2

<b>CONTROL</b>			
Replicate	<i>S. zeamais</i> nos.	% grain damage	%dry-weight loss
1	438	75.3	3.1
2	511	76.5	3.3
3	483	79.2	3.2
4	399	63.9	3.6
5	476	78.6	5.0
6	571	77.3	3.7
Mean	479.7	78.3	3.5
St. Dev.	59.3	2.0	0.2

**APPENDIX 2**

**The effect of *A. calandrae* on *P. truncatus* population and activity on maize.**

TREATMENT				
Replicate	<i>A. calandrae</i> nos.	<i>P. truncatus</i> nos.	% grain damage	%dry-weight loss
1	649	19	93.1	33.3
2	594	18	89.8	32.6
3	638	25	90.6	35.2
4	537	22	91.9	30.9
5	486	16	85.5	35.9
6	713	21	86.2	34.8
Mean	602.7	20.2	89.6	33.8
St. Dev.	82.2	3.2	3.0	1.9

CONTROL			
Replicate	<i>P. truncatus</i> nos.	% grain damage	%dry-weight loss
1	1129	83.6	52.2
2	1205	86.5	51.4
3	1152	90.2	49.4
4	998	90.8	55.1
5	1038	87.3	43.9
6	1003	84.6	46.3
Mean	1087.5	87.2	49.7
St. Dev.	86.4	2.9	4.1

**APPENDIX 3**

**The effect of *D. basalis* on *C. maculatus* population and activity on cowpeas.**

<b>TREATMENT</b>				
Replicate	<i>C. maculatus</i> nos	<i>D. basalis</i> nos.	% grain damage	%dry-weight loss
1	178	8	75.8	42.5
2	256	87	73.4	45.4
3	280	46	76.2	39.3
4	273	68	78.1	50.1
5	138	46	72.4	43.4
6	169	42	74.9	46.1
Mean	215.7	49.5	75.1	44.5
St. Dev.	61.1	26.7	2.1	3.7

<b>CONTROL</b>			
Replicate	<i>C. maculatus</i> nos	% grain damage	%dry-weight loss
1	1172	79.2	54.2
2	1408	83.6	56.4
3	997	79.9	54.6
4	1613	76.5	53.9
5	2059	75.3	55.1
6	869	81.8	54.4
Mean	1353.0	79.4	54.7
St. Dev.	438.8	3.1	0.8

**APPENDIX 4****The effect of *D. basalis* on *P. truncatus* population and activity on maize**

TREATMENT				
Replicate	<i>P. truncatus</i> nos	<i>D. basalis</i> nos.	% grain damage	%dry-weight loss
1	963	0	94.1	22.6
2	882	0	92.3	19.9
3	798	0	87.4	20.1
4	929	0	90.1	25.7
5	769	0	89.2	28.1
6	826	0	91.1	24.2
Mean	844.5	0	90.7	23.4
St. Dev.	13.0	0	2.4	3.2

CONTROL			
Replicate	<i>P. truncatus</i> nos	% grain damage	%dry-weight loss
1	872	92.8	21.6
2	901	88.6	20.8
3	893	91.4	25.4
4	987	90.5	19.5
5	932	83.9	21.1
6	805	89.3	24.9
Mean	898.3	89.4	22.2
St. Dev.	20.2	3.1	3.4

**SUMMARY OF ANALYSIS OF VARIANCE****APPENDIX 5*****Prostephanus truncatus* emergence**

<u>Sources</u>	<u>df</u>	<u>ss</u>	<u>MS</u>	<u>F</u>	<u>Pr &gt; F</u>
Treatment	2	26.0	13.005	9.16	0.0073
Error	9	12.77	1.419		
Total	11	38.78			

**APPENDIX 6*****Anisopteromalus calandrae* emergence**

<u>Sources</u>	<u>df</u>	<u>ss</u>	<u>MS</u>	<u>F</u>	<u>Pr &gt; F</u>
Treatment	2	27.94	13.97	10.66	0.0001
Error	9	11.77	1.31		
Total	11	39.71			

**APPENDIX 7****Preference of *A. calandrae* for LGB larval instars**

<u>Sources</u>	<u>df</u>	<u>ss</u>	<u>MS</u>	<u>F</u>	<u>Pr &gt; F</u>
Treatment	2	25.23	12.62	8.89	0.0005
Error	6	8.54	1.42		
Total	8	33.77			

**APPENDIX 8****Parasitoid development time for LGB larval instars**

<u>Sources</u>	<u>df</u>	<u>ss</u>	<u>MS</u>	<u>F</u>	<u>Pr &gt; F</u>
Treatment	2	24.87	12.44	24.88	0.0001
Error	9	4.47	0.50		
Total	11	29.34			