CROP POST HARVEST PROGRAMME

Development of IPM techniques for the control of Larger Grain Borer and effective management of household food grain stocks in sub-Saharan Africa (2nd Phase Project)

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Executive summary

Food insecurity is chronic and recurrent amongst many households in sub-Saharan Africa. Poor African farmers face considerable storage problems caused by insect pests that must be overcome if food security incomes from agricultural production of durable food crops are to be maximised. In recent years, the Larger Grain Borer (LGB), *Prostephanus truncatus,* has become a major pest of stored maize and cassava in many African countries, including Tanzania and Ghana. Where this pest occurs, weight losses of grain have roughly doubled from around 5% to 10%. Such losses are not expected every year as LGB attack varies very considerably between years Effective integrated pest management for small-holder farmers has remained elusive and despite the apparent effectiveness of pesticide application, synthetic pesticides pose serious and increasing risks. Recommended insecticides for use on grain such as organophosphates are associated with health and environmental problems. They are not cheap and insecticide treatment failures in grain stores have frequently been linked to under-dosing due to cost constraints. While improved practice may limit pesticide misuse, safe alternative measures appropriate to the needs of poorer households are needed.

This project has succeeded in the development of a risk warning system for LGB that enables those advising farmers to predict when 'bad years' for LGB attack are expected. This is a crucial step towards integrated pest management as it will permit farmers to make decisions based on risk. In addition, a method of targeting pesticide treatment within the grain stock, so that up to 80% less pesticide is required, has been developed that improves the cost effectiveness and reduces the risks of pesticide usage.

Both the new methods have been presented to technical audiences from East, West and Southern Africa and targeted pesticide has been the subject of farmer participatory research and stakeholder analysis. For both methods to impact on farmer livelihoods, decision frameworks must be developed that are directly applicable to the farming communities in question. Such a decision framework is being proposed for development under a future CPHP project in northern Ghana. This will form the basis for frameworks for use elsewhere and so facilitate the spread of appropriate and effective pest management to maintain food security and food quality among small-holder farmers.

CONTENTS

Background

Poor African farmers face considerable storage problems caused by insect pests that must be overcome if incomes from agricultural production of durable food crops are to be maximised. In recent years, the Larger Grain Borer (LGB), *Prostephanus truncatus,* has become a major pest of stored maize and cassava in many African countries, including Tanzania and Ghana. Where this pest occurs, weight losses of grain have roughly doubled from around 5% to 10% (Dick 1989). In Ghana for example, maize production is about 1 million tonne/annum (1993 figures) and a large percentage of this is stored on the farm. Thus even small reductions in losses of say 0.5 to 1% can give significant saving of grain (5K to 10K tonnes), especially when such savings are accumulated year on year.

Currently the simplest and most effective method to control the pest is to shell maize cobs and to treat the grain with a suitable insecticidal dust. However, uncertainty of the risk of LGB infestation will lead some farmers to treat all the time, even when the risk may be low (demonstrated in East Africa, Golob *et al.,* 1999) and others to decide not to treat until an infestation is detected, risking large food losses (e. g. Golob, 1991). The application of pesticide is necessary but is generally considered to pose risks to health and the environment and is a significant financial cost to subsistence farmers. In Europe, the use of organophosphorous insecticides, types used in grain treatments, is increasingly criticised on health and environmental grounds and there is a need now to take action to limit their use.

In its first phase this project was restricted to Ghana although it was acknowledged that its research findings would probably have applicability elsewhere. The geographical focus of this second phase has been increased to included East and Southern Africa (Tanzania and Zimbabwe). This gives the opportunity to test and promote project outputs in other countries. This will raise the profile and credibility of outputs and position them well to have an impact in those areas of Southern Africa which in due course may be seriously affected by LGB. The activities reported here are in several cases those which were initiated during the first phase of the project and there is some overlap between those reported here and the FTR of the project in its first phase.

Evidence from survey work undertaken by the DFID LGB Project in Ghana (TC project 1993-96) has shown that farmers need solutions to the problem posed by LGB infestation. LGB was first observed in Ghana in 1989 and is still spreading in this and other countries, especially areas of southern Africa (it was recorded for the first time in South Africa in June 1999), thus demands to limit this pest will increase. The research work undertaken in project R6684 was a response to this.

Research activities in West Africa on Larger Grain Borer continue to receive support through IITA based in Cotonou where the main study is the development of models to predict the outcome of different IPM strategies against LGB and other storage pests. In Tanzania, a recent study funded by the RNRKS and Rockefeller Foundation (Golob *et al.* 1999: ‘Farmer Coping Strategies Against the Larger Grain Borer in East Africa’) has shown that farmers regard LGB as potentially still the greatest post-harvest problem, although, as in Ghana, there is considerable year to year variation in the extent of attack. The LGB problem has resulted in the adoption of much more widespread use of pesticides with the concomitant increase in storage of shelled maize. Tanzanian authorities have being considering developing their own risk warning system based on pheromone trapping. This project offers technical support to enable the Tanzanian Plant Protection Division to achieve this. In Zimbabwe, the use of pesticide to protect farm stored maize is widespread as farmers tend to grow HYVs that are particularly susceptible to insect attack. Technology developed in Ghana on reduced insecticide usage stands to offer cost and environmental health advantages to these farmers.

Project purpose

The purpose of the project fall falls directly within the Crop Post Harvest Programme output of 'Strategies developed and effectively promoted which improve food security of poor households through increased availability and improved quality of cereals and pulse foods and better access to markets'.

The research objectives of the project seek to enable extension services and other bodies to give farmers an early warning in those years when serious LGB infestation is likely, provide a means by which farmers can limit the amount of pesticide used on their stored crops and maximise the benefit of biological control. These In fulfilling the objectives food losses will be reduced and grain quality preserved by timely pest management action against Larger Grain Borer. Extension services will be able to predict years in which there is significant risk of LGB attack, enabling them to focus their efforts with farmers, encouraging the use of appropriate storage technologies. Financial, health and environmental gains will be made from reducing the amount of pesticide that needs to be applied to grain and by realising the potential for relying on a no-cost biological control procedure using the predator *Teretrius nigrescens* (Tn).

Research activities associated with output 1

Output 1: Risk assessment systems validated and available for use in West and East Africa.
OVIs - Extension services actively testing the risk assessment system in at least one region of Ghana by 2002 and this method adopted by 2004.

1. Can 'bad' years for *Prostephanus truncatus* damage be predicted?

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Introduction

Prostephanus truncatus differs from other common beetle pests in maize storage in the tropics such as *Sitophilus* spp. in that the level of damage for any one store is particularly unpredictable, and those farmers who are affected can suffer such extreme losses that a season's harvest can be effectively lost. This uncertainty makes it difficult for farmers to plan their action against this pest. They currently have two options. Either take action every season and perhaps use pesticides and other resources unnecessarily, or incur the risk of high food losses.

We suggest that there are two main contributors to this unpredictability of store infestation. First, at any one time some stores will be highly infested while others remain undiscovered by the pest. This is because *P. truncatus* does not locate maize or cassava in store by responding to volatiles from the commodity itself; the initial colonisers arrive by chance (Hodges, 1994; Fadamiro *et al.*, 1998; Scholz *et al.*, 1997a). Once even a single male has arrived and releases an aggregation pheromone signal, however, the store and the commodity is placed under increased threat (Scholz *et al.*, 1997b; Birkinshaw and Smith, 2000).

Second, farmers from several countries report that there is substantial year to year variation in the number of stores that are damaged. We start with the hypothesis that, for a given length of storage period, year to year variation in damage across a community, is determined by annual variation in the numbers of dispersing adults. Since the initial colonisers arrive by chance, then we predict the correlation between flight activity and store colonisations to be particularly good. Obviously the length of a storage season will also be an important determinant of food damage. If, for example, the harvest is poor and stores only contain food for 2-3 months, then the percentage of damage will be much lower than for food stored for six months and over (see Holst *et al.*, 2000, for a model of how damage increases with time).

It is possible to sample the dispersing population of *Prostephanus truncatus* using flight traps baited with synthetic aggregation-pheromone (Dendy *et al.*, 1989; Richter and Biliwa, 1991; Fandohan *et al.*, 1992; Hodges and Pike, 1995). Samples taken using pheromone-baited traps are not likely to be random samples of the dispersing population, however they are the best practical measure currently available. Four years of trapping data from Ghana showed that the mean trap catches over a year can vary by over threefold. Perhaps more importantly, the peaks of catches that can occur near the beginning of a storage season varied by almost tenfold between years (see data in Birkinshaw and Hodges, 2000). Females caught in traps are mostly inseminated and able to reproduce as soon as they locate a plant host (Scholz *et al.*, 1998; Hodges and Birkinshaw, 1999), although further mating will increase their rate of offspring production (Li, 1988). No large differences in the reproductive potential of insects caught in different seasons were found in a range of habitats (Scholz *et al.*, 1998; Hodges and Birkinshaw, 1999).

To investigate whether the trap catches of *P. truncatus* are a good predictor of store colonisation rates, the current study measured prevailing *P. truncatus* trap catches, and the incidence of colonisation of purpose-built mini stores. Here we present some data obtained in this project's predecessor (experiments A and B)(*) to allow all the evidence to be brought together for assessment. These estimates of how changes in trap catches relate to the risk of stores being colonised were then compared to observations of real farmers' stores at the end of a storage season. This on-farm validation of the risk assessment model used stored dried cassava (kokonte) in the Kete Krachi district of the Volta Region. Cassava is the main staple crop grown in this area, some is used for family food and some is sold to a trading company for cash. There is one main season for kokonte production normally falling between December and April. The kokonte is then often stored for up to a year until the next harvest.

Methods

'Mini' stores

Experiments were done in villages in Ghana and Tanzania as shown in Table 1. Two contrasting areas in the Volta Region of Ghana were chosen. First the forest-savannah transition zone of Hohoe/Jasikan district, and second the semi-arid zone of the Nkwanta district. A semi-arid area with high reliance on maize was chosen in Tanzania.

Table 1.1: Summary of the locations, dates and commodities used in mini-store experiments

Location	Dates	Number of stores	Total number of hits during experiment
A. Ghana		4 maize	57
5 villages in Hohoe/Jasikan district	2/4/1998 -	4 cassava	17
5 villages in Nkwanta district	20/1/1999	1 maize and cassava mix[a]	5
B. Ghana			
5 villages in Hohoe/Jasikan district	29/3/1999 -	9 cassava[b]	163
5 villages in Nkwanta district	30/9/1999		
C. Tanzania			
5 village in Kilosa district	16/8/2000 - 30/3/2001	9 maize	26

[a] Data from mixed commodity stores has been excluded from all analyses
[b] In this experiment traps were only present for half the time

In each village, nine mini-stores were constructed, each consisting of a chicken wire cage supported by a wooden frame, and protected from the rain by a thatch roof. The design of the stores was slightly different in Ghana and Tanzania, but both held a volume of approximately eight litres of commodity (60-65 cobs) 1.2-1.5 m above the ground. Local varieties of maize cobs with their sheathing leaves intact were used, and the cassava roots were dried chips about 10-15cm long and 3-7cm in diameter. None of the commodity showed any signs of previous infestation by *P. truncatus* and all was fumigated with phosphine for at least seven days and then maintained in insect-proof plastic bins prior to use. In Ghana, commodity was placed in a cylindrical mesh cage with a diameter of approximately 60cm and supported on a single wooden post running up the centre (see Hodges and Birkinshaw 2000 for further details). In Tanzania, the mesh cage was square of sides 60cm and supported by four legs, one at each corner (see Figure 1). In all stores a layer of black polypropylene was fixed directly underneath the mesh cage to allow easy detection of the characteristic dust produced by *P. truncatus* boring activity.

Figure 1.2: Tanzanian mini-store being loaded with maize cobs

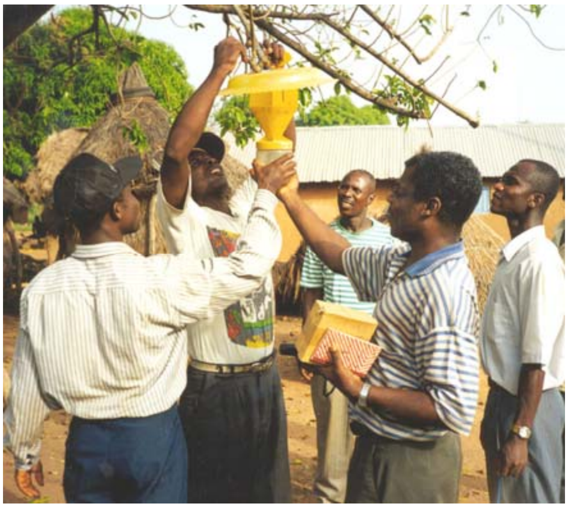


Figure 1.2: Hanging a pheromone-baited flight trap in Ghana

The pheromone-baited traps used to sample the dispersing population of *P. truncatus* were Japanese beetle type supplied by Trécé Inc., Salinas, CA., USA (see Figure 2). They consist of a yellow plastic funnel (diameter 15cm, height 11cm) with four vertical canes in the form of a cross, extending 10cm up from the funnel to form a baffle. Incoming beetles hit the baffle and then tumble into the funnel to be collected by a plastic jar attached to its base, containing a Whatman's No. 1 filter paper impregnated with a lethal dose of diluted Actellic Super EC insecticide. Each trap was baited with a standard *P. truncatus* aggregation pheromone lure consisting of a polythene capsule impregnated with 1mg each of Trunc-call 1 and Trunc-call 2. Four traps were hung 1.5-2m above the ground on any conveniently located vegetation, often a mango tree branch. The arrangement of traps and stores in villages is shown in Figure 1.3.

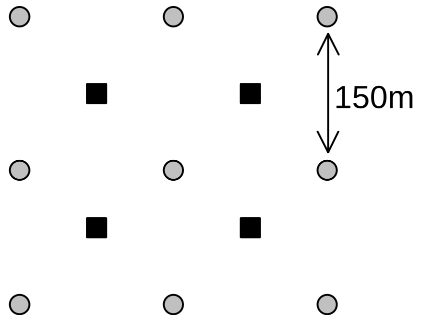


Figure 1.3. Plan view of the arrangement of mini stores (squares) and traps (circles) in each village. The exact spacing was limited by the availability of a suitable branch for the traps and by the positioning of households to keep an eye on the stores, however traps and stores were never closer than 100m from each other.

Villages were visited every two weeks to collect and count the numbers of *P. truncatus* captured in the traps, to replace the existing pheromone capsule with a fresh one and to examine the mini stores for signs of infestation. Once infested, the stores were cleared of produce and were refilled with fumigated material after a fallow period of at least two weeks (sometimes longer when commodity was scarce).

In experiment B, the possible influence of the presence of the baited traps on the colonisation of the mini stores was tested. Traps were baited with pheromone in the villages for just half the time. Traps were left unbaited for every other trapping period i.e. two weeks on, two weeks off.

Binary logistic regression (Genstat 4.1) was used to determine which out of a number of possible variables significantly contributed to the risk of stores becoming infested. Whether or not a mini-store had been previously colonised was termed, 'hit before'. This variable was included to check whether our disinfestation of stores before re-loading had been successful. The length of time a store had been exposed to field conditions was termed store age. This was included in the model to determine if other factors that change with time during storage such as moisture content, or the increasing infestation from other pests might influence store colonisation by *P. truncatus.* The logistic regression equation generated by this analysis was used to predict the cumulative number of *P. truncatus* that are associated with a range of probabilities of stores becoming infested. This relationship was estimated using models including only *P. truncatus* trap catch as an explanatory variable. The cumulative trap catch is the number of insects that need to be caught whilst using a two-weekly trapping regime, irrespective of how long this takes.

Farmers' stores

Krachi district, next to the Volta lake was chosen for the study. The villages in this district are relatively widely spaced and five villages were selected spaced approximately in a line about 10km apart. Borae was the biggest, and is the local administrative capital where there is a lot of trading in produce. All the other villages were fairly small farming communities. Kokomba, Chokosi, Ntsumuru, Kokotoli, Krachis, and Hausa ethnic groups are all represented, but the Kokomba predominate in all villages, followed by the Krachis. The Kokombas mostly store their kokonte in traditional structures called katchalla. These were roughly cylindrical in shape and of mean height 130cm, diameter 215cm and 40cm off the ground.

Figure 1.4: Typical katchalla style cassava store of the Kokomba people

Figure 1.5: Participating community in Kete Krachi district of Ghana.

Eighty farmers, from the five villages were selected for this study: Borae (13), Peposu (14), Ankase (21), Ehiamankyene (21), Adomang (11). All farmers stored their kokonte (dried cassava chips) in katchalla stores (Figure 1.4). None of the farmers treated their kokonte with any protectant against insects. Mostly cassava was unloaded from stores gradually in small amounts, initially mostly for sale, then for family food towards the end of the season.

Locally recruited and trained staff were given plastic boxes and asked to collect samples of kokonte with farmers during the final unloading of stores. Samples were later checked by project staff for the presence or absence of *P. truncatus*. Samples given towards the end of storage when approximately one tenth of the original quantity of commodity remained. Cassava pieces were picked at random. Ten pieces were given. *P. truncatus* initially tend to migrate to the bottom of a store (Hodges *et al.*, 1999) so sampling at this point late in the season maximises the chance of an infestation being detected from such a relatively quick sampling protocol. For each store, the following information was recorded.

- Date the store was loaded
- The dimensions of the store
- Whether the wooden construction of the store was old or new this season
- Date the cassava was sampled
- Whether or not *P. truncatus* was found in the cassava sample
- The cumulative mean number of *P. truncatus* caught per trap in the village where the store was located, between the date the store was loaded, and the date the store was sampled. Since traps were emptied only every two weeks, the nearest trap catch to the dates of sampling were used.

Results from 'mini stores'

There was considerable variation in trap catch between different sites and over time (Figs. 1.6 to 1.8). Trap catches were mostly under 1000 beetles per trap per two weeks, but some peaks were in excess of 3000 beetles per trap per two weeks. These trap catches were found to be a significant determinant of store colonisation in experiments in Ghana, but not in Tanzania (see Tables 1.2, 1.3 and 1.5). However the estimates of the relationship between trap catch and risk of store colonisation were similar across all sites (Figure 1.9). The estimates predict that in a two-week trapping regime (using standard traps and lures), 50% of mini-stores will be infested by the time the cumulative trap catch reaches approximately 2-4 thousand insects.

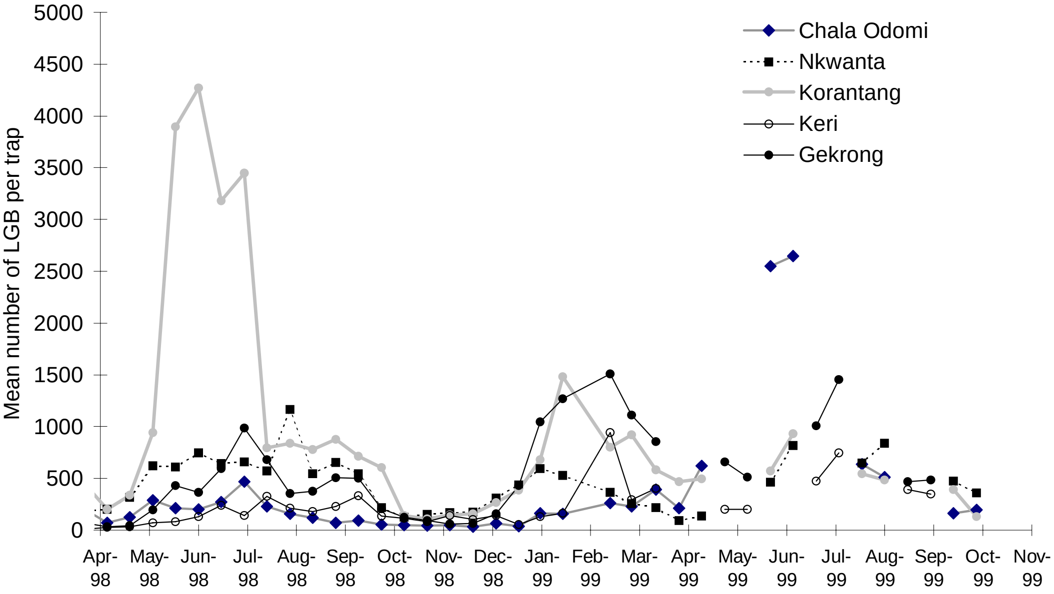


Figure 1.6: Mean number of* P. truncatus *caught per flight trap per two week trapping period in the Hohoe/Jasikan village cluster

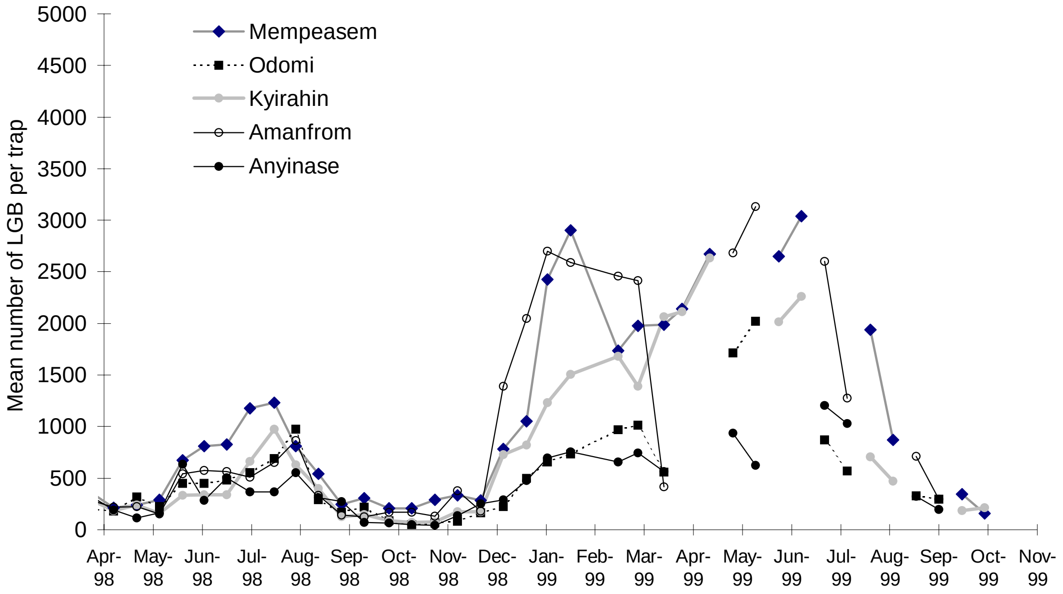


Figure 1.7: Mean number of **P. truncatus** *caught per flight trap per two week trapping period in the Nkwanta village cluster*

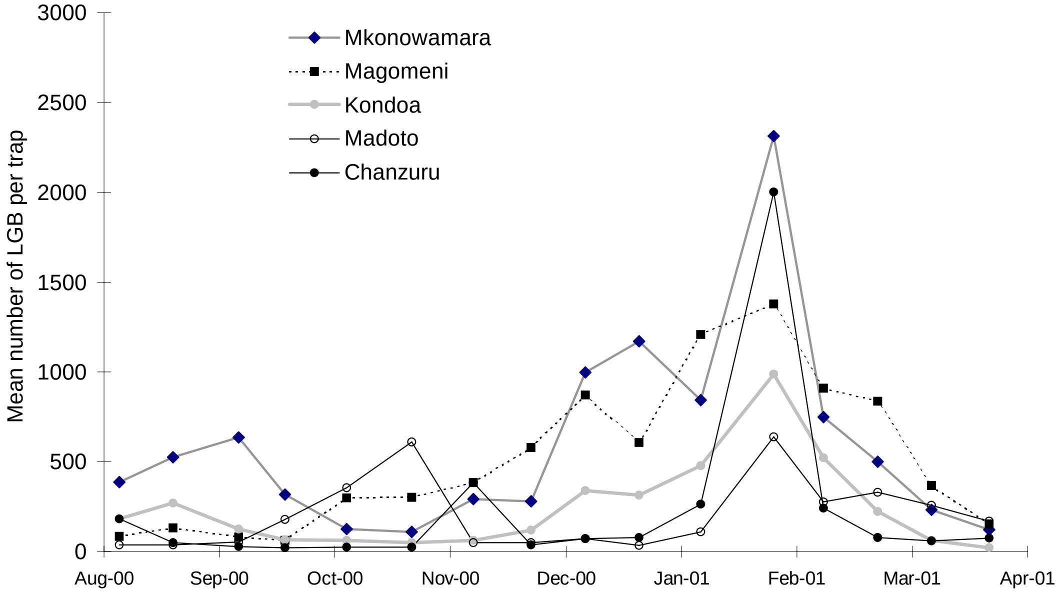


Figure 1.8: Mean number of **P. truncatus** *caught per flight trap per two week trapping period in the Kilosa village cluster.*

Table 1.2: Estimates of the influence of factors on the chance of mini stores becoming colonised in experiment A in Ghana (maize and cassava). Overall mean deviance = 10.8, p<0.001, d.f. = 4

	Estimate	SE	t	p-value
Constant	-3.69	0.33	-11.1	<0.001
Maize vs. Cassava	1.29	0.29	4.49	<0.001
Hit before?	-0.213	0.257	-0.83	0.41
Store age	-0.0243	0.0133	-1.82	0.068
P. truncatus trap catch	0.000532	0.000132	4.04	<0.001

Table 1 3: Estimates of the influence of factors on the chance of mini stores becoming colonised in experiment B in Ghana (cassava with and without traps). Overall mean deviance = 4.8, p<0.001, d.f. = 4

	Estimate	SE	t	p-value
Constant	-2.83	0.29	-9.94	<0.001
Presence of traps	0.308	0.172	1.79	0.073
Hit before?	0.533	0.190	2.81	0.005
Store age	0.0357	0.0148	2.41	0.016
P. truncatus trap catch	0.000351	0.000106	3.31	<0.001

Table 1.4: Frequency of mini-store colonisations occurring in the presence and absence of traps (experiment B in Ghana)

Village	Traps absent	Traps present	Chi squared	p-value
Nkwanta	8	12	0.40	N.S.
Gekrong	5	9	0.57	N.S.
Chala Odomi	12	13	0.02	N.S.
Korantang	4	22	6.23	<0.025
Keri	4	3	0.07	N.S.
Bowiri Ayaniase	2	5	0.64	N.S.
Bowiri amanfrom	4	7	0.41	N.S.
Bowiri Kyriahin	10	6	0.50	N.S.
Akpafu Odomi	12	4	2.00	N.S.
Akpafu Mempeasem	11	10	0.02	N.S.
TOTAL	72	91	1.11	N.S.

Table 1.5. Estimates of the influence of factors on the chance of mini stores becoming colonised in experiment C in Tanzania (maize). Overall mean deviance = 2.3, p = 0.072, d.f. = 3

	Estimate	SE	t	p-value
Constant	-4.04	0.46	-8.77	<0.001
Hit before?	0.004	0.563	0.01	>0.99
Store age	0.0512	0.026	1.98	0.048
P. truncatus trap catch	0.000523	0.000421	1.24	0.215

The commodity type (maize compared to cassava) filling the store was found to influence store colonisation (see Table 1.2). The regression equations suggest that cassava is more likely than maize to become infested at low beetle density. In general the results suggest that cassava is less sensitive to changes in beetle numbers i.e. increases in beetle density do not result in as much increase in risk as observed in maize-filled stores.

There is no overall consistent influence of the presence of traps on the store hit-rate. The stores in Korantang village however, were hit over five times more frequently in the presence of traps than when they were absent (see Table 1.4).

Results for farmer stores

Again there was variation in trap catches between villages (Figure 1.9). In four of the five villages, predictions (based on the data from the mini-store experiments) of the colonisation rate of barns given their exposure to flying *P. truncatus* were good. However, Borae village was an outlier, where, although trap catches were high, the proportion of stores infested was relatively low.

Regression analysis on the entire data set indicates that the age of wood used in the construction of the store, was a significant factor in store colonisation. Only about a quarter of stores with new wood (7 of 27) became infested compared to two thirds of those with old wood (35 of 53). Thus age of the wood proved to be a significant factor in determining the likelihood of infestation (Table 1.6). In contrast, store size did not appear to be a significant factor, although there was little variation in the sizes of stores used in the experiment. The length of time between loading and sampling for *P. truncatus* was a significant determinant of store colonisation by the pest. Obviously time exposed co-varies with the cumulative trap catch of *P. truncatus*.

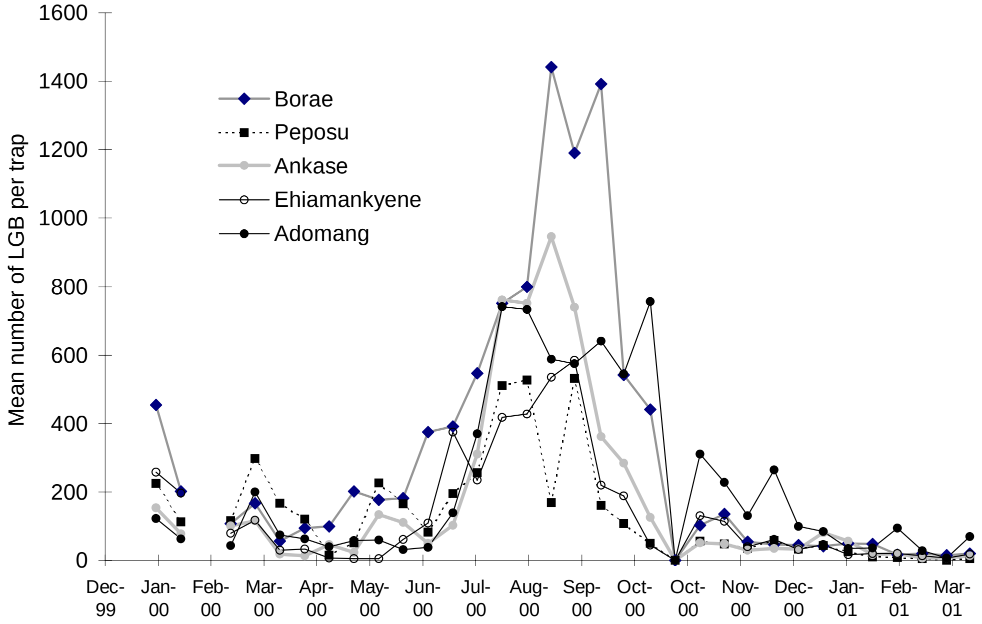


Figure 1.9: Mean number of **P. truncatus** *caught per flight trap per two week trapping period in the Kete Krachi village cluster*

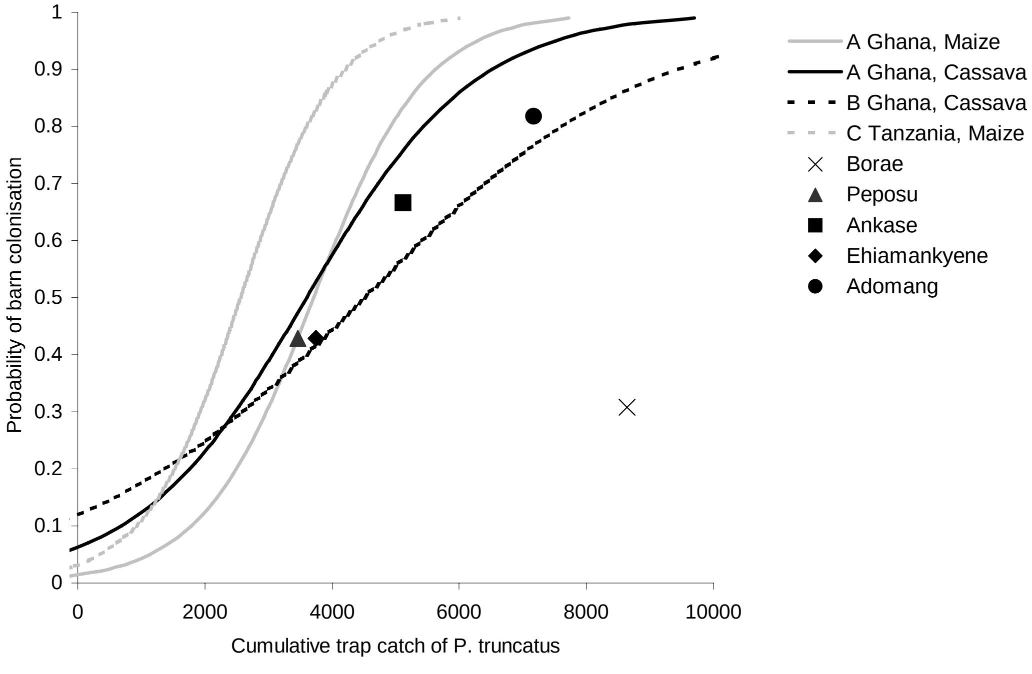


Figure 1.10: Estimates of the relationship between cumulative trap catches of **P. truncatus** *and probability of store colonisation generated during experiments A,B and C, and actual data points from observation of farmer cassava stores in Keta Krachi in Ghana.*

Table 1.6: Estimates of the influence of factors on the chance of katchalla being colonised at the end of the storage season. Overall mean deviance = 4.39, p = 0.002, d.f. = 4

	Estimate	SE	t	t probability
Constant	-5.25	2.47	-2.13	0.034
Store wood new?	1.97	0.60	3.30	<0.001
Store size (area in profile)	-0.31	0.56	-0.55	0.58
Time exposed	0.084	0.045	1.89	0.058
P. truncatus trap catch	0.000192	0.000141	1.36	0.17

Discussion

Dispersal activity, as measured using flight traps was a significant predictor of mini-store colonisation in most datasets. A cumulative trap catch of about four thousand insects is predicted to be associated with a 50% chance of store colonisation.

Mini-stores loaded with cassava were more likely to become colonised than those loaded with maize cobs at lower beetle dispersal activities. We suggest that this may be a consequence of the relative ease with which *P. truncatus* can bore into cassava compared with the sheath-covered cobs. *P. truncatus* may be more likely to resume flight if landing on cobs than cassava. In the mini-store data there was some evidence that the length of the time the commodity had been in the store influenced the chance of *P. truncatus* colonisation during any two-week period. The length of time farmer stores were loaded was also approaching significance as a factor. This suggests that the action of other storage factors such as changes in moisture content to the action of other insects may also make stores increasingly open to *P. truncatus* invasion.

When these predictions were tested on much larger stores used by farmers, the results closely matched the predictions for four out of five villages. There did not appear to be a large increase in the risk of store colonisation from the increase in size of the stores. Such an increase may have been offset by cases where colonisations were not detected with the sampling protocol used. The size and inaccessibility of much of the cassava in the katchalla stores precluded any kind of comprehensive sampling plan. Alternatively it may be that *P. truncatus* start to orientate directly to stores over short distances in response to short-range cues. Direct orientation towards stores over short distances (say a few metres) may reduce the significance of store size compared to completely random location. Although long range attraction has been ruled out, short-range attraction may be possible, especially in the case of cassava (Hodges, 1994; Scholz *et al.*, 1997a).

Farmers' stores have structural timbers the age of which had a clear influence on store colonisation. This confirms the importance of earlier observations that *P. truncatus* may survive between storage seasons in wooden storage structures (Kossou 1992). Farmers, particularly around Ho, reported an increase in their replacement of store wood in response to this threat (Addo *et al.*, in press).

There is some anecdotal evidence to support our hypothesis that year to year variation in risk of is determined by annual variation in the numbers of dispersing *P. truncatus*. In Tanzania, trap catches were relatively high in Morogoro/Kilosa districts in 1998 and farmers reported this year as being particularly bad for *P. trunca*tus damage (William Riwa, unpublished data). Likewise, particularly high levels of *P. trunca*tus damage were experienced in northern Ghana in 2000/2001, where it was estimated that there was a tenfold increase in reports to the local ministry of agriculture (A. Fuseini pers. com). Although long-term trapping data is not available for this region, traps in place in Tamale were catching over a thousand beetles per two weeks from September to November, the beginning of the storage season.

A survey of farmer's experiences since the arrival of *P. trunca*tus into the Volta region of Ghana did not, however, reveal a close link between trap catch data and farmers' experiences of damage (S. Addo, unpublished data). However, those years with high levels of insect dispersal activity were also years of poor harvest so that the storage seasons were much reduced and with it the opportunity for populations of *P. truncatus* to grow large enough for significant losses to be sustained.

Higher dispersal activity will not only increase the rate at which stores become colonised, it is also likely to influence the immigration rate of insects responding to aggregation-pheromone signals from male colonisers. We don't yet know the implications of higher flight activity on the speed at which stored commodity becomes damaged after its initial invasion, however Scholz suggests that this may be low since reproduction within the store is more important (Scholz *et al.*, 1997b).

Any warning system will necessarily need to be fairly crude in its predictions. Flight activity varies between villages that are geographically quite close and obviously flight activity is not the only influence on store infestation. Any *P. truncatus* infestation remaining in store wood, the type of commodity and length of storage are examples of other factors that our study has confirmed as influential. However, when trap catches soar into the thousands, particularly if this occurs early in the storage period then we would class this as 'high risk'. The risk system will need to be developed with stakeholders to ensure that information is provided in the most useful and appropriate form. Radio programmes and the extension services were highlighted as two important information providers in the Volta region of Ghana (Addo *et al.*, in press). More pest control activities are undertaken on maize than cassava, which remains largely untreated, but this does not mean that cassava farmers could not benefit from risk warning. Farmers may invest more in inspection if a 'bad' year is coming and benefit from more timely selling of their commodity if their store is attacked.

The main constraints to the implementation of such a system are likely to be the sustainability of the measurement of flight activity. Previous risk assessment systems using insect trapping have faltered because the co-ordination and resources required to maintain the trapping network is too great. Separate studies in this project, presented in the next section, show that climatic factors can be used to predict trap catches. Africa is already well served with meteorological stations and in the future remote methods of sensing climate may prove to be an even more convenient and cost-effective source of climate data.

Implications of results

- We are now confident that LGB trap catches can indicate years of high risk to farmers' stores, provided storage seasons are long enough for damage to build up.
- Cumulative trap catches of about four thousand insects are associated with a 50% chance of a barn becoming infested.
- The use of store wood over more than one season is again highlighted as a cause of store colonisation, presumably because the wood harbours the pest whilst the store is empty.

Acknowledgements

The LGB team in Ho, Ghana, Israel Tetty, Hillarious Penni and Daniel Asempah are thanked for their diligent field work which was often long and arduous. In Tanzania, work in the field would not have been possible without Mathias Deusdedith. The authors are also very grateful to Dudley Farman who prepared the LGB pheromone capsules and Dr John Gates and Dr David Jeffries for their assistance with statistical analysis.

2. Can observation of climatic variables be used to predict the flight dispersal rates of *Prostephanus truncatus*?

Hodges R.J., Addo S. and Birkinshaw L.A.

Introduction

An ability to predict the risk of serious pest attack is an important goal in agriculture (Nieminen, Leskinen & Helenius 2000) and forestry (Ravlin, 1991) and enables increasingly targeted and effective control measures. This approach would be of value in the case of *Prostephanus truncatus*. Monitoring the incidence of *P. truncatus* using pheromone-baited flight traps has shown that the number of beetles trapped varies considerably between seasons and years in Mexico (Rees, 1990), Kenya (Giles *et al.,* 1995) and Benin (Borgemeister *et al.,* 1997a). Further, it has been shown that there is a significant positive correlation between trap catch and the likelihood that stored food becomes infested. However, pheromone traps are expensive and time consuming to deploy so their long-term use by extension services in developing countries is unlikely to be sustainable. As an inexpensive alternative, the current study set out to test whether climate data could be used to predict years when dispersing *P. truncatus* are particularly abundant.

Climate may have an effect on the abundance of dispersing *P. truncatus* in both the long- and short-term. Dispersal of *P. truncatus* is believed to result from crowding and degradation of food resources (Fadamiro & Wyatt, 1995; Scholz *et al.,* 1997). The rate of insect development and consequently the rate of population growth is affected by long-term climatic conditions. In the laboratory, the optimum conditions for development of the pest on maize are 32°C and 70-80% r.h., when the life cycle can be completed in about 27 days (Subramanyam & Hagstrum, 1991); adults live at least four months (Guntrip *et al.*, 1996). Humidity effects on development appear to be non-linear with a more or less on/off response while temperature effects are more or less linear (Meikle *et al.,* 1998). In the short-term, climate has a direct affect on the propensity of insects to disperse by flight. Fadamiro & Wyatt (1995) observed an optimum temperature for flight in the range of 25º– 30ºC, a non-linear response, and a progressive (linear) increase in flight as relative humidity rose from 25% to 50% to 75%, although differences were not statistically significant.

Several authors have used multivariate analysis to investigate the relationship between climatic variables and *P. truncatus* trap catch (Tigar *et al.,* 1994; Nang'ayo, 1996; Giles *et al.,* 1995). However, where predictions have been made they have been very different in scale from observed catches and Farrell (2000) notes that their main use may lie in predicting relative rather than absolute abundance. Very recently, a study of flight activity in south Benin (Nansen *et al.,* 2001) identified day length, minimum relative humidity and minimum temperature as important variables for predicting *P. truncatus* trap catch and offers some improvement on earlier attempts to predict trap catches.

The current study sought a means of predicting years when dispersing *P. truncatus* are particularly abundant. The first step was to examine the association between climatic variables and observed seasonal and annual variations in *P. truncatus* trap catch of a tropical rain forest-savannah transition zone in Ghana. The second step was to devise a rule-based model from this association and prior knowledge of the pest's biology. The use of such models in pest management has been discussed in detail by Holt & Day (1993). The model was subsequently validated with climate data and trap catches from two semi-arid areas.

Materials and methods

Procedures adopted for Hohoe/Ho

Pheromone trapping was undertaken at Hohoe, in a tropical rain forest-savannah transition zone of the Volta Region in Ghana and climate data collect from the Meteorological Station at Ho about 45 km south of Hohoe; the climate of the two towns is similar (Table 1). At Hohoe, trapping was undertaken in five villages close to the town using Japanese beetle traps (Compton *et al.* 1997) following the procedure described in Birkinshaw *et al.* (in press). In each village, four traps were hung from trees about 1.5m from the ground, with about 100m to 150m between traps. Traps were emptied and pheromone capsules changed on a two-weekly routine over a period of five years (1996-2001). For logistical reasons trapping was discontinued on four short occasions.

The Ho Meteorological Station provided daily maximum and minimum temperature (mercury thermometers), daily rainfall, daily windrun expressed as cumulative wind in km/h measured from 9h to 9h using a mechanical anemometer, and relative humidity (wet and dry bulb thermometers). For purposes of comparing trap catch and climate data, comparisons were made with humidity at mid-day and mean temperatures calculated from the daily maxima and minima. This method of calculating the mean temperatures is convenient but the values may be somewhat different from the true mean. To observe what differences there might be during the course of a year, hourly temperature data were collected by an electronic thermohygrograph (Temperature and Humidity Recorder model CT 485RS, White Box Co., USA) located at the laboratories of the Ministry of Food and Agriculture in Ho. The temperature and humidity sensors were placed in a ventilated polystyrene box suspended in the shade just below the eves of a building. Data from six days of the month, spaced more or less evenly, from February 1999 to January 2000, were analysed. The averages from hourly observations through out the day were then compared with those derived from maxima and minima.

Analysis of data

The initial analysis was used to explore the relationship between trap catch and climatic variables. An informal approach was chosen due to the non-linearity of the effects of temperature and humidity on development and flight activity. Linear regression and CUSUM analysis (Oakland, 1987) were used, the latter to provide a clear view of when changes in conditions and in trap catches occur. The technique involves calculating the deviation of values from their average over the years and presenting a plot of cumulative deviation.

$$Sr = \sum_{i=1}^{r}(x_i - \bar{x})$$

Where Sr is the CUSUM score
x_i is the result from the individual sample i
$\bar{x}$ is the mean of all samples for the period in question

The technique is well known in process control and is very powerful for the detection of trends. When looking at CUSUM plots the absolute values are not important, the slope of lines conveys the meaningful information. In this case CUSUM plots enabled easy comparison between years and gave clues to the relationship between some variables.

The explorative analysis was tested by the development of a rule-based climate model, to predict *P. truncatus* trap catch, on an Excel spreadsheet. Rules were developed from observation of the relationship between trap catch and climatic variables in Hohoe and Ho respectively and prior knowledge of the biology of the pest.

Procedures at other locations
The rule-based model, was validated on trap catch and climate data from two other locations in different agro-climatic zones, Nkwanta in Ghana and Morogoro in Tanzania (Table 1). In Nkwanta, four Japanese beetle traps were located in each of five villages and the procedure was the same as in Hohoe. Climate data was collected at the Kete Krachi Meteorological Station about 40km from Nkwanta, in the same manner as Ho. At Morogoro, single traps were located at nine sites and most were within 20 km of the Kilosa Meteorological Station (Table 1) which collected climate data similar to that in Ghana except that only humidity at 15.00h was available and so had to be used in the model. There were two important trapping differences from Ghana, delta traps (Hodges & Pike, 1995) were used instead of Japanese beetle traps and these were emptied monthly (Table 1).

Table 2.1 Locations used for trapping* P. truncatus *and collection of climate data

Trapping location	Vegetation type (US CIA, 1997)	Meteorological station	Trap type and frequency	Duration and no. of trapping periods
Hohoe, Ghana, (7°19'N, 0°27'E)	Tropical rain forest - savannah transition	Ho (6°45'N, 0°35'E)	Japanese beetle trap - 14 days	Jan. '96 - Sept. '01 129 trapping periods
Nkwanta, Ghana, (8°16'N, 0°31'E)	Deciduous woodland savannah	Kete Krachi (7°8'N, 0°0'E)	Japanese beetle trap - 14 days	Jan.'97 - July '99 66 trapping periods
Morogoro, Tanzania (6°47'S, 37°43'E)	Short grass steppe	Kilosa (6°47'S, 37°02'E)	Delta (sticky) trap - 28 days	Sept. '97 - Dec. '99 24 trapping periods

Results and conclusions

Observations Ho/Hohoe Volta Region Ghana

In Hohoe, the typical annual pattern of *P. truncatus* trap catch is two distinctive peaks, one during the Harmattan period (Dec.- Feb.) and the other 'Mid-year' (May - August) (Fig. 2.1). In 1998/99, the two peaks were not clearly defined and instead one massive peak arose from December through to July. In 99/00, there was a massive Harmattan peak but a much reduced Mid-year peak. Compared with 96/97, catches in 97/98 and 98/99 were 1.4 and 4.0 fold greater, respectively. Over a period of five years abundance in dispersal varied greatly, offering an opportunity to deduce which factors influence trap catch. Preliminary analysis of the data suggested that neither windrun nor rainfall could be used directly to predict *P. truncatus* trap catch (Table 2.2), thus attention was focused on the statistically significant variables, humidity and temperature, to give an explanation of the occurrence and varying heights of the Harmattan and Mid-year peaks.

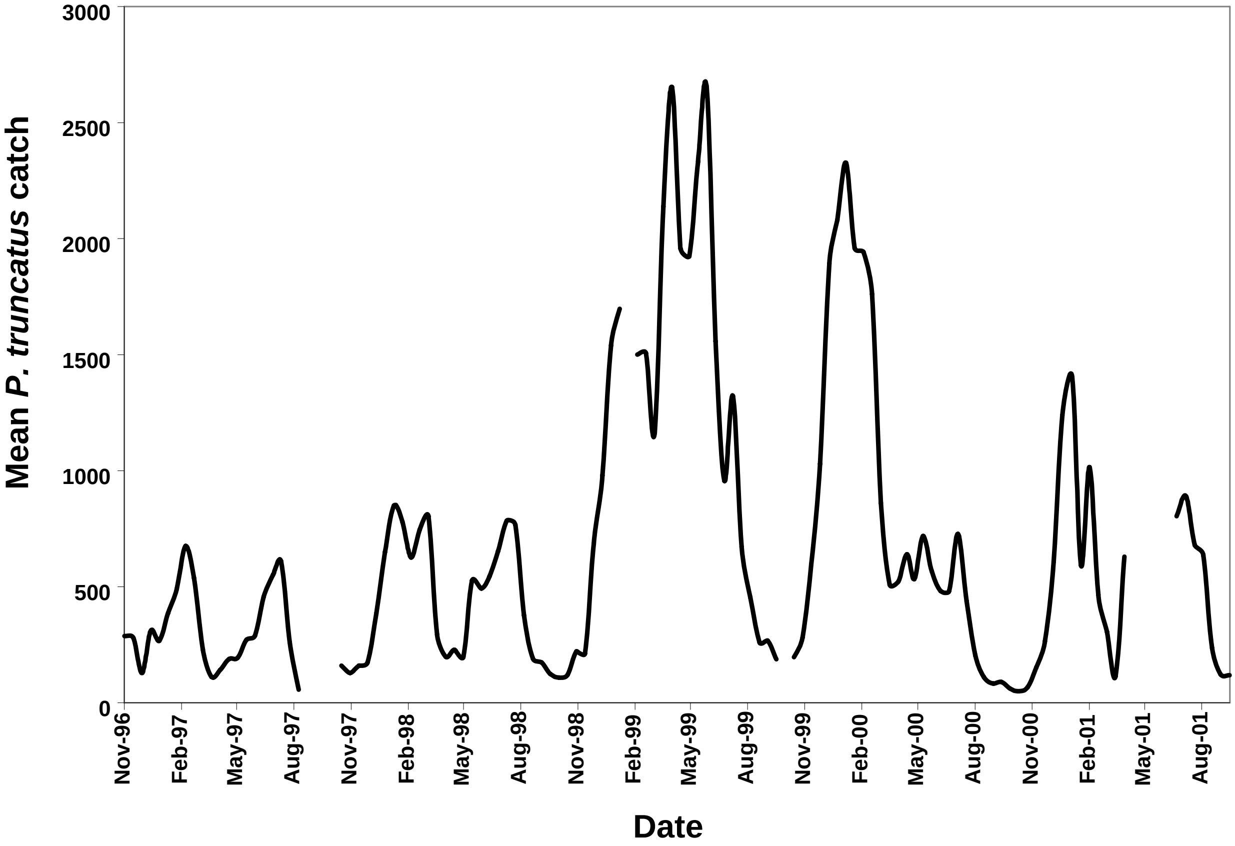


Figure 2.1: Annual variation in* P. truncatus *trap catch in five villages close to Hohoe (Ghana), 1996 - 2001

Table 2.2: Linear regression of climatic variables on* P. truncatus *trap catch at Hohoe (Ghana, Volta Region) for the period Nov. 1996 to Sept. 2001

Period	Variable	b*	F	P
Nov '96- Sept. 2001	Mean % r.h. (at mid-day)	-0.27	8.25	0.005
	Mean temperature	0.23	6.24	0.014
	Mean windrun	0.11	1.84	0.177
	Mean rainfall	0.13	1.42	0.236
Nov 1998 - Oct. 1999				
	Mean % r.h. (at mid-day)	-0.34	3.27	0.083
	Mean temperature	0.56	11.64	0.002

*b = standardised regression coefficient

Humidity

During the course of a typical year, humidities varied widely from 20% to 80% r.h. (as measured at mid-day). There are very clear annual patterns with below average humidities in the period of the Harmattan in December/February and above average in May/October (Fig. 2.2). Across the five years of study there was a sharp change in humidity conditions during the Harmattan of 1998/99 when humidities only dropped to 45%; unusually this was not associated with a decline in *P. truncatus* catch (Fig. 2.1). In other years, the falls had been from 38% to as low as 20%, suggesting that in 1998/99 the humidity did not seriously limit flight activity and that another factor(s) was the dominant influence over the numbers of catches in flight traps.

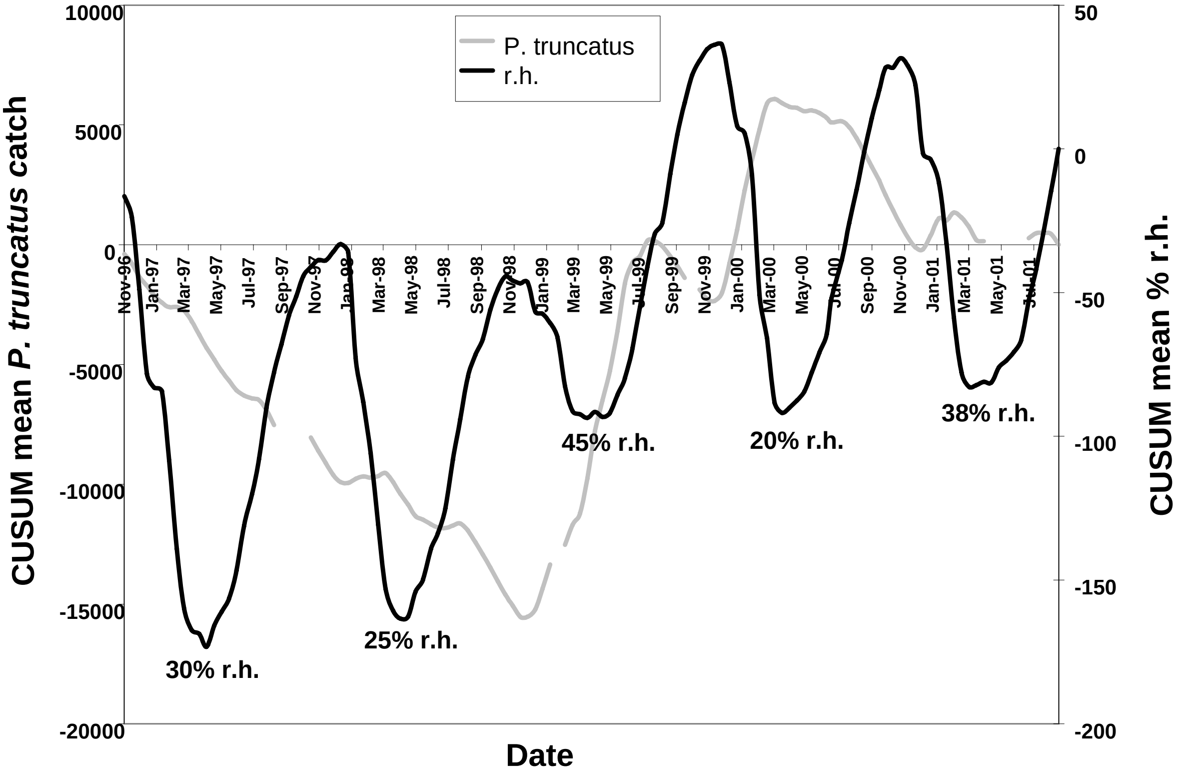


Figure 2: CUSUM for mean % relative humidity at Ho and* P. truncatus *catch at Hohoe (Ghana, Volta Region), 1996 - 2001

Temperature

During the course of a year, mean temperatures generally rise in the period from September through to March/April. Thereafter, they decline reaching their lowest values in the three months from July to September (Fig. 2.3). In 1996/97 and 1997/98, *P. truncatus* catches continued to rise as these mean temperatures fell and only went into decline at the time that the lowest temperatures, 25°- 26°C, were reached. A similar pattern was observed in 1999, except that the very high levels of *P. truncatus* catch had already been reduced somewhat in advance of the lowest mean temperature, but there was as before, a final substantial drop at the lowest daily mean temperatures of about 25°C (Fig. 2.3).

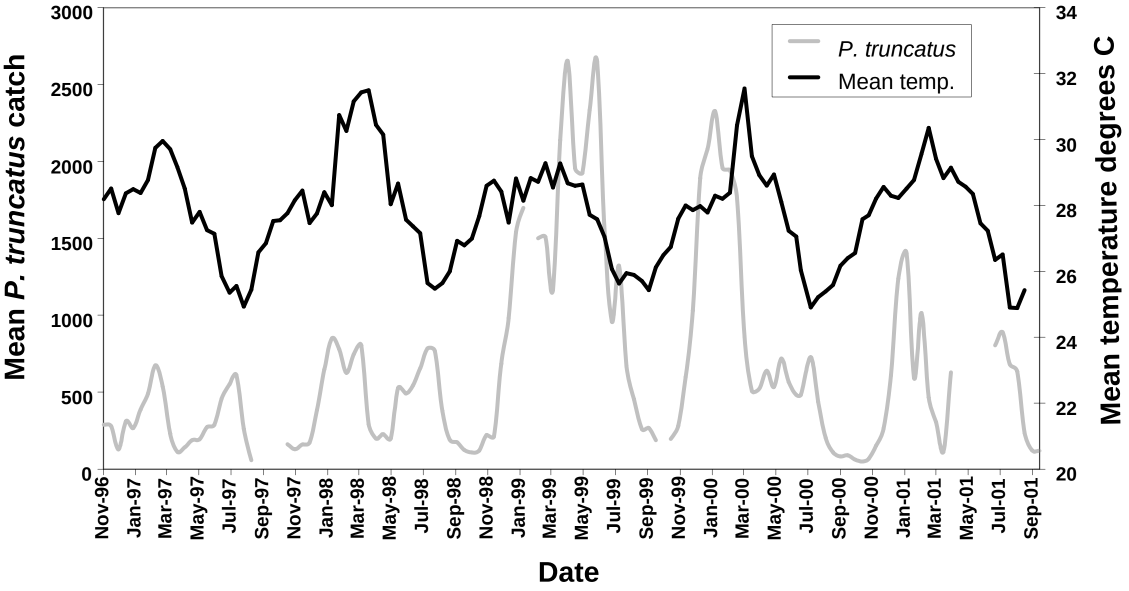


Figure 2.3: Mean temperatures at Ho and* P. truncatus *catch at Hohoe (Ghana, Volta Region), 1996-2000

The typical CUSUM plot for temperature during the course of a year appears to be a bell-shaped curve (Fig. 2.4a & b). There was no consistent pattern between rise in mean temperature and change in catch in 1996/97 (Fig. 2.4a) or in 1997-98. However, in 1998/99 the CUSUM slopes for temperature and *P. truncatus* catch are similar; two offset bell-shaped curves with catch lagging 4 to 12 weeks behind (Fig. 2.4b). This indicates a linear relationship between catch and mean temperature; there was a strong positive regression of temperature on catch compared with humidity (Table 2.2). The CUSUM plot for humidity (Fig. 2.2) suggested that during 1998/99 a factor other than humidity was controlling *P. truncatus* catch. From the evidence available, this factor appears to be temperature.

The mean temperatures used in this study were derived from the average of daily maxima and minima. A comparison with mean daily temperatures derived from hourly observations shows that means from maxima and minima always give values that are higher, by on average (± s.e.) 1.3ºC±0.22. The discrepancy was least in July, with a 0.78ºC difference and greatest in September with a 2.0ºC difference. The difference between the months is affected by the extent to which the diurnal temperature peak is spread across the day, the more evenly it is spread the lower the deviation between the two means. This has an important bearing on the performance of the rule-based model since this has to rely on temperature means derived from maxima and minima.

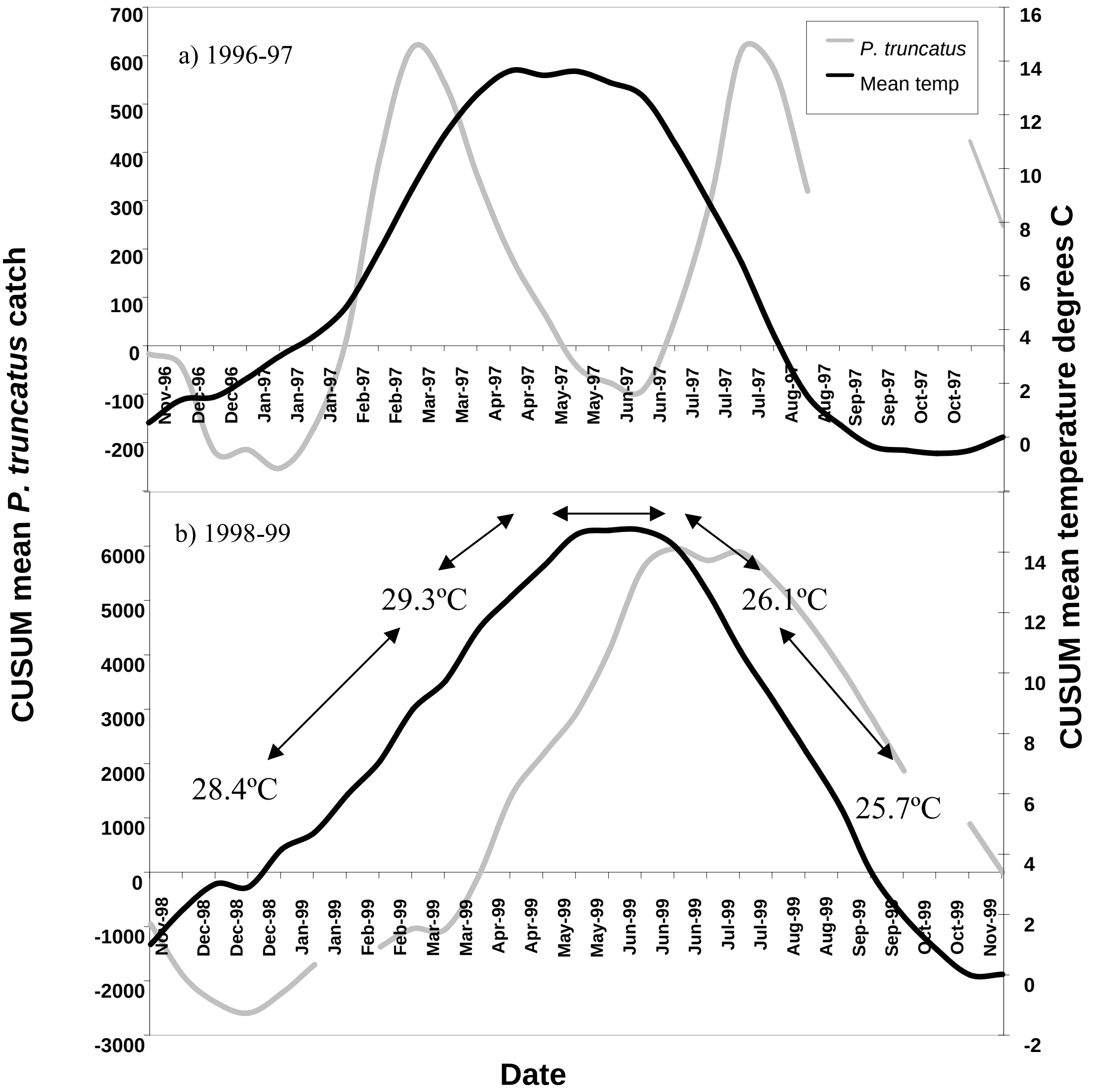


Figure 2.4: CUSUM mean temperature at Ho and* P. truncatus *catch at Hohoe (Ghana, Volta Region) in a) 1996-97 and b) 1998- 99. The temperatures indicated on 3b are means illustrating changes during the course of the year.

Explanation of observed pattern of P. truncatus *flight activity at Hohoe*
We suggest that relative humidity (linked to rainfall distribution) together with temperature are major determinants of the observed patterns and magnitude of *P. truncatus* trap catches in the Hohoe area of the Volta Region. The two typical peaks in *P. truncatus* flight activity each year could arise as follows. During the short rains, from September onwards, the moist conditions and rising temperatures lead to a rise in *P. truncatus* population that starts to manifest itself as increased beetle catch from November onwards. As rainfall diminishes, moisture conditions become limiting and a sharp fall in *P. truncatus* activity is recorded. This defines the first peak. The long rains start after the Harmattan and as heavy rain set in, mean temperatures begin to fall. It would be expected that humidities raised above those of the Harmattan would favour *P. truncatus* population growth and although temperatures fall they remain long enough in a favourable range, 29° to 27°C (Subramanyam & Hagstrum, 1991), for good *P. truncatus* population growth to occur. Together these factors promote a rapid rise in *P. truncatus* catch. As the lowest mean

temperatures are reached, there is a sharp fall in *P. truncatus* trap catch, defining the second peak. In essence, the Harmattan peak is generated by a rise in temperature and terminated by lack of moisture. The Mid-year peak is generated by wet conditions with falling temperatures and starts to decline at about the time when mean temperatures fall to 26°C (more like 24-25°C if the error in calculating daily means is taken into account).

Differences between years in climatic conditions could account for dramatic differences in the magnitude of *P. truncatus* trap catches. In Hohoe, in 1996/97 and 1997/98, low moisture conditions terminated the Harmattan peak by March. The pattern in 1998/99 was quite different. Rainfall and humidities remained high and a single massive peak developed. The effect of favourable moisture conditions was that the CUSUM curve of *P. truncatus* catch was almost identical in shape to that for mean temperatures (Fig. 2.4b). This suggests that if humidities remain above a critical value, in this case the lowest two week period averaged about 45% with the majority of days in this period above 50%, then the major determinant of *P. truncatus* catch is probably mean temperature.

In 1998/99, the typical two peaks probably merged into a single large peak as the habitat did not dry out fully during the Harmattan. Following the Harmattan, there was no need for the rains to rehydrate the food sources before the population could continue to grow. As the population was already active and at a high level, it continued to increase further until exceptionally heavy rains in May/June followed by low temperatures in August brought sharp reductions in *P .truncatus* catch.

It is clear that temperature and humidity have a profound effect on annual and seasonal variations in the abundance of *P. truncatus* dispersing by flight and that these factors could be used in a rule-based model to predict catches.

Rule-based climate model to predict P. truncatus *trap catch*

Six rules for predicting trap catch (Table 2.3) were elaborated from the foregoing observations on the responses of *P. truncatus* flight behaviour to temperature and humidity, allowing lags for long-term effects, as well from prior knowledge and assumptions about the biology of the pest. Climate data were entered into a spreadsheet as two-weekly means of daily mean temperature (T) and % r.h. at mid-day (R) and the actual number of days with less than 40% r.h. at mid-day (H).
An important element of the model is an estimation of the favourability of climatic conditions, F, for *P. truncatus* development. This was derived by inverting the development period curves for various temperatures and humidities, prepared by Subramanyam & Hagstrum (1991) from the data of several authors, so that long development periods equated with low F values (Fig. 2.5). The value for F at 25°C and 40-50% r.h. was set at 1, since at conditions below this the beetle population is in decline. The values of F for more extreme climatic conditions were attenuated to take into account the difference between means based on laboratory data from a narrow range of condition and field data where means, although appearing favourable, may represent a range wide enough to include values which are unfavourable.

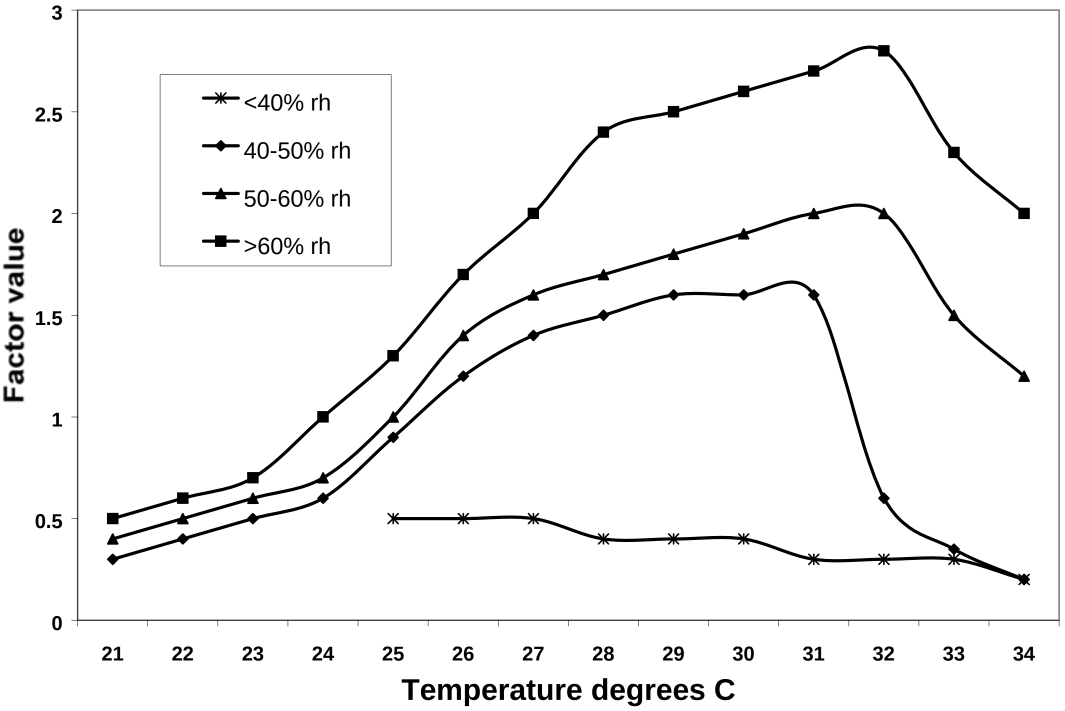


Figure 2.5: Factor values, associated with temperature and humidity combinations, used in the climate model for determining the potential* P. truncatus *trap catch

The first five rules of the model were used to determine the numbers of beetles that would be available to fly, referred to as the potential dispersing population (D). The first step in estimating the current value of D is to calculate 'r_t', the change in conditions between two consecutive two-week period determined by dividing the current value of F by that in the previous two weeks (Rule 2 in Table 2.3). The product of D, in the previous two week period, and 'r_t' ,either four or eight weeks previously depending on whether prevailing temperatures are above or below 26°C, determines the current value of D (Rule 4). These rules constitute a simple discrete model of *P. truncatus* population dynamics broadly equivalent to the population model of Meikle *et al.* (1998) but lacking any density effects. On the very first occasion that the potential dispersing population is estimated (Rule 4) there is no previous value to use in the calculation. A value was therefore determined by trial and error to obtain a good fit of the model to the data. This value affects the scaling of the y-axis of all subsequent predictions and may thus be regarded as a ‘scaling factor’ for the environment in question. During the preparation of the model it became apparent that *P. truncatus* developing at lower than 26°C had a reduced propensity for taking flight. The same effect has been observed in the closely related beetle *Rhyzopertha dominica* (Perez-Mendoza *et al.*, 1999). Rule 6 (Table 2.3) estimates the effects of low temperature during development on the proportion of D taking flight (D_t'). When temperatures are less than 26°C at 6, 8 or 10 weeks earlier, the potential dispersing population is reduced by 85%, so that

$$D_t' = \begin{cases} 0.15 D_t & \text{if } \min(T_{t-3}, T_{t-4}, T_{t-5}) < 26 \ \ ^\circ\text{C} \\ D_t & \text{otherwise} \end{cases}$$

Table 2.3: Variables and parameters used for the rule-based model

Rule 1	$F = f(T, R)$	Estimation of favourability of mean temperature (T) and mean % relative humidity (R) for *P. truncatus* development and survival. Discrete values of r are selected from a table.
Rule 2	$r_t = \begin{cases} \frac{F_t}{F_{t-1}} & \text{if} \quad F_t < 2.0 \\ \frac{F_t}{F_{t-1}} + 0.2F_t - 0.39 & \text{if} \quad 2.0 \le F_t < 2.3 \\ \frac{F_t}{F_{t-1}} + 0.1 & \text{if} \quad F_t \ge 2.3 \end{cases}$	r_t is a change in the favourability of conditions between two-week periods and determines how much the previous estimate of the potential dispersing population should be increased or reduced. If consecutive F values are the same then r_t will return a value of 1, leading to no change in numbers dispersing. Under favourable conditions, F≥2, some increase is expected so r_t is supplemented in increments starting at 0.01 and increasing by 0.02 for F = 2.1-2.3 but by a flat rate of 0.1 when F > 2.3.
Rule 3	$r_t := 1 \text{ if } \sum_{t=-3}^{-1} H_t > 20 \text{ and } r_t > 1$	Persistent low humidity conditions, for periods of six weeks or more, are especially damaging to the growth of the dispersing population. When the number of days at <40% r.h. is more than 20 any r_t values >1 are returned to 1.
Rule 4	$D_t = \begin{cases} r_{t-4} D_{t-1} & \text{if} \quad T_t < 26 \ ^\circ\text{C} \\ r_{t-2} D_{t-1} & \text{if} \quad T_t \ge 26 \ ^\circ\text{C} \end{cases}$	The current potential dispersing population, D, is estimated by multiplying the value of D in the previous two-week period by r_t from Rule 4. To provide a lag between changed environmental conditions and the numbers of beetles that develop, the r_t used is from four weeks previously if the T≥26°C in the current two-week period or from eight weeks previously if T<26°C.
Rule 5	$D_t := \begin{cases} 2D_t & \text{if} \quad F_t - F_{t-1} < -0.7 \\ D_t / 2 & \text{if} \quad F_t - F_{t-1} > 1.1 \end{cases}$	Sudden changes in the favourability of climatic conditions for *P. truncatus* development appear to be buffered by the beetle's sheltered micro-habitat. To take account of this, if between consecutive two-week periods F rises by more than 1.1 then the potential dispersing population is halved or if it falls by more than 0.7 then the potential dispersing population is doubled. These critical values were determined by trial and error and help to eliminate small abnormal peaks and troughs.
Rule 6	$D_t' = \begin{cases} 0.15D_t & \text{if } \min(T_{t-3}, T_{t-4}, T_{t-5}) < 26 \ ^\circ\text{C} \\ D_t & \text{otherwise} \end{cases}$	Low temperature conditions during the development of the beetles reduces the number taking flight (D'). If temperatures are less than 26°C at 6, 8 or 10 weeks earlier then the number of flying beetles is only 15% of its potential.

Comparison of trap catch predicted by the model and actual catch

The actual trap catch observed and that predicted by the rule-based model match very closely (Fig. 2.6). The greatest deviation between modelled and actual catch occurs during December to March in years when there are sudden rises and falls in humidity such as 1996/97, 1997/98 and 2000/01. In these years there is consistent under estimation (Table 2.4). It would appear that the rules governing the outcome in this situation have still to be accurately defined. When the Harmattan is not severe, so that there is a large Harmattan peak in flight activity, the deviation is small, only +5% in 1998-99 and -1% in 1999-00 (Table 2.4). There is a tendency for the Mid-year peak to be over-estimated, on average by about 13%. It would appear that large year to year variations in the numbers of *P. truncatus* distributing by flight are explained by climatic variations and that in the case of Hohoe humidity and temperature are the most important factors.

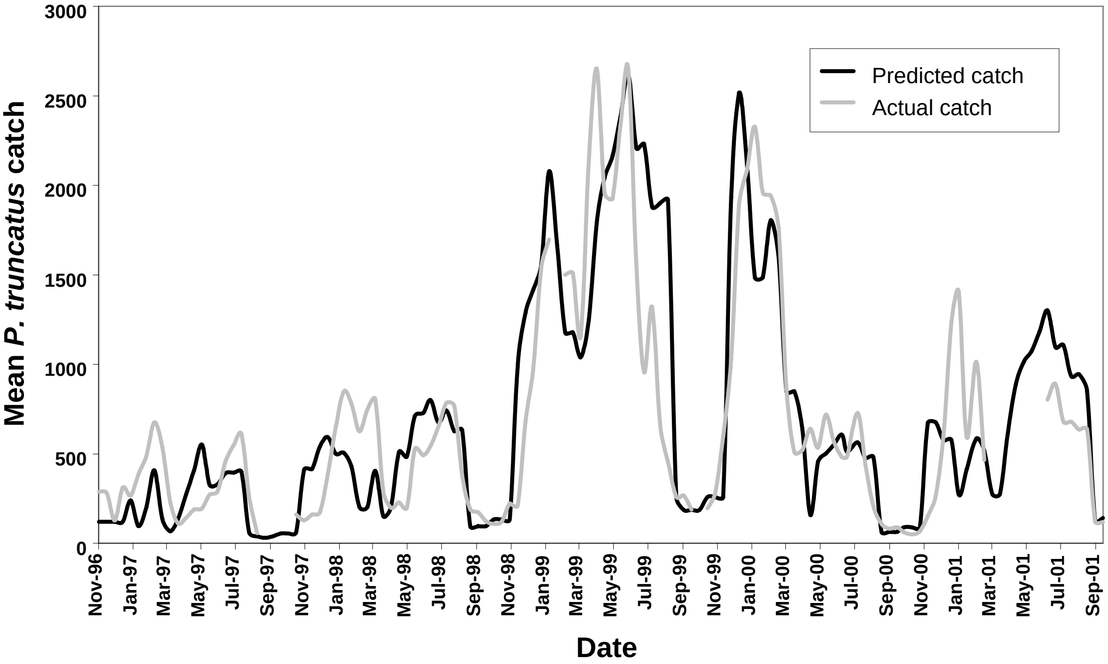


Figure 2.6: Actual mean* P. truncatus *trap catch at Hohoe (Ghana, Volta Region) compared to the catch predicted by the rule-based climate model, 1996 - 2001 (n = 20)

Table 2.4: Percentage deviation of the area under the curve of P. truncatus trap catch predicted by the rule-based climate model from the actual trap catch in Hohoe (Ghana, Volta Region) for the two annual peaks in trap catch

Year/annual peak	Harmattan	Mid-year
1996-97	-56%	+15%
1997-98	-21%	+21%
1998-99	+5%	+18%
1999-00	-1%	-1%
2000-01	-25%	-

The predicted potential dispersing populations (D) is considerably greater than the predicted numbers taking flight (D') in July and August when temperatures are lower (Fig. 7). When temperatures subsequently rise in September/October this large breeding stock apparently gives rise to the very rapid increase in dispersal observed in November. The height of the Harmattan peak is thus a function of the size of the resident population of beetles during the cooler period and how favourable conditions are during the Harmattan, especially how limiting moisture conditions become. There is further very rapid increase during the hotter period of the year (March /May) in response to the rise in ambient humidity. Presumably conditions are sufficiently warm that this rise is achieved by rapid population increase from a much smaller initial population than that responsible for the Harmattan peak.

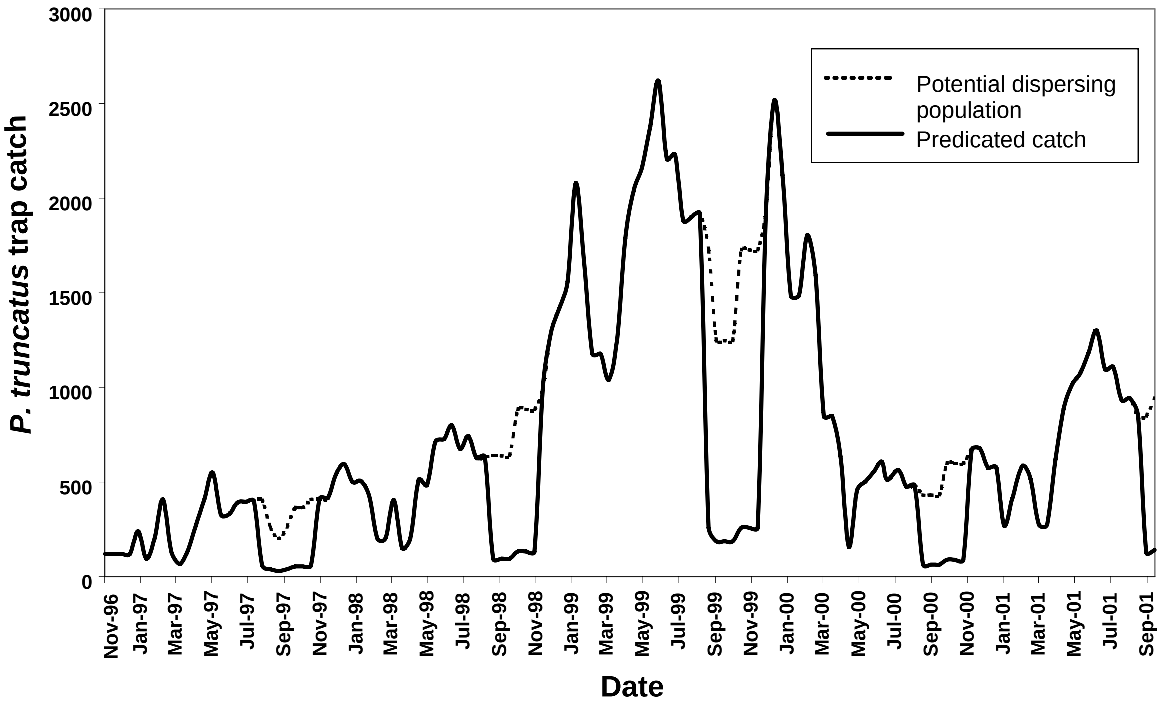


Figure 2.7: The potential and predicted numbers of flying **P. truncatus** *at Hohoe Ghana, Volta Region)*

Observations at Nkwanta (Ghana) and Morogoro (Tanzania)

Nkwanta, like Hohoe, has a Harmattan and a Mid-year peak in *P. truncatus* flight activity (Fig. 2.8). To improve the fit of the model for Nkwanta data, two modifications to the rules were adopted. For Rule 3, which reduces r_t values due to low humidity conditions in the preceding six week period, r_t values greater than one are halved rather than reduced to one as in the model for Hohoe.

$$r_t = r_t/2, \sum_{t=-1}^{t=-3} H > 20 \text{ and } r_t > 1$$

This lessens the effect of low humidity on the trap catch since ΔF values at the end of periods of low humidity in Nkwanta tend to be very high, e.g. in excess of 5. These are thus reduced to values over 2.5 instead of to 1. It is not certain whether this is required because of a greater tolerance of beetles to dry conditions in Nkwanta or because the host substrate is more able to retain moisture. Rule 6, the critical temperature to determine the number of beetles taking flight, was increased to 28°C. The predicted and actual trap catches in Nkwanta are closely matched (Fig. 2.8).

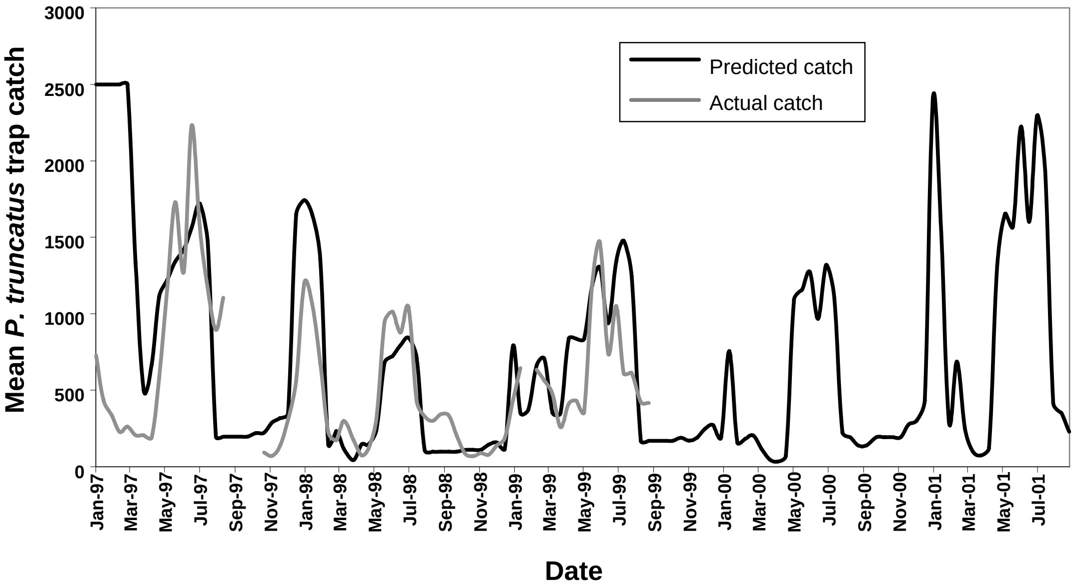


Figure 2.8: Actual mean P. truncatus trap catch in Nkwanta (Ghana, Volta Region) compared to the catch predicted by the rule-based climate model, 1997 - 1999 (n = 20)

In Morogoro, *P. truncatus* catch rose to a single large peak in the period November 1997 to September 1998. In the following twelve months, *P. truncatus* numbers remained low during the entire period of trapping (Fig. 2.9). Only one modification was required to improve the fit of the model for Morogoro data; the critical temperature to reduce the number of beetles taking flight (Rule 6) was increased to 28.5°C. The predicted and actual trap catches in Morogoro are very closely matched (Fig. 2.9) with a large annual peak in 1997/98 and only low peaks in the other years studied.

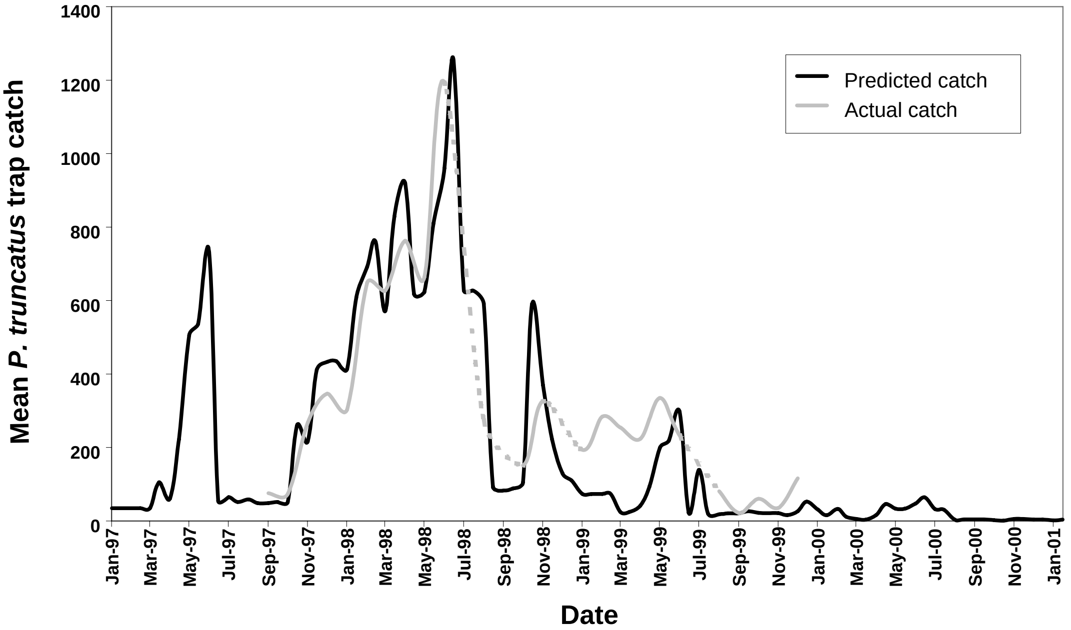


Figure 2.9: Actual mean* P. truncatus *trap catch in Morogoro (Tanzania) compared to the catch predicted by the rule-based model (dotted line shows interpolated values for actual catch) (n = 9)

Discussion

Those times when *P. truncatus* abundance was observed to be exceptionally high, presenting a greater risk to farmers, were related to the coincidence of favourable temperatures and humidities. At Hohoe in Ghana, this happened when the Harmattan was less severe so that moisture conditions remained high enough for the beetle to be able to benefit from the higher temperatures at that time of year. At Morogoro in Tanzania, there was an exceptionally high peak in numbers in 1998. Although not presented here, a check of the climate data for 1998 shows that the normal rise in temperatures in November/December unusually coincided with a rise in humidity; in other years, humidities only rose once temperatures had already started to decline. Farmers had complained to the District authorities during 1998 that they were suffering unusually heavy attack by *P. truncatus* in their maize stores (William Riwa, personal communication). Their complaints corroborate both the abnormally high peak in dispersing beetles and the connection between this and the increased likelihood of stores becoming infested. In Hohoe, the years of high pest flight activity coincided with poor harvests where storage periods were short, consequently farmers were largely unaffected (S. Addo, unpublished data).

In Ghana, the towns of Hohoe and Nkwanta typically had distinct Harmattan and Mid-year peaks in *P. truncatus* flight activity. Similar peaks in catch have been reported previously from Mono province in Benin (Borgemeister *et al.* 1997a) but not from the coastal zone where there is a single annual rise and fall, presumably because humidities there do not drop below 50% during the period of the Harmattan. In the case of the

Benin coastal zone, *P. truncatus* trap catch was related only to mean temperature (Borgemeister *et al.,* 1997a; Scholz *et al.,* 1998); a finding consistent with the current study in years when humidity is not limiting. The observed response of the beetle to low humidity conditions confirms previous reports. On wood, which is believed to be the common host in the natural environment, it has been concluded that *P. truncatus* cannot breed unless the moisture content is above 10% (Nang'ayo *et al.,* 1993). For a variety of tree species, held at 55% r.h., the equilibrium moisture contents ranged from 9.5% to 10.4% (Nang'ayo, 1996). Thus, humidities much below 50% are unlikely to be able to support *P. truncatus* development on the wood species that have been tested. However, the moisture content/r.h. equilibrium seems to be a little different for maize. At 40% r.h., the moisture content of grain of a local Tanzanian variety is still 10.5% and the intrinsic rate of increase of *P. truncatus* is 0.46/week compared with 0.73/week at 70% r.h., equivalent to 14.2% grain moisture content (Hodges & Meik 1984). Thus *P. truncatus* can probably develop on maize, and possibly some other hosts, under rather drier conditions than on the wood species that have been studied.

An interesting feature of the model is the apparently strong effect of low temperatures during development on the beetle's subsequent tendency to distribute by flight (Rule 6). The critical temperatures used in Rule 6 varied between habitats, Hohoe 26°C, Nkwanta 28°C and Morogoro 28.5°C. Nkwanta and Morogoro are savannah woodland/short grassland habitats which would be expected to have more steeply rising and falling daytime temperatures than Hohoe which is in the tropical rain forest-savannah transition zone. They would thus show greater positive deviation in the calculation of the daily mean from the daily maximum and minimum temperature and this probably accounts for the higher critical values. Even Hohoe has a positive deviation ranging from 0.7°C to 2.0°C. This suggests that the true critical temperature is between 24.0° and 25.3°C. It is not certain why low temperatures can have such long-term influences. Low temperatures would be expected to result in a slowing of development and hence slower recruitment to the habitat but the model suggests continued development with a lower proportion of those beetles that would potentially take flight actually doing so. This happens despite the subsequent exposure of these beetles to more favourable ambient temperatures in September/October. It is possible that low temperatures affect food supply so that fewer beetles are in a suitable nutritional state to undertake energy consuming activities like flight. In the case of the related bostrichid *Rhyzopertha dominica*, beetles collected in the USA in summer had a higher lipid content and greater tendency to fly than beetles collected in spring or autumn (Perez-Mendoza *et al.,* 1999). In the case of *P. truncatus*, it would be easy to devise experiments to test whether the temperature at which beetles develop has a direct effect on propensity for flight but more difficult to include the influences of environmental conditions on the nutritional status of the pest.

In the model of Nansen *et al.* (2001), day length is an important variable for predicting *P. truncatus* flight activity. There is a suggestion that photoperiod may affect the flight activity of *R. dominica* (Aslam *et al.*, 1994). However, the evidence is equivocal as the two extremes tested, 6 h and 18 h light, differed significantly in flight activity for a lab strain but not for a field strain of the beetle. Nansen's model was able to predict trap catch data from sites 6°N to 9°N although it missed a very distinctive Mid-year peak in

1998 and consistently under predicted catch in 1999. In addition, it did not work at 10°N where conditions tend to be hotter and drier. It was suggested that it might not be driven by the same environmental conditions in all agro-ecological zones; the rule-based model also showed less accurate predictions when presented with more severe conditions. A model based on day length would also not work close to or on the equator, as Dingle (1972) has noted, those insects "...whose range spans the equator, where photoperiods are essentially constant, must rely directly on ultimate environmental factors". Day length was not included in the rule-based model and it does not appear to be deficient because of this. Day length may be a proxy for the long-term effect of temperature on propensity for flight and/or other factors such as the favourability of plant hosts.

It is clear that for those habitats studied, the rule-based model offers a convenient and easily affordable means by which extension services could predict years of greater *P. truncatus* flight activity. Once predictions of beetle numbers have been made and they exceed a threshold, based on the known probabilities of store infestation at different frequencies of dispersing beetles (Birkinshaw *et al.* in press), farmers can be warned to take action. In this system, the pest management threshold indicates the likelihood that a store had been attacked by a single beetle, it would thus be several months before serious damage would be expected. This gives a reasonable lead-time for pest management action such as marketing early or investment in methods to kill the pest such as pesticide treatment. Predictions of flight activity were consistently under estimates when climate was more severe. However, this inaccuracy would seem unlikely to affect pest management decision making since under these conditions catches were in any case low and so would be very unlikely to trigger any specific advice to farmers. Conversely, when conditions were favourable for the pest the predictions were more accurate, although they tended to be over estimates. Thus advise to farmers would expected to be 'safe', i.e. they are more likely to be advised to take action when it is not needed than advised not to take action when it is needed.

There are other possible uses for the model. In advance of the arrival of the pest in a particular country or province, the model could help to predict the likelihood that it will cause significant problems. Any such predictions would have to be treated with caution however, since although the model works well under a range of conditions in which *P. truncatus* is likely to be a significant pest, it has yet to be tested under more extreme conditions. For example, in northern Benin (10° N) where Nansen *et al.* (2001) found their model would not work. Another difficulty comes in setting the scale for the catches in situations where there is no previous data on *P. truncatus* trap catch. The scale confounds aspects of habitat suitability such as hosts, predators and parasites and, in the absence of any trap catch data, can only be set to what would be expected in other similar environments for which there is data. Earlier predictions on the potential of *P. truncatus*, based on laboratory observations on development on maize under a range of temperatures and humidities, suggested that it would develop best in warm moist conditions (Haubruge & Gaspar, 1990). In contrast, field observations across five regions of Mexico, suggested that there is higher abundance in cooler, more temperate areas, a relationship evident even from the raw data (Tigar *et al.,* 1994). This discrepancy warns that habitat suitability is more complex than just measures of temperature and humidity.

Nevertheless, the current study shows that in habitats that have a seasonal climate with distinct dry periods, *P. truncatus* develop best under warm moist conditions. Permanently warm moist conditions may be unfavourable as potential hosts may not dry out sufficiently or seasonal die back on trees, which Nang'ayo *et al.* l993 suggest provides suitable niches for the pest, may not occur.

Another use for the model might be to obtain some measure of the impact of the predator of *P. truncatus*, *Teretrius nigrescens* (Lewis). This histerid beetle has been introduced from Central America into several African countries. Determining the impact of this predator has been problematic, not least since to date its effects on *P. truncatus* have not been separable from those of climate. If suitable data sets are available from before the establishment of the predator in a particular locality then, after predator introduction, the magnitude of any fall in actual trap catches below predicted catches would suggest a measure of impact on *P. truncatus*.

Acknowledgements

In Ghana, Israel Tetty, Hilarious Penne, Emmanuel Afori and Victor Afetorgbor collected and counted the pheromone trap catches and in Tanzania trapping data was kindly made available by William Riwa of the Plant Protection Division and the GTZ Post Harvest Project. A special thanks is due to Bruno Tran who gave invaluable help and advice in setting up the model on a spreadsheet and Richard Jones who advised on CUSUM analysis. Help and advice on the manuscript was given generously by John Holt, Niels Holst, Christian Nansen and Julia Compton. Mr P.K. Obeng of the Ho Meteorological Station kindly provided us with climate data as did the Meteorological Station at Kilosa in Tanzania.

3. How can farmers be warned to take action when a 'bad year' for *Prostephanus truncatus* is expected?

The numbers of beetles flying around looking for food is strongly affected by climate (Borgemeister *et al.* 1997a; Nansen *et al.,* 2002). A rule-based model of the relationship between climate and the number of beetles flying has been developed so that numbers of beetles flying can be predicted (Hodges *et al*., in preparation). To make predictions using the model requires access to a computer with a spreadsheet program and suitable climate data from a Meteorological station.

To predict whether farmers might suffer significant attack by *P. truncatus* it is necessary to check the cumulative numbers of flying beetles over specific storage periods. In Ghana around Hohoe in the Volta Region, there are two maize harvests, the major and the minor, with associated storage periods from September to January and December to July respectively. The predicted cumulative numbers of flying beetles during the storage of the major and minor harvests over three years were very similar to the actual numbers flying as determined by pheromone traps (Fig. 3.1).

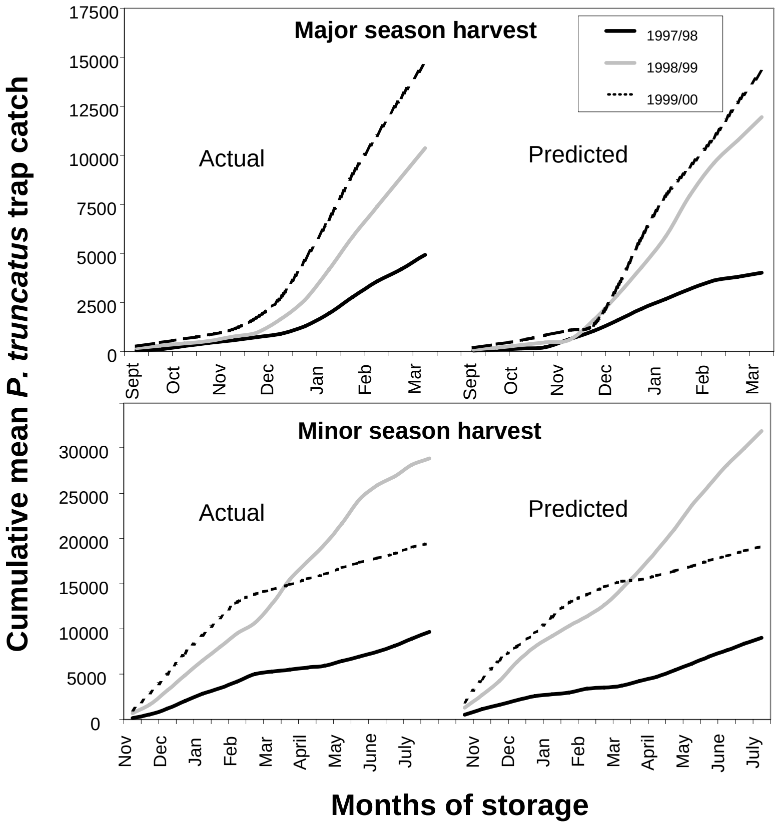


Figure 3.1: Mean cumulative catch of* P. truncatus *from twenty pheromone traps the Volta Region (Hohoe) of Ghana during the major and minor season maize harvests of 1997 to 2000 and the cumulative catch during the same periods predicted by a rule based model (Hodges in preparation)

Once predictions of beetle numbers have been made and they exceed a predetermined threshold, based on the known probabilities of store infestation, then farmers can be warned to take action. Either to market their maize and dried cassava early to avoid losses or invest in suitable pest management action. As store infestation is defined as the presence of a single beetle, it would be several months before serious damage would be expected, this gives a reasonable lead-time for pest management action. If we take a cumulative dispersal of 3,800 as the pest management action threshold, then in the case of the major season harvest in Hohoe, even in the worst year 1999/00 the cumulative beetle dispersal did not reach this level until December (Fig. 3.1). This was within a month of the end of the storage period, so it is unlikely that there would be serious losses unless farmers decided to store for longer than usual. However, during the minor season in both 1998/99 and 1999/00 the threshold was reached within the first two months of storage with the prospect of several months storage thereafter. The chances of serious damage in these two years was therefore high. In contrast in the 1997/98 minor season, the threshold was not reached until about May, close to the end of storage so little serious damage would be expected.

To implement the risk warning system in a particular locality will require a source of climate data, this would normally be available from the local meteorological station and access to a computer with a spreadsheet program (Excel). Initially, some trapping data for the area in question are needed to compare with model predictions to ensure that the model works well. For the system to trigger a warning, a pest management threshold has to be set. This needs to take into account local conditions since 1) some stores types offer better protection from beetle attack than others and 2) the length of time that farmers leave their crop in the field after maturity affects the extent of pre-harvest infestation and hence the proportion of stores infested at the time of loading.

Risk warning system in the context of integrated pest management for P. truncatus

The risk warning system will be of particular value in situations where farmers have a choice of pest management options based on the prediction of risk. For the type of smallholder farmer at risk from *P. truncatus* attack, the following options could include

- sell the maize stock within three months so that specific pest management measures are not needed.
- treat the whole stock with pesticide either maize cobs sprayed with, or dipped in, an emulsion or dusted with dilute dust layer by layer Shelled grain would be treated with dilute dust.
- treat only a portion of the stock with pesticide. If some of the grain is to be stored for less than three months then this may not require any pesticide treatment. The grain to be treated should be placed at the base of the store where insect infestation pressure is greater (Hodges *et al*., 1999), while the untreated grain is at the top and so may be easily removed for consumption or sale.
- treating the commodity with pesticides of plant origin. Farmers use a range of botanical pesticides and these vary in efficacy according to their mode of application,

time of year of collection and area of collection. They may be recommended depending on the risk of attack and the circumstances of the farmer, e.g. availability of botanicals, ability to afford more effective alternatives etc.

- inert dusts to help limit pest attack. A thick layer of paddy husk ash covering the stock is effective in preventing attack. Commercial preparations of diatomaceous earths are effective in dry areas against several pest species and are currently being tested for their efficacy against *P. truncatus*.
- adopting sealed storage systems, such as mud silos or the mudding of traditionally unmudded structures. Such sealed storage can provide a very effective barrier to pest attack and can be adopted in situations where the stock is sufficiently dry that good ventilation is not required. This has been achieved with several communities in northern Ghana who do not traditionally use mudded structures (A. Fuseini, pers. comm.). Use of mudded structures may be combined with the use of synthetic pesticides or botanicals according to risk.

The circumstances of individual farmers and the aspirations they may have for their grain stock in any particular season will vary, as does the risk of infestation by *P. truncatus*. One means of choosing which of a range of possible pest management options to use would be to use a decision tree that takes into account the options available and the prevailing circumstances. An example of such a tree for the pest management of *P. truncatus* has been published by Farrell *et al.* (1996) and an example of one in which the risk warning system has been included is shown in Figure 3.2. Both in East and West Africa, farmers tend to leave their maize in stores for extended periods (sometimes exceeding eight months) because maize prices on rural and urban markets are lowest immediately after the harvest and highest into the 'lean' season when there is little maize available (Compton *et al.*, 1998). Field work in Tanzania, Kenya and central Benin, all in relatively hot dry areas, suggests that if maize is to be stored for less than 5 months then use of pesticide was probably not justified (Henckes, 1992; Farrell, 1996; Meikle *et al.*, in press), whereas in southern Benin and southern Ghana (Meikle *et al.*, in press; S. Addo pers. comm.) this period is likely to be three months. This conclusion was based on the break-even point between the value of losses and the costs of treating grain with a dilute dust insecticide. As the value of maize and cost of pesticide treatment changes from year to year then the break-even for pesticide treatment needs to be recalculated from time to time. This would be a job for the extension services that advise subsistence farmers.

Looking at the decision tree (Fig. 3.2) it can be seen that if the storage period was to be greater than three months then knowledge of the previous history of *P. truncatus* infestation in a store is important. If there was *P. truncatus* in the store during the previous year then the risk of infestation again in the current year is higher and the admixture of a dilute dust insecticide is recommended. However, if no *P. truncatus* were observed last year then regular inspection is required. If the pest is found subsequently, then grain shelling and insecticide treatment are required. The tree could be developed much further to include more of the options listed above to enable farmers to select options that are appropriate to their circumstances and minimise losses of grain quality and quantity. It is planned that this decision approach to pest management will be implemented as part of project activities of the UK DFID's Crop Post Harvest Programme in West Africa.

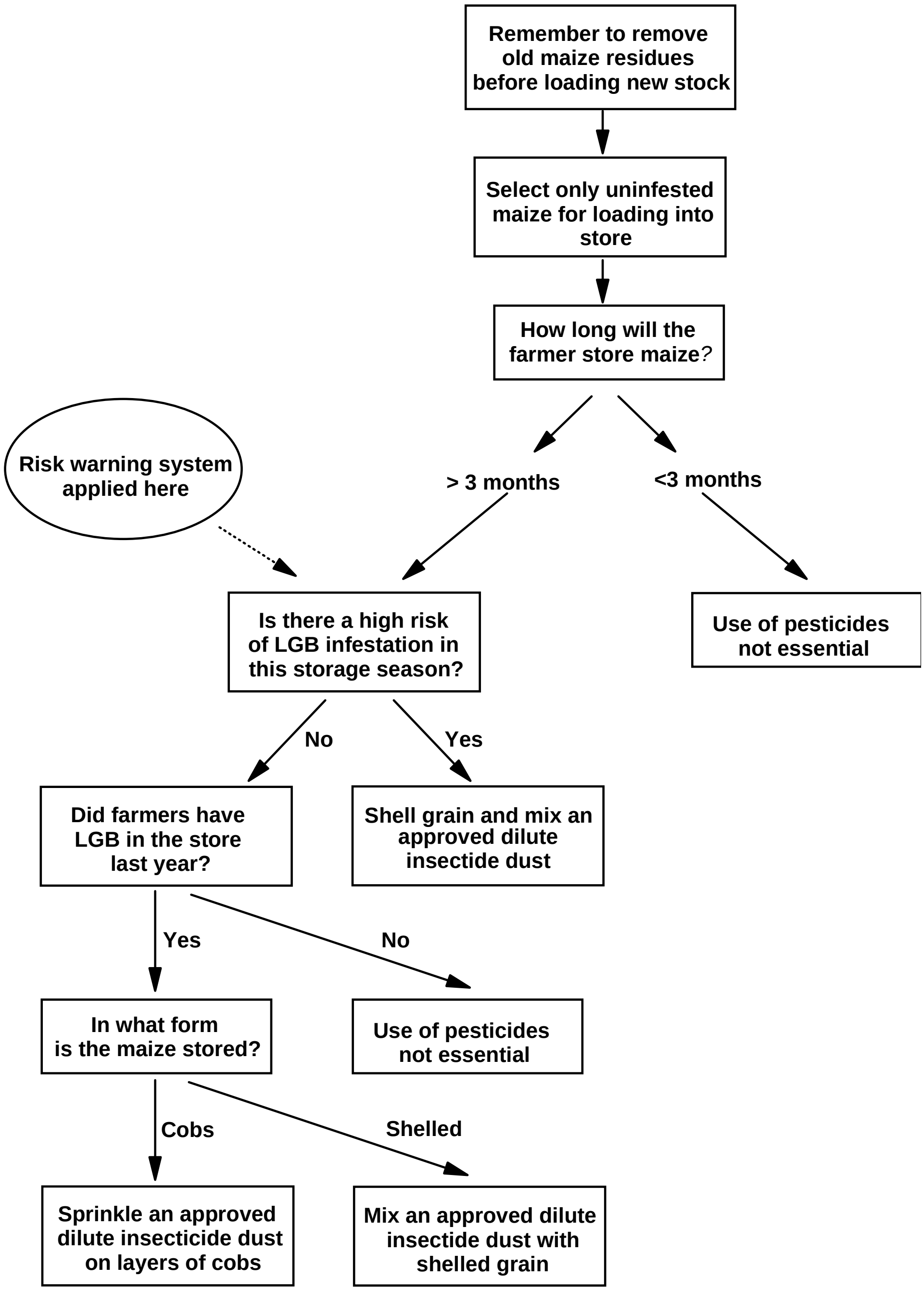


***Figure 3.2: An example of a decision tree to help extension services advise farmers on the protection of their maize against* Prostephanus truncatus**

Research Activities associated with output 2

Output 2: methods of reducing pesticide usage validated and extended by farmer participatory research in Ghana and Zimbabwe
OVIs - Extension services in at least one region of Ghana and one region of Zimbabwe actively promoting use of reduced pesticide treatment by 2002

4. Household survey to demonstrate adoption of stock protection methods

Addo S., Birkinshaw, L.A. and Hodges R.J.

Introduction

It is now just over twenty years since the beetle *Prostephanus truncatus* (Coleoptera: Bostrichidae), commonly referred to as the Larger Grain Borer or LGB, was first detected in maize and cassava storage systems in Africa (Dunstan and Magazini, 1981). The initial devastation caused by this exotic intruder to the grain stocks of small-scale farming communities elicited considerable efforts to develop ways of limiting its impact. Farming communities, in-country agricultural support systems, and donor-funded research and development, have played important roles. However, the external support (from outside Africa) against the pest has dwindled in recent years as some control options have been identified and promoted (Golob, 1991; Giles *et al.*, 1995; Boxall and Compton, 1996; Borgemeister *et al.*, 1997b).

The Volta Region of Ghana has been a focus of a relatively large effort to combat LGB damage. The beetle initially entered Ghana from Togo in 1989 and the Volta Region, situated just across the Togolese border, may still be the worst LGB-affected area in Ghana (Dick *et al.*, 1989). From 1993 to 1996 the UK government funded a technical co-operation (TC) project with the Ghanaian Ministry of Food and Agriculture with the aim to, '…develop appropriate and acceptable techniques to minimise losses in on-farm maize storage… in particular those due to the LGB…' (Boxall and Compton 1996; Compton, 1997).

Research into the pest in Ghana has continued and its has become clear that attack shows very considerable year to year variation in severity (Hodges and Birkinshaw, 1999) unlike other storage pests such as weevils (*Sitophilus* spp) which appear to present a relatively constant threat. Such variation has the potential to interfere with the uptake of storage improvements against LGB since those farmers not adopting them will often be seen to be as successful as those who do. Many existing storage practices are relatively incompatible with the control of this pest. In the Volta Region, maize is often stored on the cob stacked on a wooden platform, known as an Ewe barn (Fig. 4a) or in an inverted cone (Fig. 4b). Cobs are then withdrawn as needed for food, sale, seed and other functions. The most common initial response to reduce the LGB damage in the Volta Region was to remove maize from the store early and sell, thereby reducing food security and income, since maize prices increase as the storage season progresses (Magrath *et al.* 1996). The LGB TC project worked with farmers to develop eight control options as follows:

- Storage hygiene
- Changing or smoking storage platform woods or treating with lindane insecticide or engine oil
- Selecting maize varieties with good husk cover for storage
- Timely harvest
- Treating maize in husk with Actellic Super dilute dust (permethrin + pirimiphos-methyl)
- Shelling and then treating the maize grain with Actellic Super dilute dust
- Shelling at a threshold of infestation determined by external examination of the store
- Traditional methods of insect control.

Dissemination of these control options by the LGB TC project was undertaken using a wide variety of innovative techniques. These included training extension staff, traders, and farmers and the projection of written print-based materials, plays, radio broadcasts, T-shirts and car stickers, a decision tree and newspaper articles.

We undertook a questionnaire survey to determine the extent to which storage practices have changed in the years since the LGB Project, record the extent of adoption of project recommendations and identify which information routes are currently important and what the farmers think of them. The choice of questionnaire survey follows, and builds on, similar successful studies of earlier LGB control projects in East Africa (Golob 1991; Golob *et al*., 1998). During the survey we have show special interest in establishing which methods of disseminating information impact most on farmers. This is because our own current research project is developing an improved method of treating farm stores with insecticide which, in due course, will need to be promoted. The treatment of maize with formulations of contact insecticides is an effective, fast-acting control option for farmers (Dales and Golob, 1997). Safety, cost, availability issues and the detrimental effect on biological control agents, are all issues raised by increases in the use of such chemicals. Farmers are asked here about their changing use of contact insecticides in maize storage (including naturally derived products such as botanicals) to guide our research and future recommendations in this controversial area.

a)

b)

__Figure 4.1: Two common structures for the storage of maize cobs in the Volta Region of Ghana, a) an Ewe-style barn under construction, which has an thatched roof added at the end and b) an inverted cone__

Methods

A stratified sample of farmers was interviewed by four staff of the Post-harvest Development Division of the Ministry of Food and Agriculture based in Ho, Volta

Region. Villages were selected from four Districts to represent the main maize producing areas in the Volta Region that either produce a lot of maize for sale or have this grain as their main staple (Fig. 4.2). Surveys were undertaken between April and June, 2000, and a total of 242 maize farmers interviewed (Fig. 4.3). Ten respondents were interviewed in most villages.

The survey was based around a questionnaire (see Appendix 1) that was developed in collaboration with the survey team. The questionnaire included questions about storage practices as well as questions about the respondents themselves, particularly their sex, ethnicity, age and educational background. These were included as it seemed probable that such factors could affect either the uptake of extension messages and/or responsiveness to particular dissemination pathways. The questionnaire was then tested in Hodzo and Kodzobi on 27 and 28 March 2000. More revisions were then made following suggestions made by the survey team.

The survey team selected respondents by walking through each village looking for signs of maize storage. They then attempted to locate those responsible for maize storage in that household. They encouraged women to speak for the household even if they were not in charge of the barn and the person responsible was not available. Sampling was not entirely randomised, since occasionally, the team came across households where no-body was available to participate. Within these constraints the survey team included a range of respondents, both men and women, producing various quantities of maize. After initial analysis of the survey data, we revisited some of the survey villages to gain farmers' opinions on the likely explanations for some of our results. In order to establish whether respondents could distinguish different storage pests, dead specimens of LGB, *Sitophilus zeamais* and *Tribolium castaneum* were presented to farmers in Petri dishes. Were possible live insects taken from farmers' barns were also used.

The raw data were entered into an Access 7.0 database. Differences were compared statistically using chi-squared (χ^2) tests on the numbers of respondents in each category.

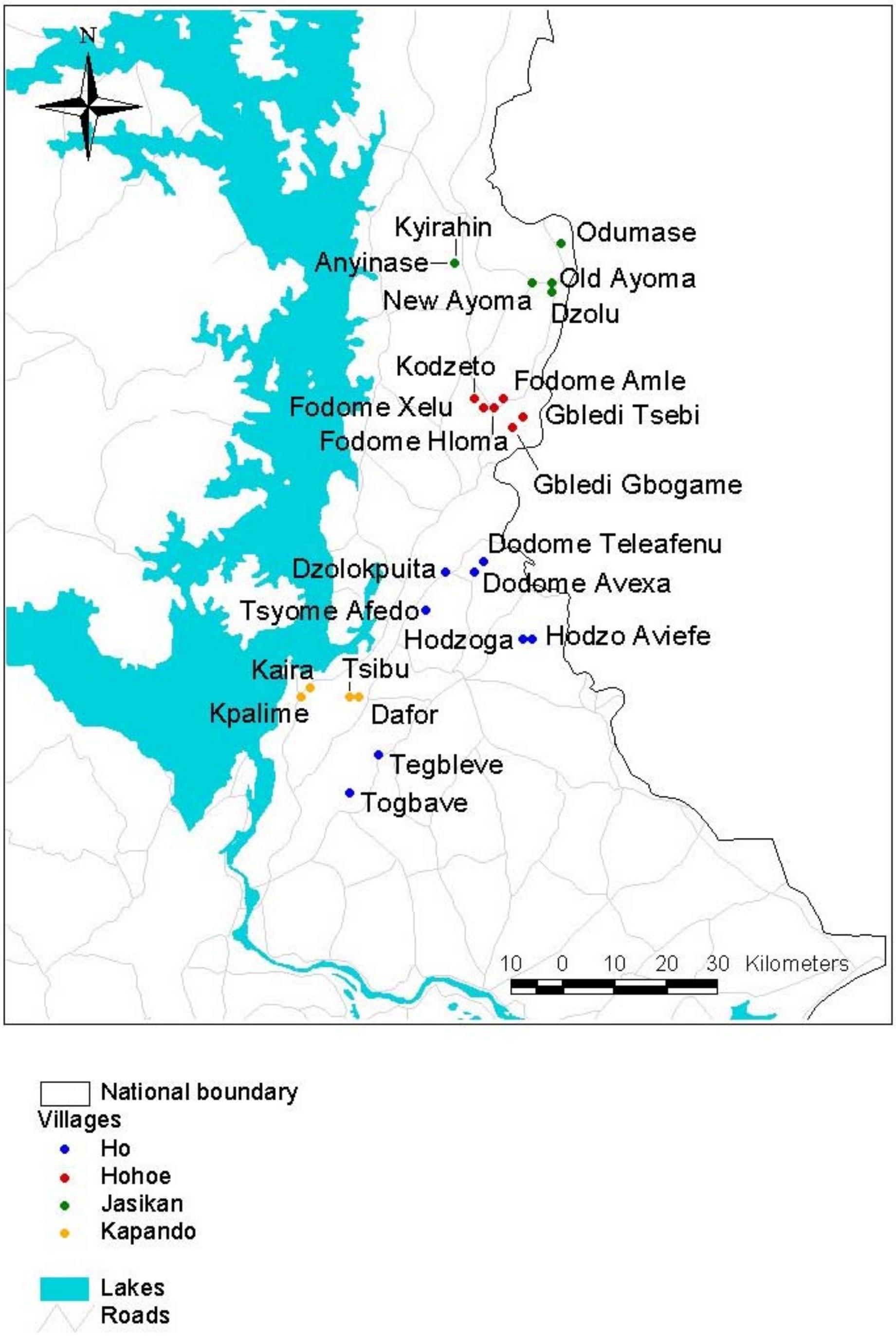


Figure 4.2: Location included in the survey

Results

Interviewees

Overall, there was a male bias in our sample, 62% men compared to 38% women (Fig. 4.3). The sex ratio sampled also varied by District. An approximately equal sex ratio was sampled in Ho and Kpando, and the most male-biased sample was from Hohoe.

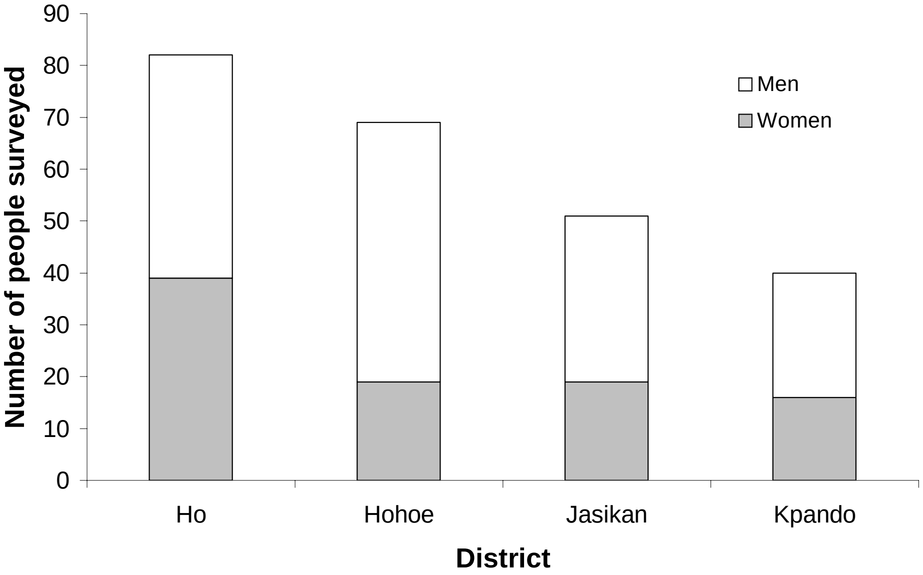


Figure 4.3: Numbers of men and women interviewed in each of the four Districts

The most prominent ethnic group in our sample was Ewe (83%), the next most frequent was Buem who were only found in the Jasikan sample and comprised two thirds of this sample. The majority (85%) of our sample were middle aged, with just seven male adolescents and 29 Elders. Those classed as adolescents were generally under 20, middle-aged, 20-50, and Elders generally older than 50.

Primary education lasts for about six years, middle education for about four years and secondary education from 5-7 years (although this system is currently being revised). The majority of our sample had finished their formal education after middle school. More women than men (even though overall the sample is male biased) had received no formal education, and only three of thirty-one respondents who had attended secondary education or university were female. The overall level of formal education received by our sample population is likely to be less than average since it is drawn from those not skilled in another trade, i.e. those who have remained on-farm and not taken up jobs elsewhere.

The number of people depending on maize for their livelihood (a measure of household size) ranged from one to 23, but the modal value was six.

Maize uses
The three most frequently mentioned uses of maize were for family food, sale and seed. When ranked, food for family was rated as the most important use. The mean amount of maize allocated for sale, by those who were selling and who were prepared to give us an estimate of the amount sold, was around 400-500kg. This is approximately twice as much as that cited for family food. This may however be an underestimate since the survey team felt that many people would not mention small quantities of maize that they had sold and the figure only represent the relatively large-scale sellers.

Maize variety and decision to store
Local maize varieties were grown and stored by the vast majority of households in our survey. Respondents in Ho District mostly grew and stored in only one season (called the major season). Most farmers in the other Districts grew and stored maize in two seasons (called the major and minor seasons) (Fig. 4.4). The length of time at least some of the maize was kept in store is also shown in Figure 4.4. There is no suggestion from our data that improved varieties (generally more susceptible to damage during storage) were disposed of earlier than local varieties.

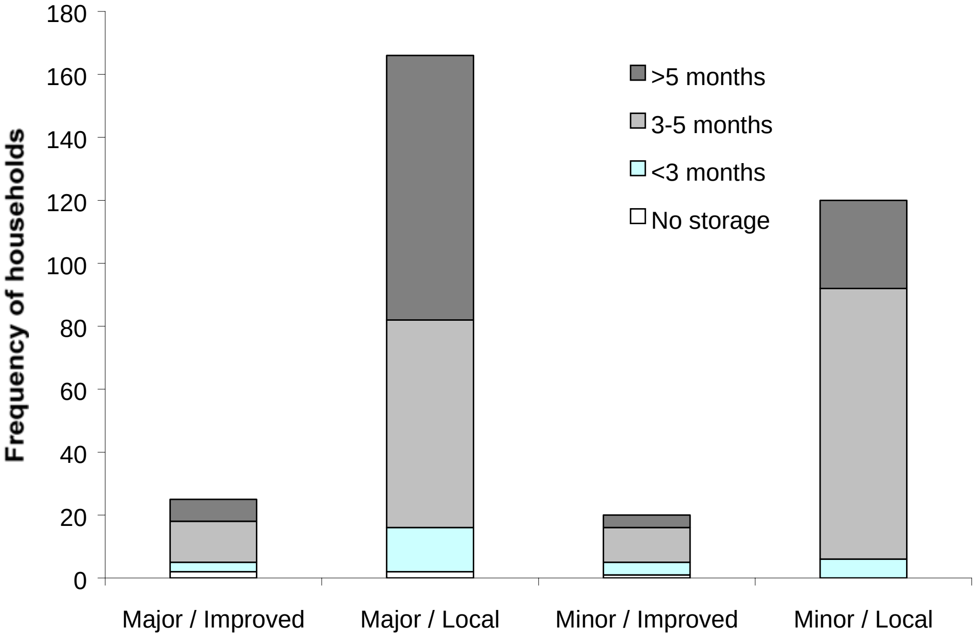


Figure 4.4: Frequency of households harvesting major and minor maize or local and improved varieties. Bars divided by storage period.

Changes in storage problems
Within the past five years, about half of our respondents said that they had experienced changes in storage problems. There was significant variation among Districts (Ho 65%, Hohoe 53%, Jasikan 25%, Kpando 53%) with fewer respondents in Jasikan reporting changes ($\chi^2 = 9.56$, 3 d.f., $p<0.025$). The two most mentioned problems were rising

insect infestation and difficulties in obtaining barn construction materials. These were mentioned significantly more frequently than the third and fourth mentioned problems, lack of barn builders and rodent damage (Fig. 4.5). There were differences between the Districts. In Ho, the issue of barn materials was cited more than increasing insect damage.

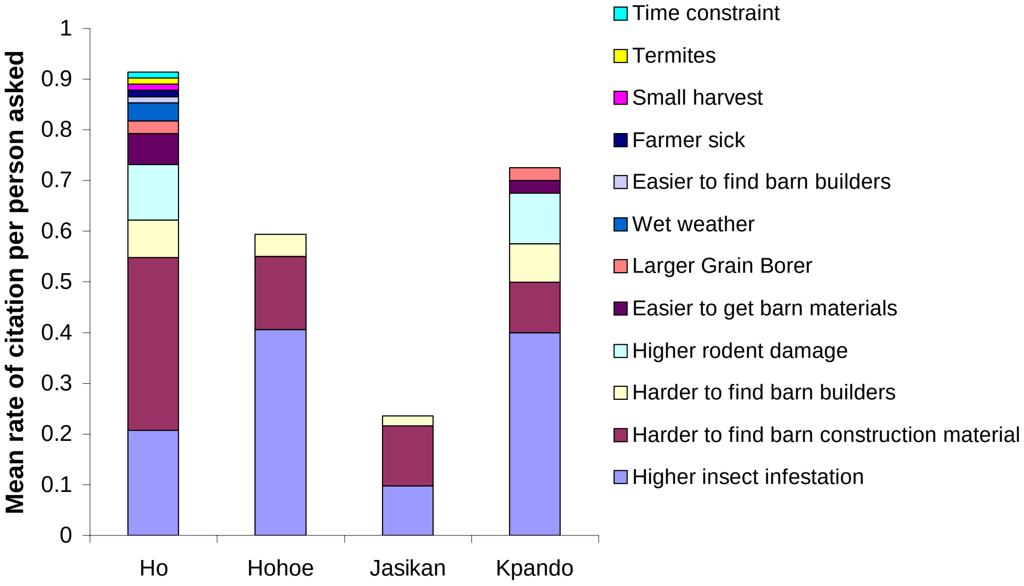


Figure 4.5: Change in storage problems cited in different Districts. Overall, considering all Districts together: Insect infestation vs. barn construction materials χ^2 = 1.42, p>0.5(n.s.); Insect infestation vs. barn builders χ^2 = 17.8, p<0.001; Barn construction materials vs. barn builders χ^2 = 10.04, p<0.005.

Insects reported in stores

Almost all farmers questioned had *Sitophilus* spp. in their stores and were able to recognise it when shown live samples by the survey team (Fig. 4.6). In contrast, approximately 15% of respondents did not recognise LGB and only up to 50% of respondents in any one District reported that they had had LGB in their stores in the past year.

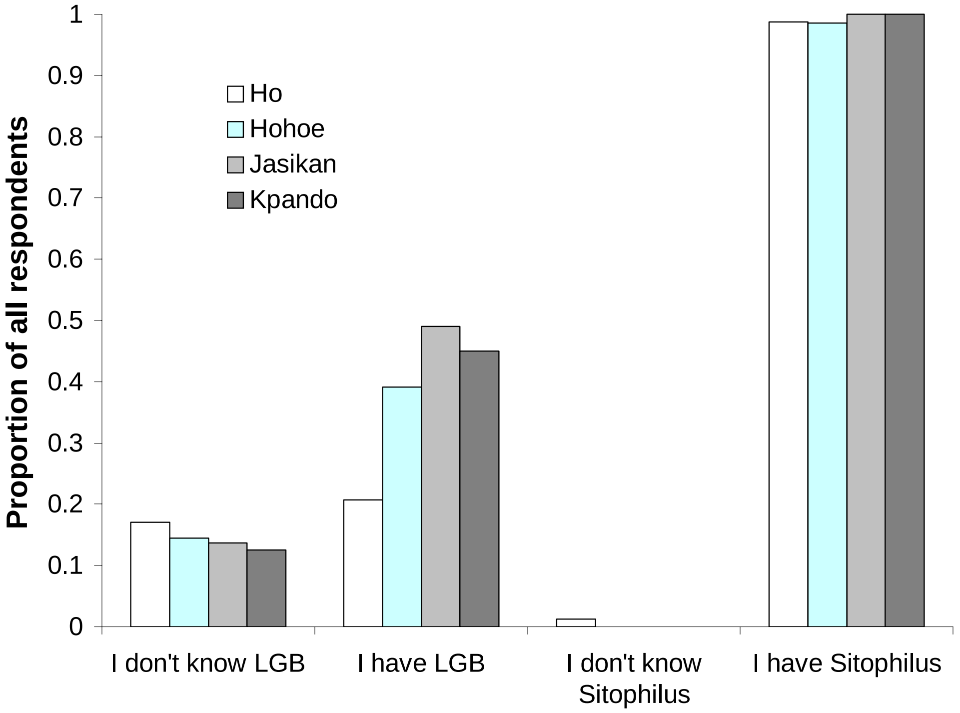


Figure 4.6: Which insects do you find in your store? Data shown for LGB and Sitophilus spp. only (by far the most frequently mentioned).

Changes in storage practice

Over half of respondents reported at least one change in their storage practice in all Districts. Although there was no significant difference between the numbers of men and women reporting that there had been at least one change in storage problem, there was, however, a significant difference between men and women reporting that they had changed their storage practice ($\chi^2 = 6.17$, 1 d.f., $p<0.025$). Of the women, 55% reported that there had been a change whereas 74% of men reported a change.

Farmers reported that the most common change in practice was a shift towards increased inspection of their barns and action taken when insect infestations reached a certain level. Some possible preventative actions were also being taken against insect damage. For example, some but not many farmers were shelling and selling early, some were sun-drying more frequently and some were replacing barn wood more often, particularly in Ho District. Just over a quarter of respondents in all Districts, reported that they have recently begun shelling maize when it becomes infested (Fig. 4.7).

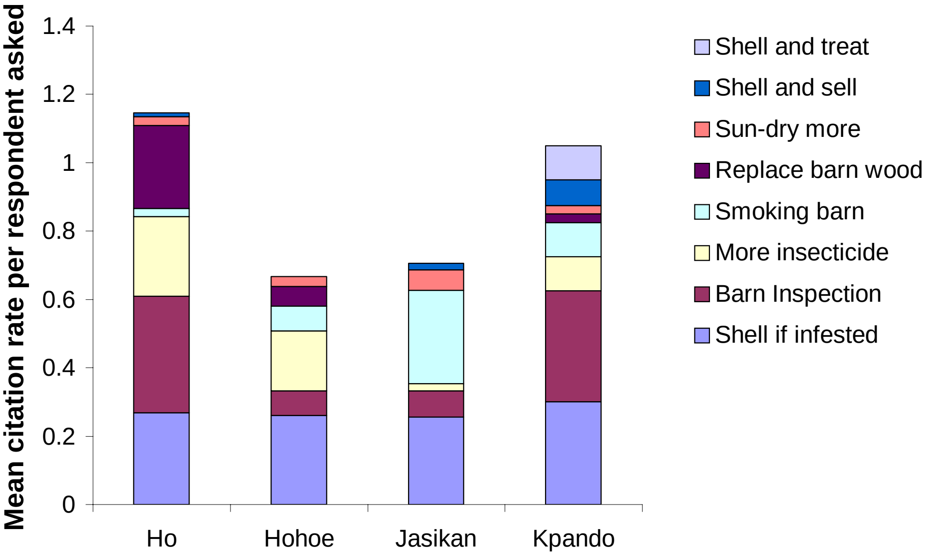


Figure 4.7: Change in storage practice by District

Storage structures currently used

The range and frequency of storage structures used by the farmers we interviewed in each District are shown in Figure 4.8. There was no significant difference in the structures used for major and minor maize crops at harvest (total: $\chi^2 = 0.39$, 3.d.f., $p>0.90$; treated: $\chi^2 = 2.66$, 3.d.f., $p>0.25$) or if the maize was moved later (total: $\chi^2 = 1.71$, 2.d.f., $p>0.90$; treated: $\chi^2 = 0$, $p>0.99$). We have therefore limited our analysis to the major harvest. Maize is most commonly stored on the cob on raised platforms and then, if it is moved during the storage season, it is most commonly threshed and bagged (Fig. 4.9). Maize stored as cobs in a room or in inverted cones (Fig. 4.1 b) was less often treated than in the other store types. This difference in the chance of different store types being treated at harvest was significant ($\chi^2 = 9.68$, 3.d.f., $p<0.025$). In cases where maize was moved into different storage structures later in the season, only grain moved into sacks was treated.

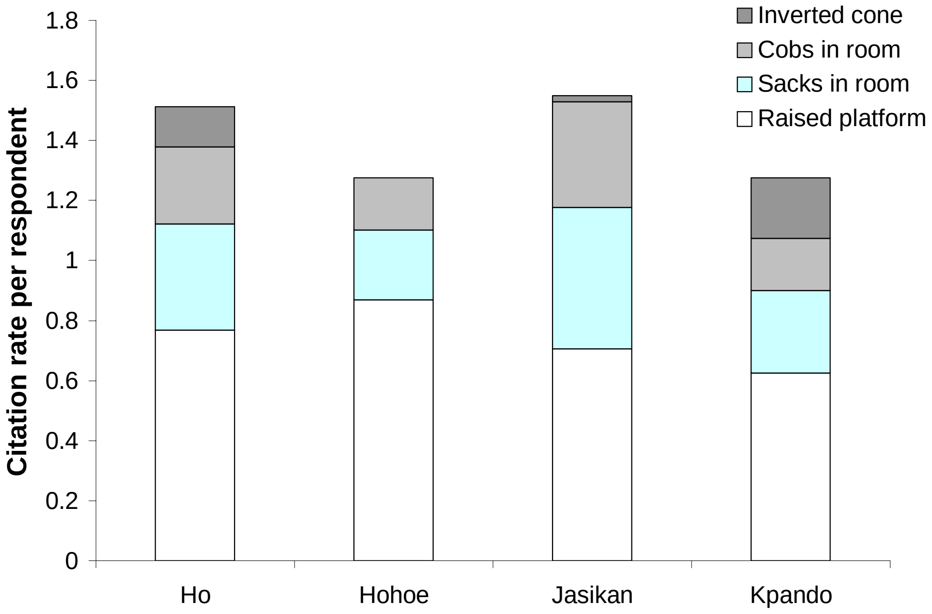
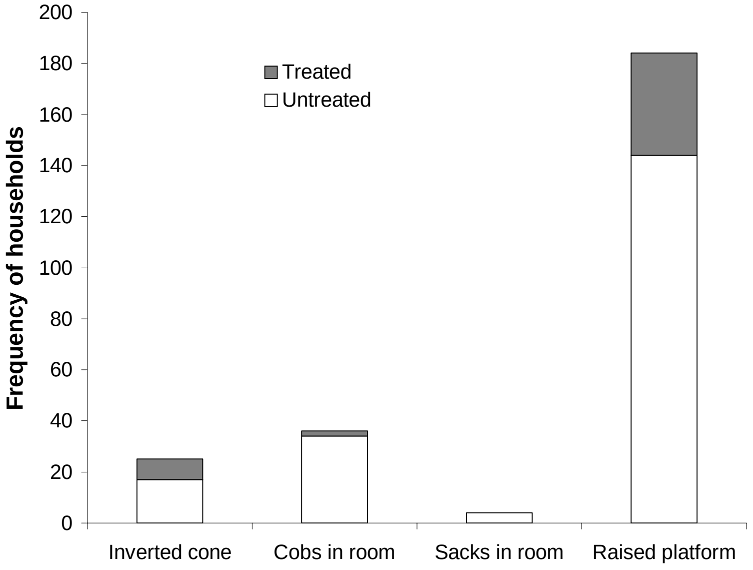
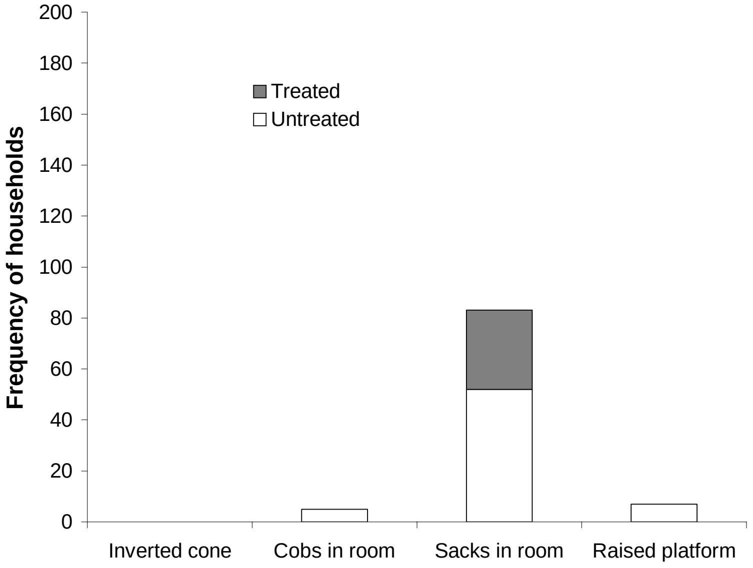


Figure 4.8: Use of different storage structures in different Districts. N.B. Each farmer can mention more than one type of storage structure.



At Harvest



If moved later

Figure 4.9: Store types used by households for the major season maize at harvest and then later if the maize is moved. The portion of those stores that have been treated with a protectant of any type are shaded.

Use of protectants

Grain protectants were used by only 45% of respondents, this includes botanicals and ash as well as commercial synthetic products. There was no evidence that those selling their maize were more likely to treat since only 48% of those who said they had maize for sale used protectants. There were also remarkably few differences in use of protectants between households storing different total quantities of maize over the year (Fig. 4.10), with perhaps some trend for those storing very little to be less likely to treat their maize. There was also a trend for respondents who had had fewer years of formal education to report that their household did not use protectants (Fig. 4.11).

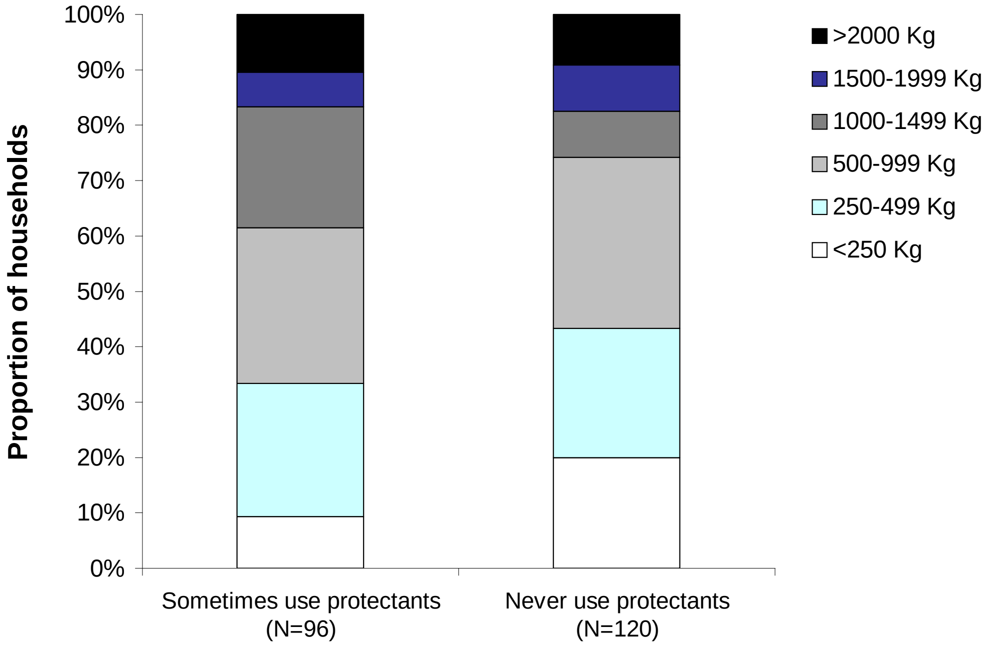


Figure 4.10: Is there any difference in the use of protectants (any) between households storing different amounts of maize?

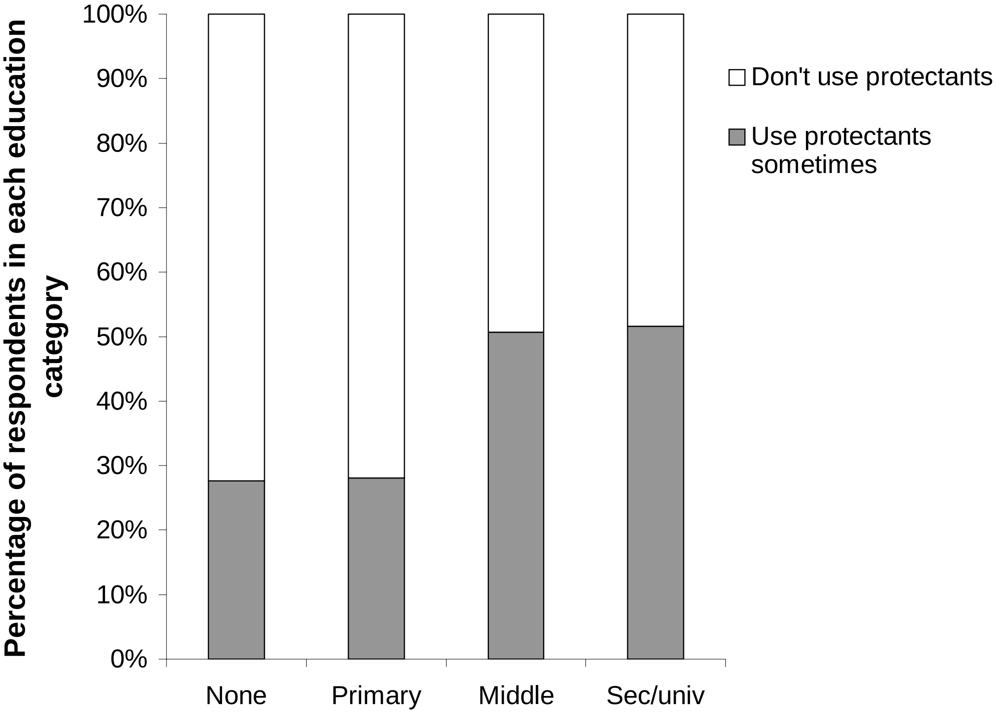


Figure 4.11: Is there any difference in the use of protectants (any) reported by responders of different levels of formal education? Significant difference between education classes in likelihood that respondents use protectants (χ^2 =8.57, 3d.f., $p<0.05$).

Cost was the most frequently mentioned constraint to the use of commercial insecticide and was cited by approximately 40-50% of respondents in all Districts and significantly more than the next most cited constraint (health hazard) (χ^2 =30.0, 1d.f., $p<0.001$) (Fig. 4.12). Three of the constraints cited have been grouped together in Figure 4.12 under the heading, 'no need for treatment' (No damage, small quantity of maize, or use maize quickly). This new heading then becomes the third most cited reason for not using commercial insecticides. Some of the constraints cited are consequences of shelling and storing in sacks, which is often the preferred way of storing treated maize. For example rodents were cited because they damage the sacks, and space was mentioned because grain in sacks is easier to steal than grain in other storage structures. This obliges farmers to keep the sacks in their houses where space is limited.

Commercial insecticides appear to be readily available to those with the money to buy them. Availability was mentioned only rarely as a constraint that prevented their use. When those who had used commercial insecticides recently were questioned, over 95% said that these protectants were, 'very easy to obtain'. The survey team noticed that most farmers felt that all protectants work. Certainly, very few people cited inefficacy as a constraint to use of commercial insecticides.

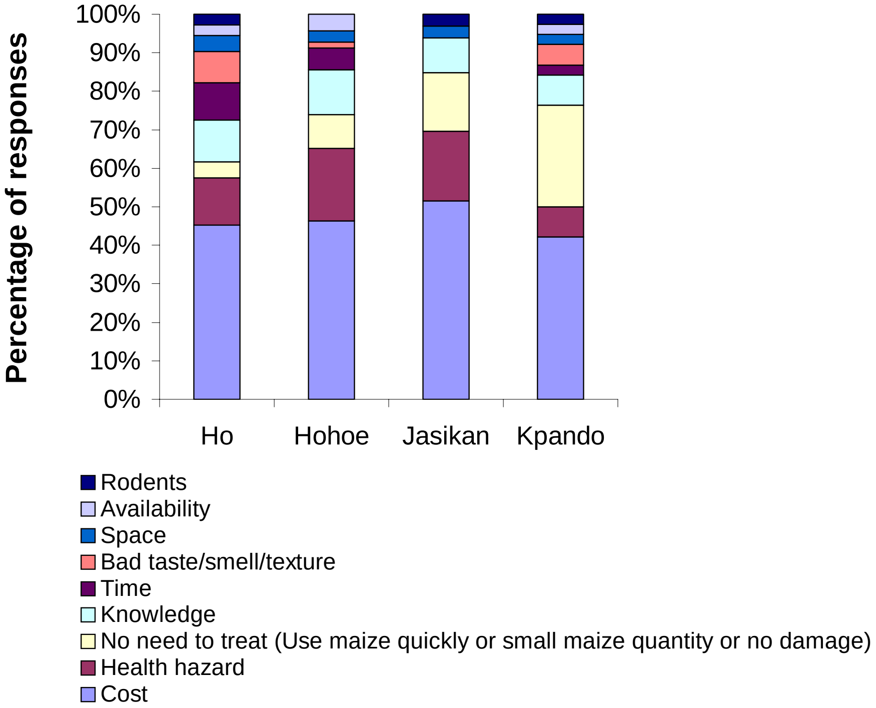


Figure 4.12: Citation rate of constraints to the use of commercial chemical grain protectants given in different Districts. Cost cited significantly more than next most cited constraint (health hazard) ($\chi^2 = 30.0$, 1d.f., $p<0.001$).

The use of various categories of insecticides by District is given in Figure 4.13**.** We have classed camphor, Commando (recommended for public health use), Gammalin 20 (recommended for cocoa crops), DDT and unknown chemicals as, 'inappropriate chemicals'. This will be an overestimation of the misuse of chemicals since some of the 'unknown chemicals' and DDT (sometimes used as a general name for insecticide) citations may in fact be use of registered grain protectants. The registered grain protectants mentioned were Actellic (pirimiphos-methyl), Actellic Super (pirimiphos-methyl and permethrin) and Sumicombi (fenvalerate and fenitrothion).

In approximately half the cases of use of botanicals, neem was specifically named; in the other half no name was given. It can be seen from Figure 4.13 that there is a considerable difference in the choice of protectants used between Districts. There was no reported use of botanicals as grain protectants in Jasikan (although it could be argued that smoking is a use of botanicals and this was mentioned under, 'changes in storage practice'). Respondents in Jasikan were most likely to cite the use of registered grain protectants and least likely to say that they used inappropriate chemicals compared to the other Districts.

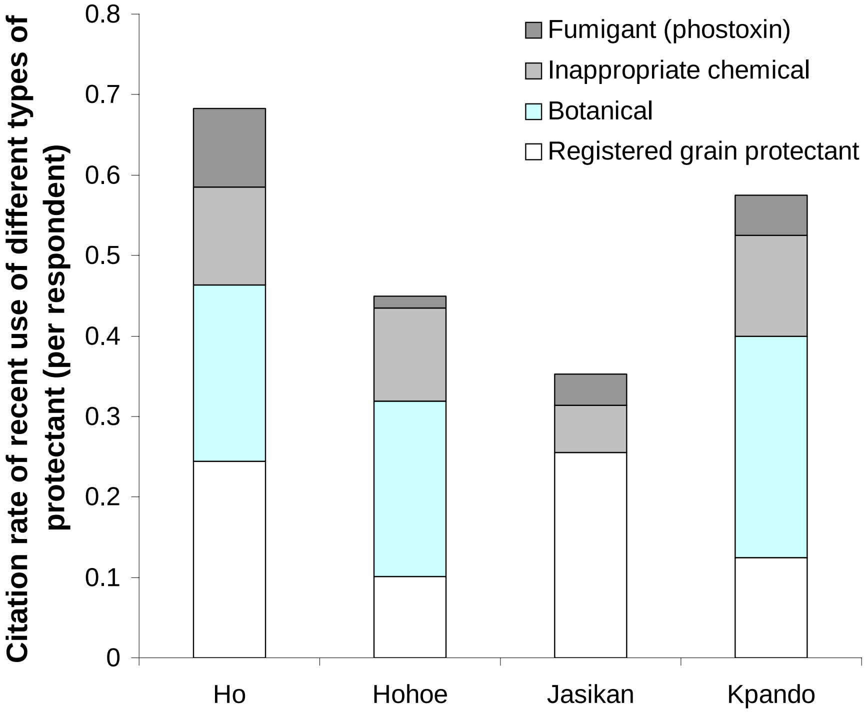


Figure 4.13: Types of protectants used in different Districts as reported by our survey sample

Storage decisions and information networks
Storage decisions were reported to be taken more often by men than women, although not exclusively so (Fig. 4.14). It is common for members of the same household to own separate barns and take sole responsibility for decisions involving that barn.

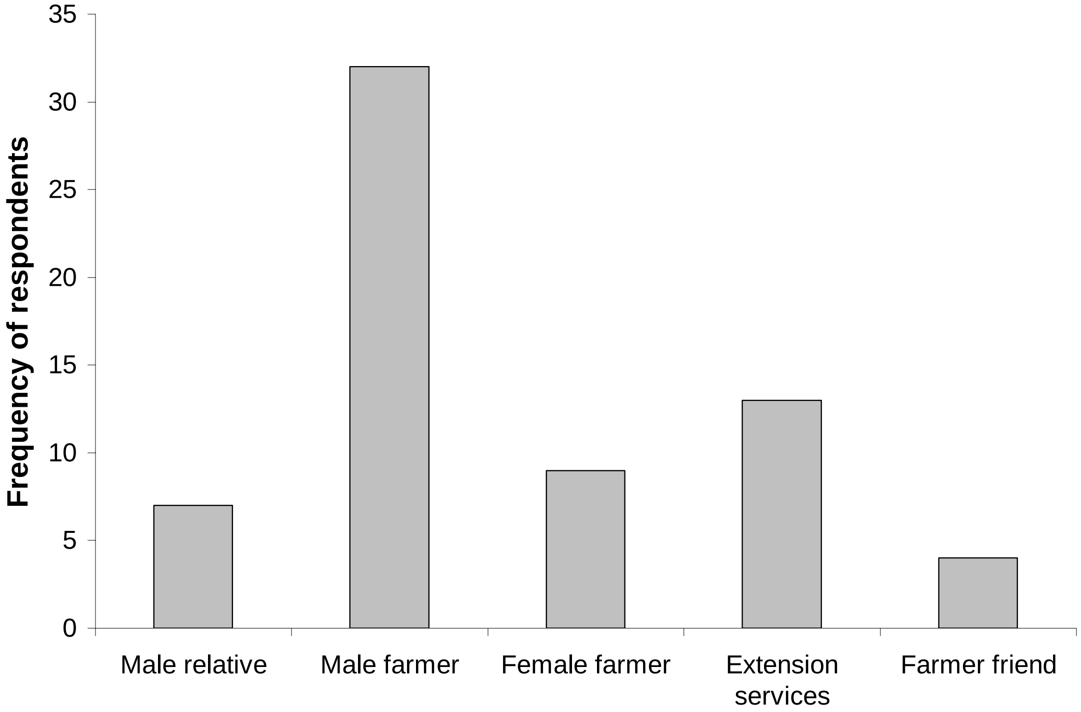


Figure 4.14: Who makes store management decisions?

Men and women cited the same top three sources of information, extension services, radio/TV, and friends, family and fellow farmers (Fig. 4.15). There is a slight tendency for women to cite extension services less often, and friends, family and fellow farmers more than men. We obtained very similar citation rates for the different sources of information in the different Districts. However, when we explicitly asked about the frequency of contact with extension services there were some differences, with respondents in Jasikan reporting the most visits from extension officers.

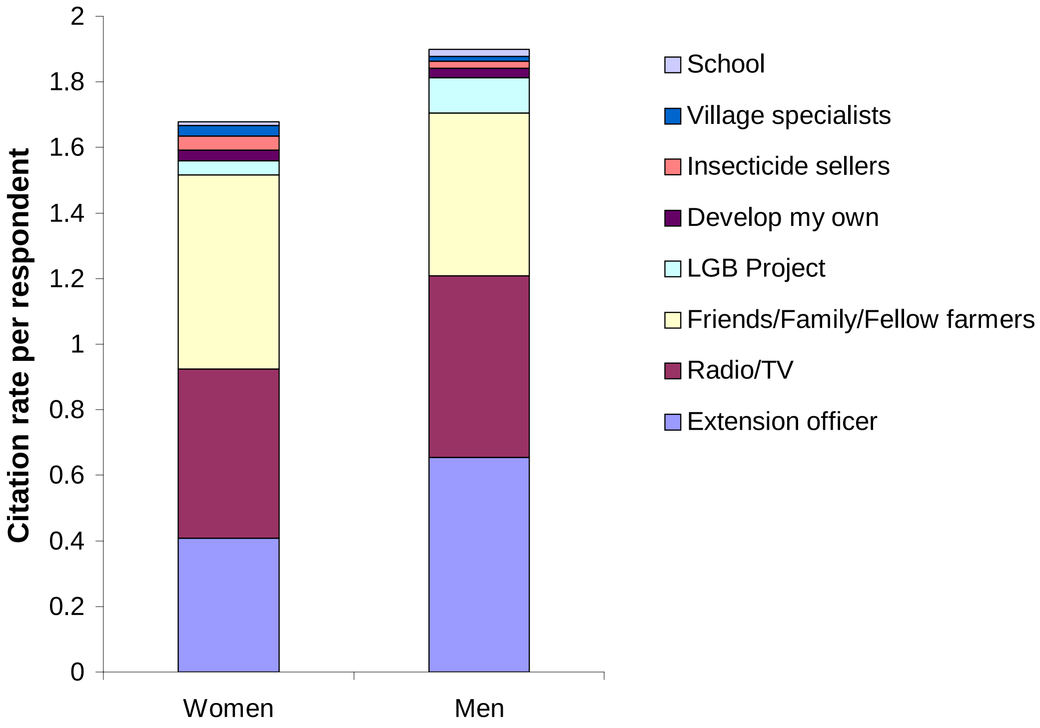


Figure 4.15: Sources of information cited by men and women. Comparison of the relative frequency of extension officers, radio/TV and friends/family/fellow farmers between men and women revealed no significant difference (χ^2=3.82, 2.d.f., p>0.10).

From the comments we received about the various sources of information, it is clear that the extension services are held in high regard. The respondents often valued the chance to ask questions and observe practical demonstrations of techniques that they may have only heard about on the radio.

There was some division in opinion of the value of the information coming from the radio. On the positive side it was felt to be up-to-date, regular and from reliable experts. On the other hand some felt these experts had little practical experience and sometimes gave advice that was impractical (too costly). Friends, family and fellow farmers were accessible, and mostly regarded as having good practical experience, although some said their information was sometimes unreliable. There are programs such as, ‘Radio gbledela’ (The radio farmer) specifically dealing with agricultural issues. One particular strength of these transmissions is that they are often repeated in many different languages (Ewe, Akan, Hausa, Ga, Nzema or Dagbani).

Discussion

Farmers spoke most often about increased insect infestation as a recent change in storage problems, but LGB was hardly ever mentioned explicitly. When asked how much the arrival of LGB had contributed to the higher levels of insect infestation, farmers gave mixed reports, some saying that LGB is a particular problem, others reporting that other species are also increasing in number. Variation between farmers in their experience of

LGB problems was expected due to the sporadic nature of the pest (Hodges and Birkinshaw, 1999).

The survey shows some distinctive differences between the Districts despite the fact that they are quite closely located. In one case the difference possibly relates to ethnicity; there was also an apparent difference between the sexes. In Ho, most farmers stored for one season only, elsewhere there were generally two storage seasons. Ho was changing its barn materials more frequently and had significantly greater problems finding barn construction materials. In Jasikan, there was much lower use of botanical protecants of grain stocks than at the other three locations. This may be a reflection of the predominance in the Jasikan area of a different ethnic group, the Buem. In Ghana, it is known that the prevalence of plant materials usage for stock protection varies according to ethnic and cultural differences in indigenous knowledge (Cobbinah et al., 1999; Belmain and Stevenson, 2001). The sex of respondent appears also to have had some influence on technology uptake since men were significantly more likely to have changed their storage practice than women. This may represent a true sex difference in the likelihood of adopting changes. Alternatively, this may be a misleading result arising from questioning women who were not directly responsible for store management decisions and possibly not aware of changes made by the men they represented.

The clear message from this survey is that farmers have changed their storage practice to include some of the recommendations promoted by the LGB TC project in the Volta Region. The dissemination pathways adopted by that project were successful. Respondents questioned in Ho and Kpando, on average, cited more changes than the other two Districts. In Ho and Kpando, maize is important both as food and a source of income and therefore farmers might be more likely to give a detailed description of their situation. In addition, a higher citation rate of changes in practice might have resulted from particularly high LGB incidence in these Districts in the past. In contrast, in Jasikan, the lower rate of problem citing may well reflect the relatively low importance of maize as a staple for these people.

Many farmers have adopted the strategy of increased inspection and then action, if a significant infestation is detected. It would be interesting to know how early farmers are detecting insect infestations and at what point they feel action should be taken. In the early 1990s, Tanzania farmers were reported to be similarly reluctant to take a prophylactic approach to LGB control (Golob, 1991). However, this may have changed as a 1997 survey in East Africa, including Tanzania, reported that farmers were more likely to shell and often treat their grain as soon as convenient after drying, whether or not insect infestation had been detected (Golob *et al.*, 1998). Similarly, a survey of farmers in three Districts of Kenya, more than ten years after the first record of LGB in the country, showed that among farmers producing a lot of maize for sale or depending heavily on maize for their food security, there was a high rate of adoption of a prophylactic, 'shell and treat' recommendation (Farrell *et al.*, 1996).

Farmers reported that increasing difficulty in obtaining barn construction materials is due to increases in the rural population and thus the amount of land being farmed. Increasing replacement of barn wood (one of the changes in storage practice) was not explicitly given as the main reason why barn materials are now harder to find. Certainly, it has been proposed that store wood is an important harborage for LGB (Kossou 1992) but another reason given by respondents for increased replacement of barn materials was an increase in the additional use of barns as storage space for household items or as kitchen areas. These raise the importance of barns, and dictate that they are built to a higher standard. Increase in barn wood replacement was mentioned most often by farmers in Ho District. There would seem to be two reasons for this. First, farmers in Ho do not produce much minor season maize and so have to store their major harvest for a long time; it is therefore especially important to have a good strong barn to last the season. Secondly, they seem to use the least durable material, palm fronds, to make their barn platforms (other Districts use planks or bamboo).

Some farmers reported an increase in the use of insecticides, presumably to combat the increased threat of insect damage, although this might instead be related to changes in the availability and cost of insecticides, but we do not have information on this. Greater use of insecticide increases their potential health risk, particularly because inappropriate chemicals were in frequent use. Increased smoking of maize was cited most often in Jasikan. This is possibly a reflection of the high humidity of this region where smoking may be particularly useful for drying the commodity. Respondents reported a relatively high usage of appropriate storage grain protectants in this District suggesting that smoking *per se* is not a sufficient response to the threat of insect damage. In fact, earlier survey work on traditional storage methods had shown that the worst infestations of LGB were associated with smoked stores and some farmers even stopped smoking their stores in the belief that it encouraged LGB (Boxall and Compton, 1996).

For the dissemination of information within villages, the agricultural extension services and radio would appear to be the main trusted routes although fellow farmers and family also have an important role. Boxall and Compton (1996) cited traders as a very important source of stock protection information, but this was not reflected in our survey. This may be a consequence of the selection of our survey villages, which were not major trading centres.

We are currently developing methods that could reduce the amount of insecticide to be used per treatment of maize cob barns yet still give acceptable protection. Such treatment would be less expensive and should therefore widen access to stock protection for those farmers who are currently constrained by cost. This approach is seen as particularly relevant in view of the fact that nearly half of all respondents in all Districts mentioned cost as the most important constraint to the use of insecticide. The extension services are clearly assisting some farmers with insecticide treatments while others appear not to have access to good information or support. If new approaches to stock treatments are introduced the dissemination of the methods and provision of clear information on the safe treatment will be needed. The best option would appear to be a campaign on the radio followed up by the extension service explaining and demonstrating the new method to key farming families; the methods identified by respondents as most effective and the key approaches used by the earlier LGB project.

Acknowledgements

We would like to thank Hilarious Penni, Monica Awuku, and Felix Motte of the Post-Harvest Management Division of the Ministry of Food and Agriculture, for their assistance throughout.

5. Targeted pesticide treatment in farm stores in Ghana and Zimbabwe

Addo S., Hodges R.J., Karuma J. and Chigariro J.

Introduction

Subsistence farmers face problems not only with the production of food but also storing it once it has been harvested. With the arrival in Ghana of LGB losses to cob maize stored over 4 months increased from about 5% up to over 30% weight loss (Boxall and Compton, 1996). Farmers in the Volta Region of Ghana who traditionally store cob maize and who have been faced with LGB attack often experiment with control measures such as smoking the store, application of woodash, admixing grains with neem leaves, selecting only maize with good husk cover for storage and replacing store materials. Although such methods work to some extent with *Sitophilus spp*., they offer little or no protection against *P. truncatus*. However, field trials in cob maize barns in the Volta Region have shown that cobs can be stored for as long as (or over) 6 months after the application of Actellic Super dust (permethrin + pirimiphos methyl) (Boxall and Compton, 1996).

Farmers in the LGB-affected areas of Ghana have been encouraged by the Ministry of Food and Agriculture extension services to ‘shell and treat’ or ‘treat cobs’. In spite of these messages, most farmers have failed to treat their maize because either they do not need to treat as they are storing for only a short period, they perceive the insecticide as presenting a health risk, they do not know how to apply insecticide or they are unable to afford it.

There is evidence of a downward movement when *P. truncatus* enters grain stores. For example, investigation of the distribution of the pest in Togolese farm granaries, containing undehusked maize cobs, showed that when the granaries had a medium or high level of *P. truncatus* infestation the pest was more prevalent towards the base of the store (Wright *et al.,* 1993); no trends were apparent when the pest population was regarded as low. In Kenya, when *P. truncatus* was placed in a central position in a crib containing dehusked maize cobs and observed over 24 weeks, it remained mostly in the central position but the first movements away from the centre were towards the base (Wekesa, 1994). In shelled grain, adults also tend to move towards greater depths (Verstraeten and Haubruge 1987; Tierto, 1994). This behaviour of insects in maize storage suggests that targeting treatment at the base of a store might be a useful tool in insect control. It has already been shown that limiting the amount of chemical used in treating small bulks of maize, by limiting treatment to the base of traditional mud silos, can be as beneficial as treating the whole store (Hodges *et al*., 1998).

Farmers in Ghana normally leave ripe maize cobs in the field for periods up to six weeks to dry. Cobs especially those close to the villages tend to have early field infestation, especially that of *S. zeamais* (pers. observation). Since the first trapping of *P. truncatus* in Ghana, (Dick and Rees, 1989), there has been an ever-increasing distribution of the pest in the West African sub-region (Hodges, 1986; Borgemeister *et al*., 1997b).
P. truncatus may also attack the mature maize crop in the field (Golob, 1988, Golob and Hanks, 1990; Wright *et al*., 1993) and such pre-harvest infestation in farmer stores can

lead to early deterioration. Aside 'carry over' infestation in the wooden structure of stores, pre-harvest infestation can result in serious damage early in the storage period in farmer barns (Golob *et al*., 1988; Boxall and Compton, 1996). Maize storage trials conducted in Benin (Borgemeister *et al*., 1998a) on maize harvested at 1, 3 and 7 weeks after physiological maturity and stored up to eight months showed very low incidence of field infestation by *P. truncatus* when compared to *S. zeamais.* The level of loss depended on how long maize was left in the field after maturity and most of the losses were attributed to *P. truncatus*. Tigar *et al*., 1994, working on field and post-maturation infestation of maize by stored pests in Mexico reported that at harvest only about 0.76% of fields had infestations of either *P. truncatus* or *S. zeamais.* However, after three months of drying in the field in stacks, 54% of fields were infested with *P. truncatus* and almost 64% with *S. zeamais*. Although maize with pre-harvest infestation may appear of good quality initially, grain losses will occur more rapidly than in stock without such infestation. Any insect attack whether pre- or post-harvest will lower the market value of maize and estimates from markets in the Volta Region show that using the damage at harvest as a baseline, for every 1% increase in damaged grains there is on the average a corresponding 1% price decrease (Compton *et al*., 1998).

In view of the known behaviour of *P. truncatus* to initiate attack towards the base of farm stores and the need to find more easily affordable means of protecting farm stores, a study in which only cobs in the basal region of the maize barns were treated was undertaken. In Ghana, this involved a series of three studies as follows:

- The efficacy of targeting insecticide was tested by treating the bottom layer of cobs stored in traditional maize barns with Actellic Super (emulsion or dust), with or without covering the sides of the barn with plastic sheeting. The objective of this work is to find out if targeted treatment works and the whether the provision of plastic sheeting gives any extra protection against insects.
- The layers within the barn that might offer potential for the application of targeted treatment were studied by treating of 20% of maize cobs in the top, middle or bottom of barns with Actellic Super emulsion.
- The possible influence of pre-harvest infestation on the efficacy of targeted treatment was investigated by building barns with cobs already infested by *P. truncatus* and *S. zeamais* with 20% of maize cobs at the bottom of the barn treated with Actellic Super (the other two trials were done using maize that was fumigated, that is, with no pre-harvest infestation).

In Zimbabwe, failures in the use of the pesticide are sometimes reported and in the case of Actellic Super this has been attributed to under-dosing. Under-dosing probably occurs because farmers are either unable or unwilling to pay for enough insecticide to give a complete dose. One solution to this problem may be to develop methods of treatment that substantially reduce the amount of insecticide required to give adequate protection. In an earlier study in northern Ghana, we tested the efficacy of pesticide treatments restricted to the bottom 20% and top 10% of maize grain in mud silos (Hodges *et al*., 1999). Such treatment was successful although losses were a little higher than might have been expected after a complete treatment. Subsequently, trials were established in Zimbabwe to determine whether the same technique could give adequate protection of grain in farm bins. The applications tested were 20% of the grain at the bottom of the bulk with or without the top 10% of the bulk treated, i.e. reductions of 70% or 80% of the normal full treatment. Two pesticides were included in the trial, Actellic Super and a diatomaceous earth preparation (Protect-it). The latter had already been shown to be a possible alternative to synthetic pesticides for the protection of grain in Zimbabwe.

GHANA TRIALS

General methodology for targeted treatment trials

The targeted insecticide treatments were tested between November 1999 and April 2002 at Kpeve Agricultural Research Station in central Volta Region, Ghana. The trials all involved maize cobs in husk, stored in typical Ewe barns. The traditional Ewe barn (which is named after the dominant ethnic group in the region) consists of undehusked maize cobs stacked in orderly layers to form a cylindrical stack with stalk ends outermost. During stacking cobs are moistened with small amount of water to keep the stack firm. Maize is stacked on a platform, which is usually 1 m or more from the ground and covered with thatch or corrugated aluminium sheet roofing (Fig. 5.1).

The trials all had the same basic methodology and the methods used are as follows.

Construction of experimental barns

Eighteen to twenty Ewe platform barns were constructed in three rows with about 2m between barns. Each barn consisted of a bamboo platform raised 1m off the ground, with legs fitted with rat guards (Fig. 5.1). On each platform a cylinder of cobs was constructed in the traditional way. Cobs used for the construction of barns were initially dampened to keep the cobs firm in the cylinder. The walls of the cylinder were prepared from two layers of cobs with their bases pointing inwards. The central portion of the cylinder was filled with cobs with no specific orientation. Each cylinder was prepared from about 200 kg of cobs of a local variety arranged in ten layers. The roof of each barn was prepared from two pieces of corrugated iron sheet resting on four wooden supports. The iron sheets were cut to give an overlap of about 25 cm all the way round the barn.

Prior to the test, cobs were fumigated for 7 days with phosphine. Five (3 g) tablets of aluminium phosphide were used in the fumigation of maize cobs in the lots of 150. After treatment an estimate of 'baseline' weight loss was made by selecting 100 cobs and subjecting them to a visual loss assessment (as described by Compton and Sherington, 1999). The visual scale had been calibrated earlier for the variety of maize used in these tests.

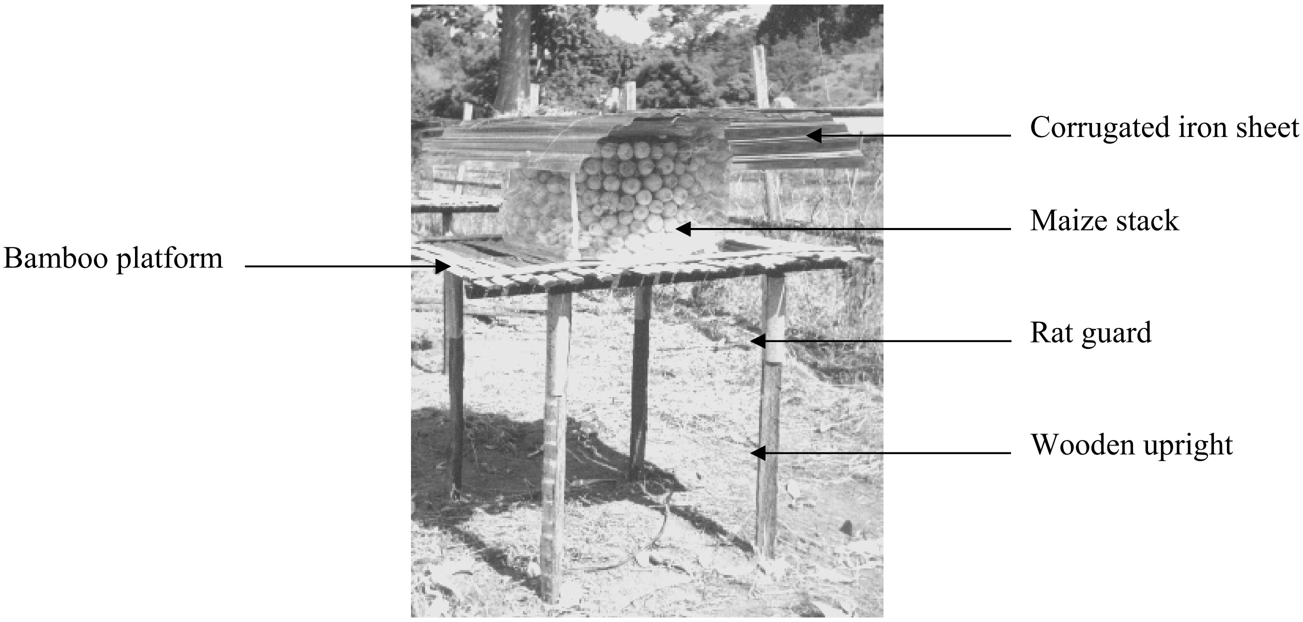


Figure 5.1: Arrangement of experimental Ewe maize barn

Seeding barns with *P. truncatus*

Attempts were made to increase infestation pressure on the barns. This was done so that the barns could get infested quickly within the experimental period. Initially, a glass jar with a sealed mesh top, holding a culture of *P. truncatus*, was placed under each barn. The intention was that this would attract *P. truncatus* towards the barns. The incidence of infestation appeared low so these jars were replaced with other jars containing *P. truncatus* culture which were open and so would allow *P. truncatus* to fly out to the barns. Six such jars were placed between barns so that all barns were equi-distant from a jar. The jars were sunk into the ground and provided with a simple rain cover. The rain cover consisted of a horizontal 38 cm-diameter plastic plate and attached by wire to the funnel-shaped top of the jar to keep the rains out of them.

Grain sampling

For the purposes of sampling grain, each barn was divided into three layers, a top (cob layers 9&10), middle (layers 6&7) and bottom (layers 1&2). Sixty cobs were removed from each layer, 30 were selected at random from the wall of the barn and a further 30 from the centre of the barn. The cobs were shelled and the grain thoroughly mixed, keeping grain, from the three layers and from the outside and inside, separate. A 1kg sub-sample from each lot was then removed by coning and quartering. This sample was sieved for insects and numbers of insects recorded. A further two sub-samples each of 100g were then removed using a riffel divider. These samples were subjected to a weight loss assessment using the count and weigh technique (as described by Boxall, 1986; and improved upon by Compton and Sherington, 1999).

Statistical analysis

For statistical analysis, % weight loss data were transformed to arcsine and subject to one way analysis of variance (Anova). Where data sets showed significant heterogeneity, means were compared using the Least Significant Difference (LSD) test. All analyses were undertaking using the Statistical Package for the Social Sciences (SPSS, 10.0.5)

Testing the efficacy of targeted treatment

To reduce damage due to *P. truncatus* in stored cob maize, farmers have made certain interventions on their own, one of which is covering barns with plastic sheeting. This farmer practice, which can serve as a barrier to the arriving insect, was simulated in this trial.

This study was undertaken with the following objectives in mind;

- to assess protection conferred on traditional Ewe maize barns when treatments of Actellic Super, dust or emulsion, are confined to the basal layers of these stores.

- to determine if any advantage is gained by covering the sides of barns with a plastic sheet, to reduce insect immigration, combined with insecticide treatment.

The experiment was initiated mid-October 1999 and sampling was undertaken twenty four weeks later in April 2000.

Methods

The following treatments were allocated randomly to the barns

- Actellic Super dilute-dust treatment
- Actellic Super dilute-dust treatment + plastic sheet
- Actellic Super emulsion treatment
- Actellic Super emulsion treatment + plastic sheet
- No insecticide (control)
- No insecticide (control) + plastic sheet

In all, there were three replicates for each of the six treatments, so 18 barns were constructed for the trial. Treatment of all maize cobs in a barn (full treatment) was not included in this trial as previous work (Compton *et al*., 1996) had demonstrated its high efficacy for protecting shelled and cob maize and its inclusion would have reduced the degree of replication of other experimental treatments.

Application of Actellic Super dust to cobs

Actellic Super dilute dust was applied to 24kg of cobs in each of the dust treated barns and confined to the bottom two layers as the barn stacks were built. The cobs were dampened before treatment to aid in construction of the barn. Seventy five grams of dilute dust was sprinkled onto each batch, which consists of 8kg of cobs using a plastic shaker with a small stone inside. The active ingredient in the dust was tested at the

Natural Resources Institute (NRI), Chatham, UK by GC analysis and found to contain 3% permethrin and 14% pirimiphos-methyl. This gave an application rate of 2.25ppm permethrin and 10.5ppm pirimiphos-methyl (on a total cob weight basis).

Application of Actellic Super emulsion to cobs

Actellic Super emulsion was applied to 24kg of cobs in each of the emulsion treated barns. The cobs were dipped briefly into the emulsion prepared with water. This used about 1.5 litres for each lot of 24kg. The active ingredient in the emulsifiable concentrate (EC) was tested at NRI by GC analysis. It was found to contain 16% permethrin and 82% pirimiphos-methyl. The emulsion was prepared by diluting 250 cm^3 of concentrate in 6 litres of water giving 0.66% permethrin and 3.4% pirimiphos-methyl. This rate is close to that recommended by the manufacturer for application to store surfaces.

Results

Weight losses

The weight loss of the 100 cobs sampled at the start of the trial averaged 1.8% and by the end of 24 weeks most samples from the barns showed increased weight losses (Fig. 5.2). The only possible exception was the emulsion-treated sheet-covered barns where the initial and final loss estimates were very similar. Weight loss data showed significant heterogeneity ($F= 53.6_{5,287}$, $p<0.0001$) and there were significant differences between most treatments (Table 5.1, Fig. 5.2). The use of a plastic sheet appears to confer some advantage but does not prevent losses. Dust and emulsion treatments were effective and combined with the use of a plastic sheet gave even greater protection.

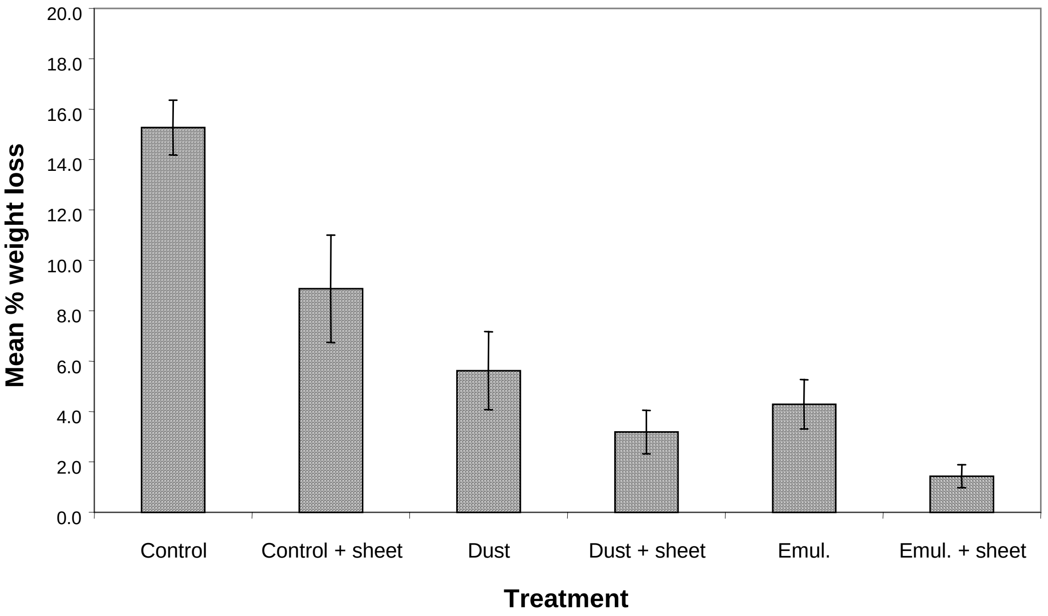


Figure 5.2: Mean % weight losses (±sem) of grain from maize cobs stored in Ewe barns for 24 weeks with various pesticide treatments confined to the bottom two layers of cobs and some barns covered with plastic sheeting. Pre-storage loss = 1.8%. (n = 3)

Table 5.1: Transformed mean % weight loss of grain from maize cobs stored in Ewe barns for 24 weeks with various pesticide treatments confined to the bottom two layers of cobs and some barns covered with plastic sheeting. Untransformed means ±sem in parenthesis. (n = 3)

Treatment	**Transformed mean % weight loss***
Control	23.03 (15.3 ±1.09) a
Control + sheet	17.36 (8.9 ± 2.13) b
Dust	13.69 (5.6 ± 1.55) c
Dust + sheet	10.30 (3.2 ± 0.86) d
Emulsion	11.97 (4.3 ± 0.98) cd
Emulsion + sheet	6.80 (1.4 ± 0.46) e

*Values with no letters in common are significantly different ($P<0.05$)

Weight losses in maize in relation to where cobs were stored in the barn (top, middle or bottom) and in relation to treatment are shown in Figure 5.3. It is noticeable in the controls that losses are fairly evenly distributed between layers, both inside and outside. Where the sheet was in place on the control, losses appeared somewhat higher towards the base. In the case of barns treated with pesticide, with or without plastic sheeting, considerable protection was conferred on all layers of the barn although basal layers always suffered slightly less damage than other layers.

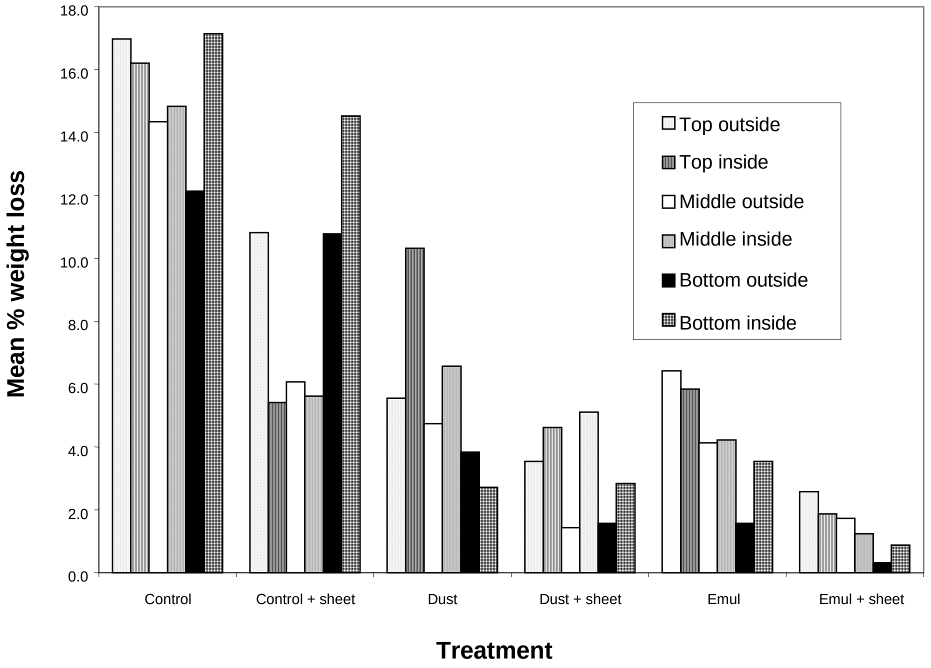


Figure 5.3: Mean % weight losses of grain from maize cobs stored at three levels in Ewe barns for 24 weeks and given various treatments (n = 3)

Insect numbers

The main species of insect pest observed in the barns were *P. truncatus*, *S. zeamais* and *Tribolium* spp. (Fig. 5.4). In each case where the sheet was employed the numbers of insects were reduced and reduced very substantially by both insecticide treatments. It is noticeable that *P. truncatus* was affected more by the Actellic Super than *S. zeamais* (Fig. 5.4). Small numbers of the predator *Teretrius nigrescens* (Lewis) (Coleoptera: Histeridae) were also found although these were rarely encountered in the barns treated with insecticide. As might be expected, the incidence of insects among treatments and control matched the occurrence of weight losses (compare Figs. 5.2 and 5.4).

The distribution of *P. truncatus*, *S. zeamais* and *Tribolium* sp. between the layers of barns not treated with pesticide was roughly even (Fig. 5.5). There was a tendency for higher numbers at the top and bottom of the barn but no consistent differences between the inside and outside layers (Fig. 5.6).

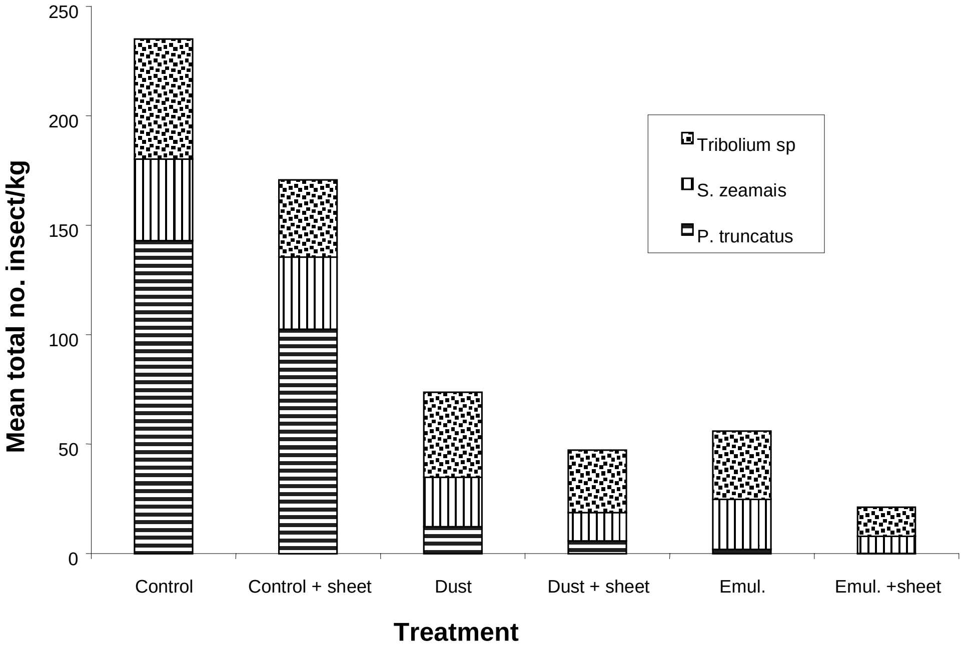


Figure 5.4: Mean total numbers of P. truncatus, S. zeamais and Tribolium spp/kg in grain from maize cobs stored in Ewe barns for 24 weeks and given various treatments (n = 3)

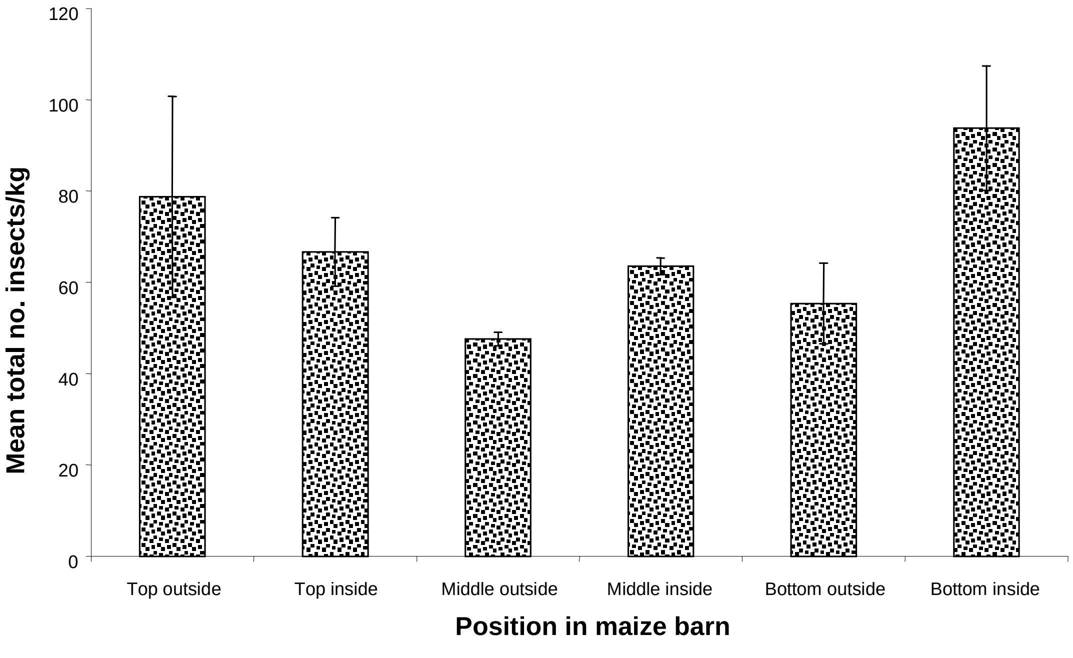


Figure 5.5: Mean total numbers (±sem) of insects in grains at various positions in Ewe maize barns used as control or control plus plastic sheet, after 24 weeks storage (n = 3)

The distributions of *P. truncatus* and *S. zeamais* between treatments and between the three layers of the barns are shown in Figures 5.6 and 5.7. In all layers of treated stores, *P. truncatus* was suppressed to a similar degree although the emulsion treatment was particularly effective. For *S. zeamais,* the suppression in treated stores was more noticeable in the lower layers. In the control there was quite a strong tendency for there to be much higher numbers of *S. zeamais* in the bottom outside layer. This was not evident in *P. truncatus.*

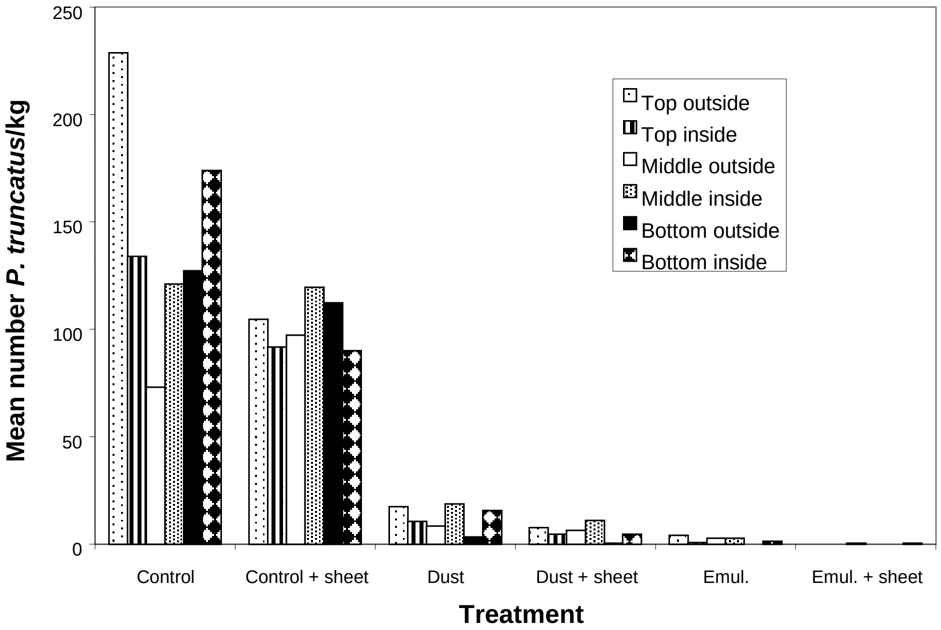


Figure 5.6: Mean numbers of P. truncatus/kg extracted from grain from maize cobs stored in Ewe barns for 24 weeks storage and given various treatments (n = 3)

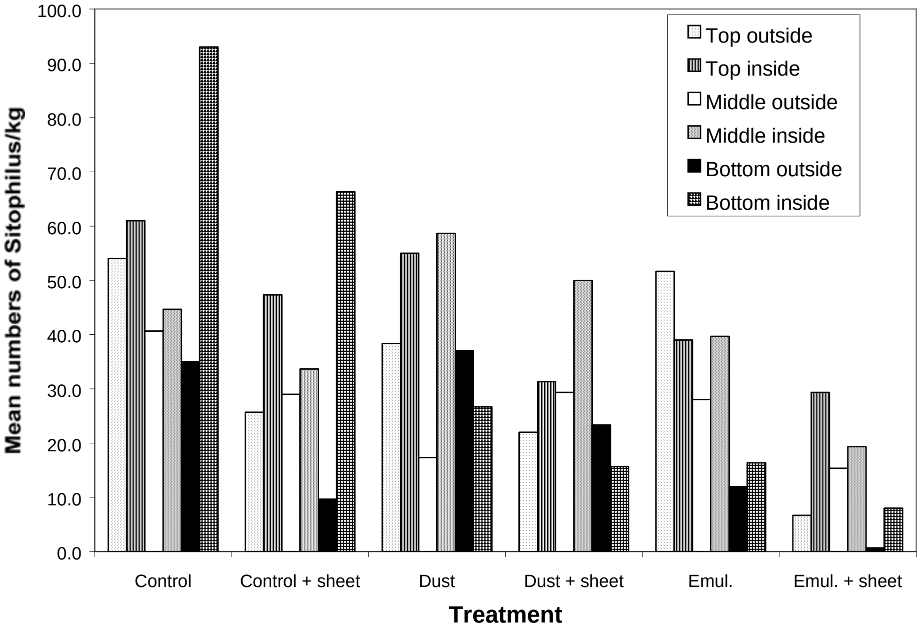


Figure 5.7: Mean number of Sitophilus zeamais/kg extracted from grain from maize cobs stored in Ewe barns for 24 weeks and given various treatments (n = 3)

Conclusions

The insecticide treatments targeted at maize cobs in the base of Ewe barns (bottom 20% of cobs) provide good protection over a storage period of 24 weeks. Weight losses can be reduced from about 15% to around 2-3% (when account is taken of the pre-storage weight loss that averaged 1.8%). The addition of a plastic sheet to cover the sides of barns conferred further advantages. In the control, this about halved weight losses, and a similar effect was observed with cobs given either the dust or emulsion treatments; average losses were reduced to only 0-1.0%, suggesting little or no increase in losses during the course of the test. The advantage in using a sheet is probably greatest where there is little or no infestation at the time the barn is covered. This was the case in this test since cobs had been given an initial fumigation with phosphine. Thus under conditions where there is a substantial infestation at the start of storage the expectation is that the benefit of the sheet would be lower.

The Actellic Super treatment proved rather more effective against *P. truncatus* than *S. zeamais* and damage in the emulsion treated barns appeared to be almost solely due to *S. zeamais* and *T. castaneum* (Fig. 5.4). Nevertheless the losses in these barns, due to these insects, were low. The fact that treatment of the two basal layers confers protection to the entire barn supports the hypothesis that initial insect attack is most prevalent in the base. It follows that a major component of subsequent insect attack is movement of insects from there upwards as the population grows. The fairly even distribution of insects in the barn at the end of the test is presumably a reflection of this upward movement. It might be thought that the use of a corrugated iron roof on these barns could have heated the upper layers of the cobs sufficiently that insects would tend to be driven downwards to be killed on contact with insecticide treatment below. This seems not to have been the case as temperature measurements with thermocouples placed in the top and other layers of cobs (results not presented here) gave no evidence of any such temperature differential even at mid-day when heating would have been strongest. In addition, the relatively even distribution of insects observed between the layers of the control barns added support to this view. It would be of value to undertake further study of the behaviour of insect in grain stores to shed further light on the typical pattern of attack so that further improvements in the extent and positioning of insecticide treatments can be made. It would seem that only treatment at the bottom would be expected to confer the advantages described here.

It is of interest to note that in barns given an insecticide treatment, the cobs in the untreated portion of the barn were not much more infested than those in the treated portions. This suggests that the observed weight losses would not have been much lower had all the cobs in the barns been treated. Clearly, limiting the application of insecticide to the bottom 20% of maize barns conferred good protection and in barns also covered by a plastic sheet, losses are even lower.

Testing the efficacy of targeted treatment in the top, middle or bottom layer of maize barns

To provide further insights into the workings of targeted pesticide treatment an investigation was made to determine whether the position of the treated 2 layers would affect the efficacy of the method.
To do this either the top, middle or bottom 20% of cobs was treated. In this case, only the insecticide emulsion was tested as this performed best in the earlier trial and farmers are, in any case, moving away from the use of dilute dust.

Methods

Two trials tested the efficacy of treating top, middle and bottom layers treated with Actellic Super emulsion. The first one was initiated in late January 2000 when it was hot and dry and sampled in July 2000 when it was wet. This period coincides with the minor maize-crop storage season. The second was initiated November 2000 which is the early part of the dry harmattan season and was sampled in April 2001 before the rainy season. This second trial falls within the major maize-crop storage season. These studies were undertaken to observe whether seasonal changes have any effect on the efficacy of targeted treatment especially as insect activity would be expected to be influenced by climatic conditions.
The following treatments were allocated randomly to the barns

- Actellic Super emulsion treatment to the two bottom layers
- Actellic Super emulsion treatment to the two middle layers
- Actellic Super emulsion treatment to the two top layers
- No insecticide (control)
- Actellic Super emulsion treatment applied to all layers

In all there were six replicates each of the Actellic Super emulsion treatment for bottom, middle and top but only one replicate each for the full Actellic Super emulsion treatment and no treatment. This required the construction of a total of 20 stores with the replication focusing on treatments to demonstrate how location of targeted treatment might affect the efficacy of the method.

Results

Minor season trial (January to July 2000)

Weight losses

The weight loss of 100 cobs sampled at the start of the trial averaged 0.5%. By the end of 24 weeks most samples from the barns showed increased weight losses (Table 5.2, Fig. 5.8,) except for the barns where all cobs were treated with Actellic Super in which case the initial and final loss estimates were very similar. Weight loss data for the barns with top, middle or bottom targeted treatments showed significant heterogeneity ($F = 4.465_{2,15}$, $p<0.030$). The middle-treated barns showed significantly less damage ($P<0.05$) than bottom treated barns but there were no significant differences between these and the barns with treated top layers (Table 5.2). The single replicate of full treatment had low weight loss of about 0.4% whereas the single barn with no treatment had losses averaging 3%.

Table 5.2: Transformed mean % weight loss of grain from maize cobs stored in Ewe barns for 24 weeks and treated in the top, middle or bottom layers with Actellic Super emulsion. Untransformed means (±sem) in parenthesis (n = 6)

Treatment	**Transformed %mean weight loss***
Top layers	6.92 (1.45 ± 0.30) ab
Middle layers	4.90 (0.73 ± 0.13) b
Bottom layers	7.75 (1.82± 0.36) a

*Values with no letters in common are significantly different (P<0.05)

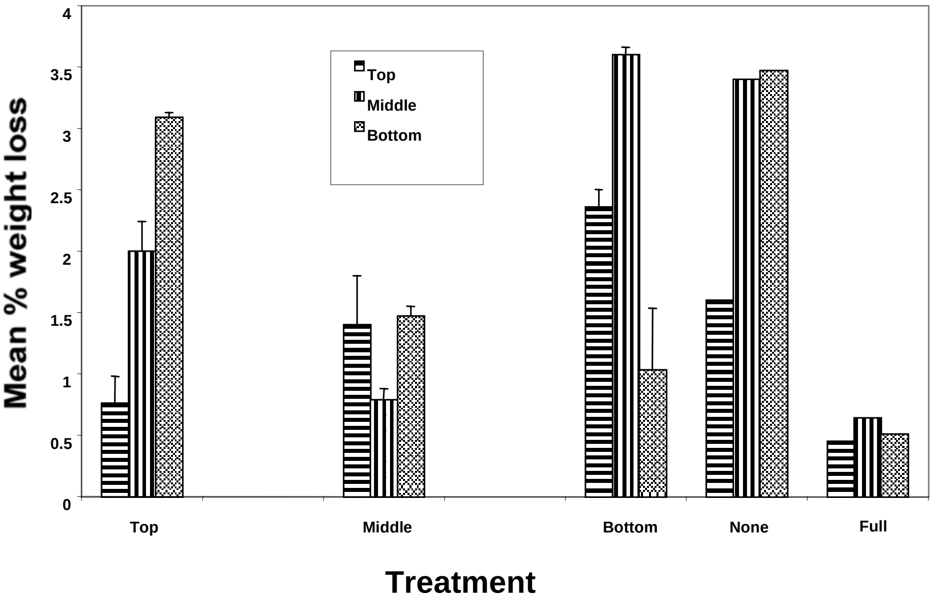


Figure 5.8: Mean % weight loss (±sem) of grain from maize cobs stored in Ewe barns for 24 weeks treated in the top middle or bottom layers with Actellic Super emulsion (n =6), untreated (n= 1) or given a full treatment (n = 1)

Insect numbers

The main species of insect pest observed in barns with no treatment was *S. zeamais*. Other species such as *Tribolium* spp, *P. truncatus*, *Cathartus* spp, *Carpophilus* spp and *Dinoderus* spp were found but in smaller numbers (Fig. 5.9). The treated barns were similar but had fewer insects. The pattern of distribution of *S. zeamais* (Fig. 5.10) in target treated barns follows almost exactly the observed pattern of weight loss (Fig. 5.8). Although the numbers/kg were quite high compared to the observed losses, for example in the bottom treated barns the mean number per kg was 51 ± 36/kg and weight losses averaged only 1.82%. When no treatment was applied, greater numbers of *S. zeamais* were observed as expected but the distribution pattern did not match the observed weight losses quite so closely (Fig. 5.9 and 5.10).

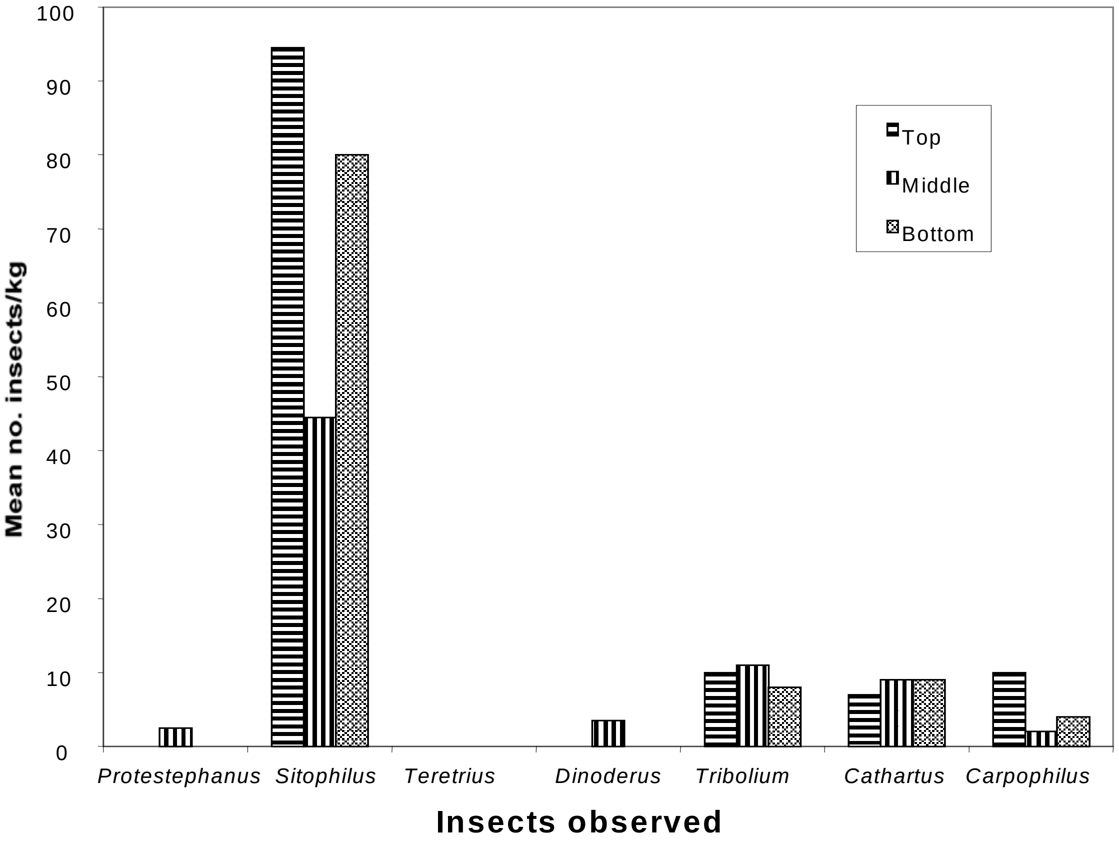


Fig. 5.9: Mean numbers of various storage insects extracted from grain from maize cobs stored in an Ewe barn for 24 weeks and not treated with insecticide (n = 1)

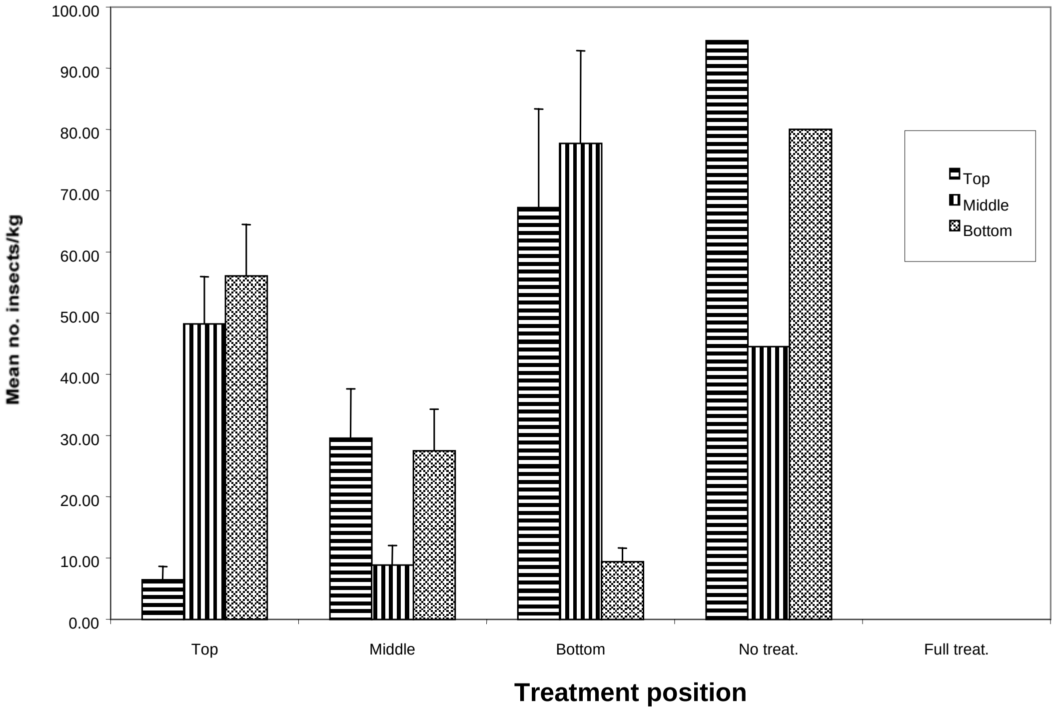


Figure 5.10: Mean number of Sitophilus zeamais/kg (±sem) of grain from maize cobs stored at three levels in Ewe barns for 24 weeks. Barns treated with Actellic Super in the top, middle or bottom two layers (n = 6), untreated (n = 1) or with all layers treated (n = 1)

Major season trial (November 2000 to April 2001)

Weight losses

The weight loss of 100 cobs sampled taken at the start of the trial averaged 0.6%. By the end of 24 weeks most samples from the barns showed increased weight losses (Table 5.3 and Fig. 5.11) except for barns with full emulsion treatment where the initial and final loss estimates were very similar. Weight loss data showed no significant heterogeneity (F= 0.088 $_{2,15}$, p = 0.916) which precludes any testing for differences between the weight loss means (Table 5.3).

Table 5.3: Transformed mean of % weight loss of grain from maize cobs stored for 24 weeks in Ewe barns treated with Actellic Super in the top, middle and bottom three layers. Untransformed means (± sem) in parenthesis.

Treatment	**Transformed % mean weight loss**
Top layers	8.01 (1.94 ± 0.38)
Middle layers	8.41 (2.14 ± 0.49)
Bottom layers	8.89 (2.39 ± 0.59)

Weight losses in maize in relation to where cobs were stored in the barn (top, middle or bottom) and in treatment seemed to be very similar (Fig 5.12). It is noticeable that even in the untreated control, loss values are equally low (mean of 4.5%). The main species of insect pest observed in the untreated barn was *S. zeamais* and even this had less than 10 per kg of maize grain sample. The insect infestation rates appear to have been low in this trial, and even lower than the minor season trial.

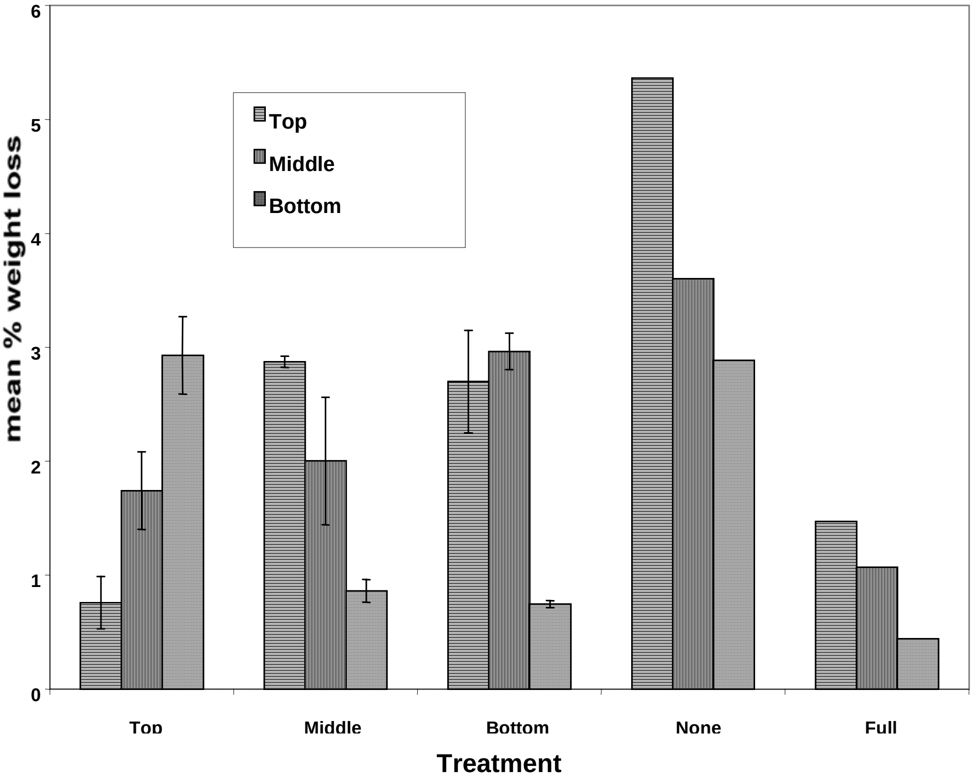


Figure 5.11: Mean % weight (± sem) of grain from maize cob stored in Ewe barns for 24 weeks and treated in the top, middle or bottom three layers with insecticide (n =6), untreated (n= 1) or given a full treatment (n = 1)

Conclusions

The results from the minor and major storage season trials on the efficacy of targeted treatment to the top, middle and bottom layers of the barn show relatively little difference in the degree of protection provided. These trials were initiated at different times of the year to bring into focus seasonal variations in insect activity. Although the middle treatment was consistently better than bottom treatment in the minor season trial, the difference between them amounted to only just over 1%. The single replicate untreated barns had a weight loss of only 2.33% for the minor season and 3.5% for the major season trial (both after correction for initial loss). This suggests that the infestation pressure was low during the course of these trials compared to the previous bottom only treatment trial where mean weight losses had been 13% after a similar duration of storage. In the previous trial, where only bottom layers were treated, the untreated controls similarly had an average of only 54.7 ± 9 *Sitophilus*/kg but also large numbers of *P. truncatus* (143 ± 52/kg) suggesting that this species was responsible for most of the observed 13% weight loss. This bears out Dick's (1988) statement that *P. truncatus* has on average at least doubled the loss caused in African farm stores. It is probable that the conditions prevailing at the time of the two trials resulted in a low infestation pressure for *P. truncatus*. It is known that the extent of *P. truncatus* infestation varies greatly from year to year. The likelihood that stores become infested has been connected to the numbers of beetle dispersing by flight (Birkinshaw *et al*., 2002) and these numbers are influenced strongly by climatic conditions which vary for year to year (Hodges *et al*., in press). The provision of a source of *P. truncatus* close to the barns clearly did very little to increase the infestation and it may be assumed that the beetles here were also affected by adverse climate as those elsewhere in the habitat

These trials were unable to demonstrate any difference in the efficacy of targeted treatment according to whereabouts in the barn the treatment was located. The extent of weight losses in the treated barns were consistent with those observed previously but these do not provide any sure evidence of the efficacy of the targeted treatments due to the relatively low weight losses observed in the untreated barn.

Efficacy of targeted treatment in barns with pre-harvest infestation

When maize cobs are infested by storage insects before harvest, storage losses can be significantly increased. In previous tests on targeted treatment, this pre-harvest infestation has been removed as an experimental variable by using only fumigated maize cobs for the construction of experimental barns. In this experiment, the efficacy of targeted treatment in the presence of pre-harvest infestation is tested by introducing insects into fumigated cobs prior to barn construction. This trial tested the hypothesis that weight losses in barns given a targeted insecticide treatment remain within acceptable limits, compared with a full pesticide treatment, even when there is pre-harvest infestation by *P. truncatus* and *S. zeamais*.

Methods

Aside the general methodology used for the targeted insecticide treatment work, the following additional procedures were adopted for this experiment. Previously fumigated cob maize was infested with insects at least one week prior to barn construction. The sheathing leaves of the maize cobs were carefully opened at the cob apex and either 5 young adults *P. truncatus* or *S. zeamais*, from fresh laboratory maize cultures, were added. Cob sheathing leaves were then held securely in position using an elastic band. Each cob was placed in a transparent plastic bag so that any insects escaping from the cobs could be seen and returned to the cobs. To avoid confusion, *S. zeamais* cobs were marked with a blue spot and *P. truncatus* with red a spot.

A total of 180 pre-infested cobs were prepared, 90 infested by *P. truncatus* and 90 by *S. zeamais*. For infested barns, one cob was placed at the centre of each layer, making a total of ten cobs per barn, with the *P. truncatus* cobs and *S. zeamais* cobs alternating between layers. There were six replicates of each treatment and half the replicates started with a *P. truncatus* infested cob in the bottom layer and the other half started with a *S. zeamais* infested cob in the bottom layer.

Experimental treatments for layers of cobs in Ewe barns with pre-harvest infestation

Barns were constructed to give the following treatments-

- Cobs with pre-harvest infestation and with Actellic Super emulsion treatment to the two bottom layers (six replicates)
- Cobs with pre-harvest infestation and with no Actellic Super emulsion treatment (six replicates)
- Cobs with pre-harvest infestation and with full Actellic Super emulsion treatment to the whole barn (six replicates)
- Cobs with no pre-harvest infestation and no Actellic Super emulsion treatment to the cob (two replicates)

Duration of trial

The trial was initiated in late October 2001, a cool damp period of the year at the end of the minor rains and was terminated in April 2002, the storage period for maize from the major season harvest.

Results

Weight losses

The weight loss of 100 cobs samples taken at the start of the trial averaged 0.8% and by the end of 24 weeks of storage most samples from the barns showed increased weight losses (Table 5.4, Fig. 5.12). Weight loss data for the barns with full, bottom or no treatments showed significant heterogeneity ($F_{(2,17)} = 76.029$, $p<0.0001$). Weight losses for completely treated pre-infested barns were low (about 2%) while the bottom-only treatment of such barns was unable to prevent substantial losses (11%). Infestation in barns with pre-harvest infestation and no insecticide treatment was severe and resulted in an average of 15% weight loss; similar losses to those experienced in the control barns of the very first experiment. Untreated barns with no pre-harvest infestation suffered only about 5% weigh loss.

Table 5.4: Transformed mean % weight loss of grain from maize cobs stored in Ewe barns for 24 weeks. Barns subject to pre-harvest infestation, given a treatment with Actellic Super emulsion on the bottom two layers, fully treated or given no treatment. Untransformed means (±sem) in parentheses

Treatment	**Transformed % mean loss***
Pre-harvest, full treatment	6.78 (1.45 ± 0.28) a
Pre-harvest, bottom treatment	19.63 (11.53 ± 1.65) b
Pre-harvest, no treatment	23.01 (15.33 ± 0.81) c

*Values with no letters in common are significantly different (P<0.05)

Although average weight losses for bottom only treatments was as high as 11% (Fig. 5.12) a careful look at the weight loss within the layers show that this has resulted largely from the infestation of the untreated middle and top layers (Fig. 5.13). This suggests that bottom treatment would have been good if maize is not left for as long as 6 months or if the household had consumed the top and middle layers during the period.

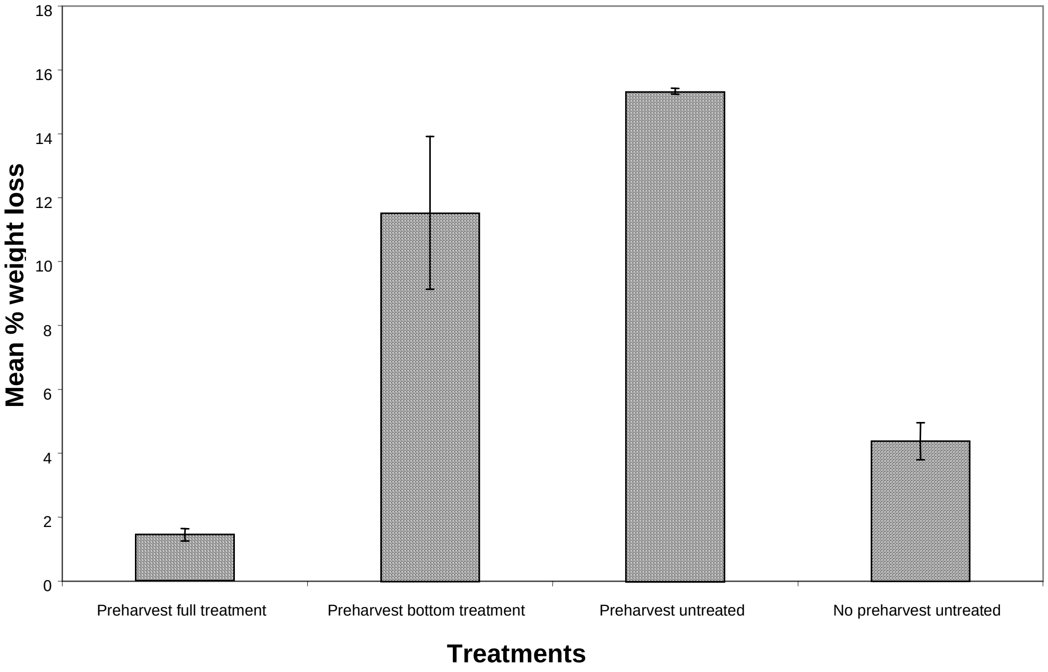


Figure 5.12: Mean % weight loss (± sem) of grain from maize cobs stored in Ewe barns for 24 weeks. Barns subject to pre-harvest infestation and given a treatment with Actellic Super emulsion on the bottom two layers, fully treated or given no treatment (all n = 6) or untreated and with no pre-harvest infestation (n = 2).

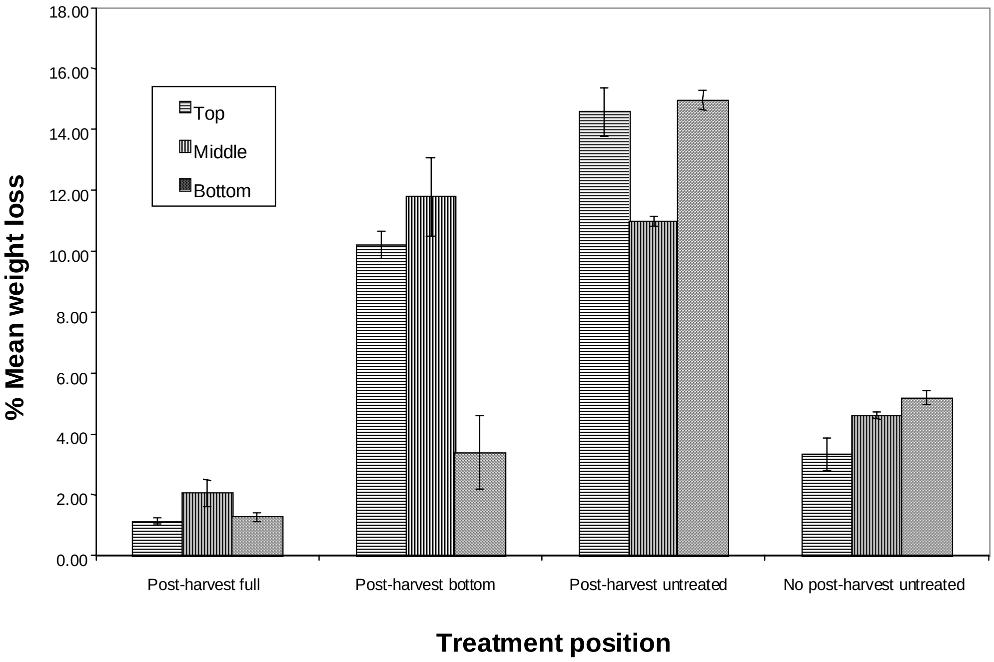


Figure 5.13 Mean % weight loss (±sem) of grain from maize cobs taken from the top, middle or bottom layers of cobs stored in Ewe barns for 24 weeks. Barns subject to pre-harvest infestation and given a treatment with Actellic Super emulsion on the bottom two layers, fully treated or given no treatment (all n = 6) or untreated and with no pre-harvest infestation (n = 2)

Treatment of the bottom layer, in the presence of pre-harvest infestation, would appear to halve the number of insects found infesting a barn (Fig. 5.14). Comparing the mean weight loss and insect numbers for untreated barns, with or without pre-harvest infestation (Figs. 5.12 and 5.14), it can be seen that *P. truncatus* rather than *S. zeamais* is responsible for most of the observed losses. Similar observations have been made for rural maize stores in Mexico (Tigar *et al*., 1994) where *S. zeamais* was most numerous and most frequently encountered insect. *P. truncatus* was not common but where it was present it was thought to have been responsible for most of the observed damage.

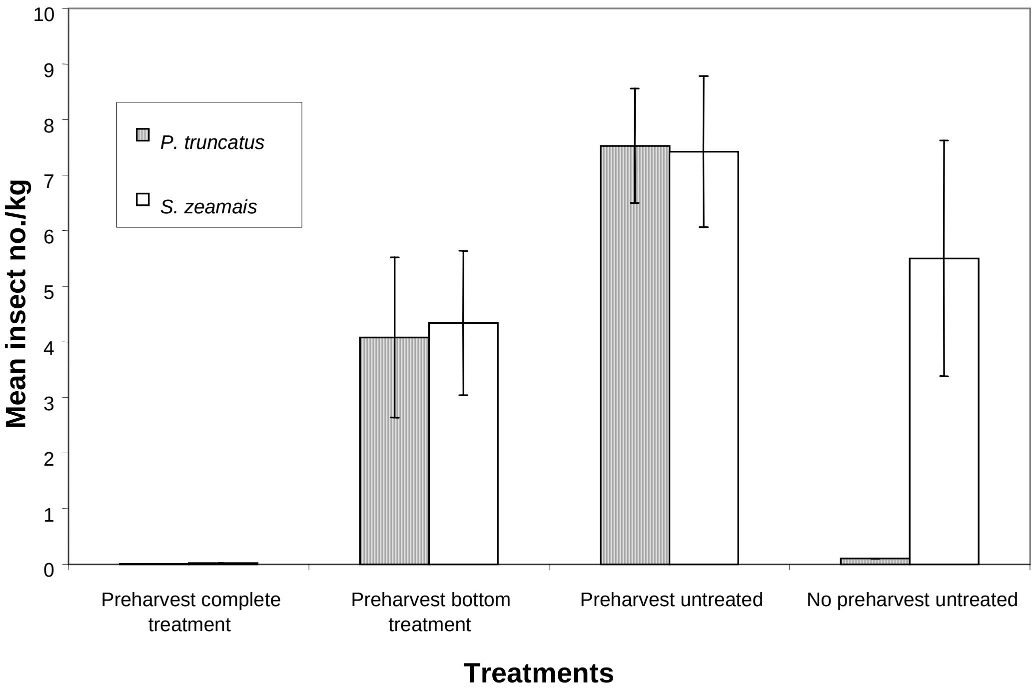


Figure 5.14: Mean numbers of* P. truncatus *and* S. zeamais *(±sem)/kg of grain from cobs of maize stored for 24 weeks with pre-harvest infestation in barns (n = 6), no pre-harvest (n = 2).

Conclusions

The initial hypothesis was that after targeted treatment with insecticide at the base of a store, losses in barns that have a significant pre-harvest infestation by *P. truncatus* and *S. zeamais,* would remain within acceptable limits when compared with full treatment of the maize stock. The observed levels of damage suggest that pre-harvest infestation seriously reduces the efficacy of the method. Both *P. truncatus* (Hodges, 1991; Cork *et al*., 1991) and *S. zeamais* (Schmuff *et al*., 1984; Phillips *et al*., 1985) produce a pheromone secretions that attract both males and females of their own species. In the case of *P. truncatus*, a single male on a single maize cob can attract about 50 to 60 conspecifics in one week (Scholz *et al*., 1997). Farmers cannot benefit from targeted treatment if they hold grain stocks with a pre-harvest infestation and store their maize for as long as 6 months. Maize storage pests can infest the crop at anytime from field maturation to the storage period (Tigar *et al*., 1994) and the presence of field infestation by *P. truncatus* has been documented in West Africa (Borgemeister *et al*., 1998a). With *P. truncatus,* the earlier it arrives in the cob, the greater the risk of loss not only from the progeny of the initial colonisers but other adult beetles attracted to existing infestations. To avoid pre-harvest infestation and severe *P. truncatus* damage to stores very early in the storage season farmers should harvest maize cobs soon after maturity. Farmer practices such as selection of uninfested cobs for storage (although very tedious) should be encouraged, especially where no insecticides are used or targeted treatment is planned. Farmers who adopt targeted treatment should adhere to initial store hygiene and remove all potential pest reservoirs. In the Volta Region of Ghana, farmer practices are such that cob maize is removed from the top of barns for meals or sale as the storage season progresses (Magrath *et al*., 1996). For such farmers, bottom treatment would still have been useful since consumption from the top would have reduced losses while the bottom remained relatively unaffected.

General conclusions on targeted treatment of maize cobs

In the absence of pre-harvest infestation, targeted treatment appears to offer a good degree of protection. It is an effective pest control option, especially for farmers who cannot treat the whole barn. Targeted treatment is also advantageous because it is an environmentally friendly method using only a minimal quantity of chemical. This work has shown that applying insecticide to the bottom layers of the barn is the best option since insects (*S. zeamais* and *P. truncatus*) tend to migrate to the bottom layers when they infest a store (Hodges *et al*., 1998). Results achieved when using targeted treatment can be even better if a plastic sheet is included. This technique is already well known by farmers, consequently it should be easy to encourage more frequent use as a component of a strategy to reduce storage losses.

Experiments to determine whether targeting zones other than the bottom might be effective were inconclusive since the levels of infestation were too low. *P. truncatus* trap catch from five Hohoe villages (40 km north east of Kpeve) (Fig. 5.15) collected over the same period when trials were running were relatively low, explaining the low rates of infestation in stores. Numbers of *P. truncatus* flying at the time were presumably too low to ensure that the maize stores became infested hence there were no significant differences between different zones in the stores.

Pre-harvest infestation appears to have a detrimental effect on the efficacy of target treatment and would preclude its use in situations where there are significant pest numbers at the time stock is placed in store. However, if grain stocks are to be consumed during the storage period, starting as usual from the top, then targeted treatment could prove beneficial. In order to test whether farmers can gain benefit from the targeted treatment, with or without preharvest infestation and with or without consumption during the storage period, a simple financial analysis was undertaken using the following assumptions. At the end of a six-month storage period the losses in barns with no preharvest infestation and a full or bottom-only insecticide treatment would amount to 1.5% and 4% respectively. In the case of a barn with the targeted treatment and a preharvest infestation, the loss would amount to 6%. To test for the effect of consumption on losses it was assumed that farmers would remove 10% of their stock each month and that during the first three months there would be no noticeable losses. Thereafter, if there was no pre-harvest infestation losses in the untreated grain would rise at the rate of 1.5%/month (i.e. after 6 months losses would total 4.5% of what untreated stock remained) while the treated stock at the bottom of the store would only have lost 1.5% in this period. Based on these assumptions the total weight loss for a bottom treated store with no preharvest infestation and 10% consumption per month would be 2.1%.

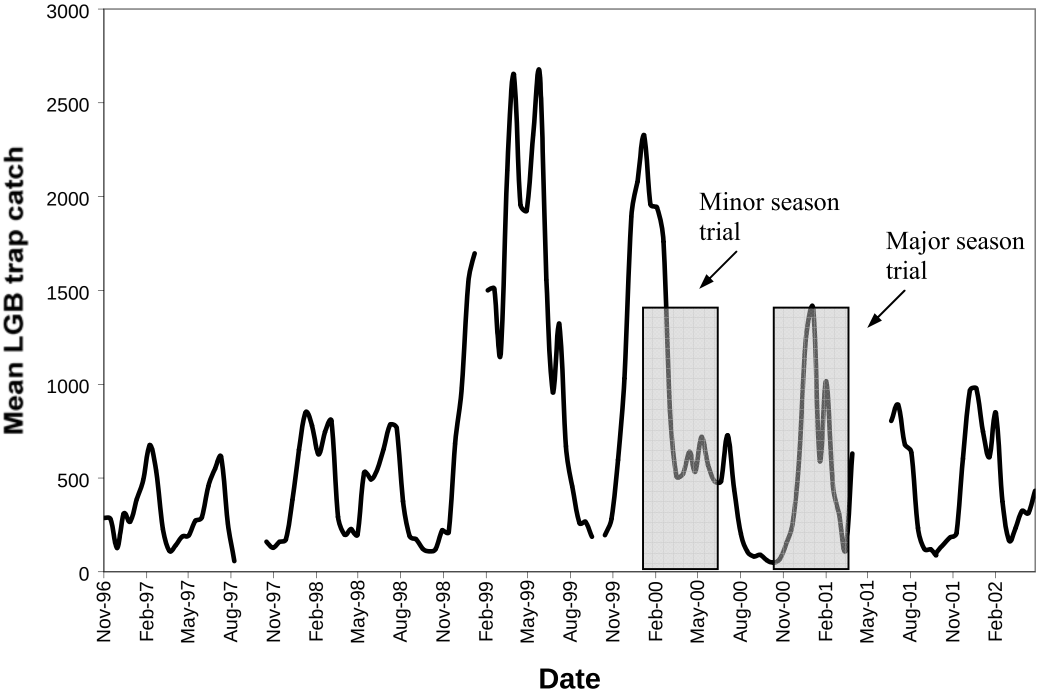


Figure 5.15: Mean trap catch (mean of twenty traps) of* P. truncatus *in five villages close to Hohoe, showing flight activities during the trial periods at Kpeve

For bottom-treated stores with a pre-harvest infestation it was assumed that losses would become apparent after the second month and rise at 1.5%/month so that any untreated stock remaining after 6 months would have lost 6% in weight. Based on these assumptions the total weight loss for such a store would be 4.5%. The cost of insecticide treatment is assumed to be Gh¢50/kg. This amounts to 7% of the value of a kilogram of maize at it lowest price (Gh¢700). Without any treatment, losses in a bad year can be expected to amount to at least 15%, so there is clearly an advantage in using some treatment when stock is at risk provided that the price of maize does not fall below Gh¢333/kg (i.e. this is the point when the cost of treatment is 15% of the price of maize).

The financial analysis was undertake to compare the total costs of treatment, which is cost of insecticide plus the value of any losses that might occur, with a range of possible maize prices. This is particularly pertinent for farmers who would have to buy maize on the market if they lose some of their stock due to insect infestation. They have to weigh up the value of maize saved from insect attack against the cost of insecticide treatment. Clearly, the use of treatment becomes increasingly favourable as the cost of treatment becomes a smaller proportion of the price of maize. This analysis is much less useful to farmers who want to sell their grain since the appearance of damaged grain rather than weight loss *per se* is the critical issue (Compton *et al.*, 1998).

The results of the analysis are shown in Figure 5.16. It is clear that if there is significant pre-harvest infestation and no consumption during storage then full treatment would have to be recommended. However, if there is consumption of the stock then even when there is some preharvest infestation, targeted treatment could be a preferred option. The most favourable outcome would be where there is a targeted treatment, little or no preharvest infestation and some consumption during storage (Fig. 5.16).

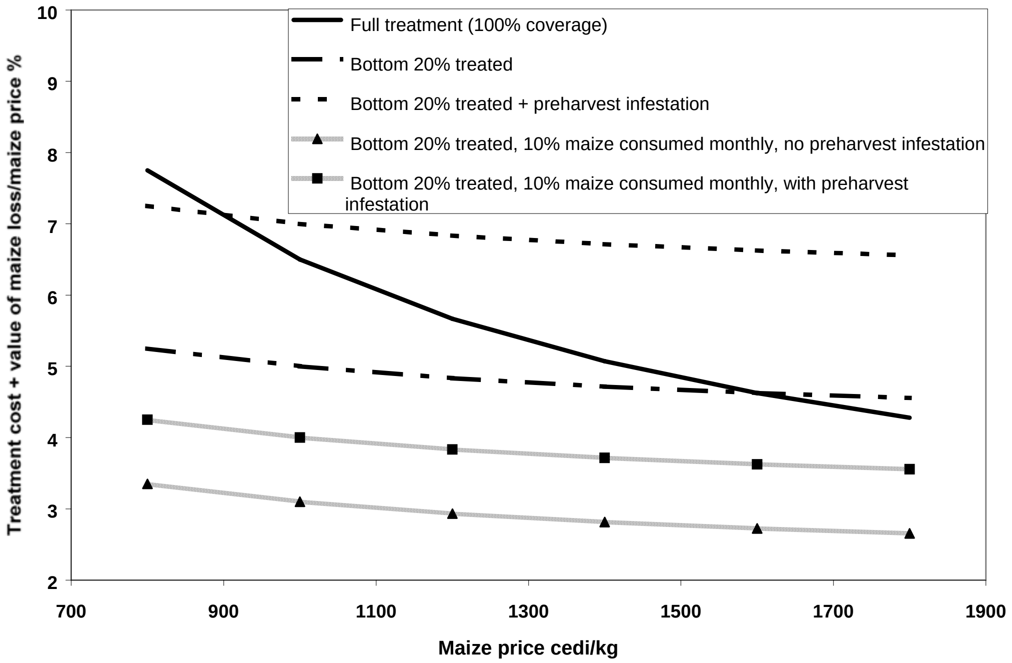


Figure* 5.16*: Changing benefit from different approaches to insecticide application as price of maize varies, based on the following assumptions. Treatment costs Gh¢50/kg, weight losses with no consumption during storage are - full treatment 1.5%, bottom 20% treated and no pre-harvest infestation 4%, bottom 20% treated and pre-harvest infestation 6%. When there is consumption, bottom 20% treated and no pre-harvest infestation 2.1%, bottom 20% treated and pre-harvest infestation 3%

The same type of analysis could be used to investigate the benefits of using a plastic sheet to cover the barn. Here the assumption is that a typical maize barn holds about 500kg of grain and that a plastic sheet of an appropriate size cost Gh¢5000, so that the additional treatment cost is Gh¢10/kg. The performance of treatments with or without sheets and with or without consumption during storage is shown in Figure 5.17. In the scenarios tested, the use of a plastic sheet would seem to be favourable. However, it is not clear what benefit might be gained in cases where there are substantial pre-harvest infestations. It could be assumed that at least the rate of immigration would be slowed so lowering losses but this would be a suitable subject for further research.

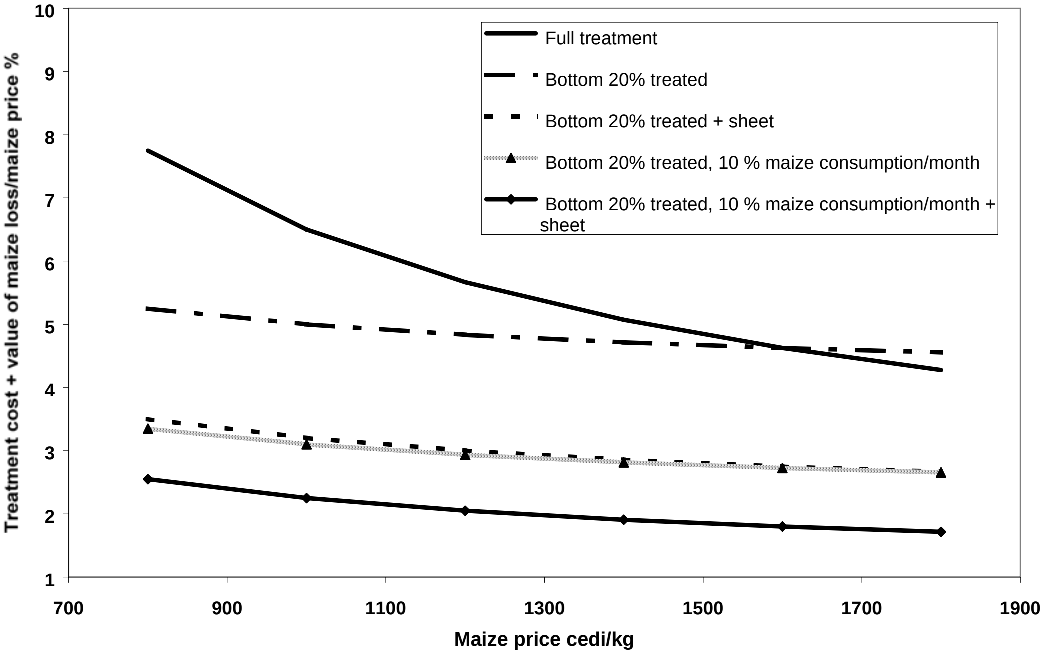


Figure 5.17: Changing benefit from different approaches to insecticide application, and the use of a plastic cover sheet, as the price of maize varies. This is based on the following assumptions, a treatment cost of Gh¢50/kg and Gh¢10/kg for the plastic sheet. Weight losses with no consumption during storage were - full treatment 1.5%, bottom 20% treated 4% loss, bottom 20% treated and sheet cover 2% loss. With consumption of the stock at 10%/month bottom 20% treated 2.1% loss, bottom 20% treated and covered with a sheet 1.05% loss.

Whilst advising farmers on targeted treatment, two issues are of particular importance especially if the storage period is to be of six months or more, first whether or not here is a pre-harvest infestation and second the consumption pattern of maize by the farmer and his household. Bottom treatment only is advisable for farmers who consume maize from the top of the barns during the storage season, but for farmers who keep the barn intact, it would appear to be a safer option to treat the whole barn. Farmers in Volta Region, Ghana, usually have field infestation of their cob maize especially from *S. zeamais*. A common practice of farmers in this part of eastern Ghana is the building of two barns; one for food and the other for future sales when maize prices are highest. The food barn is also for small sales to buy daily household items and usually do not last the whole storage season. These types of barns could have a bottom treatment only. The maize for sale is usually kept in store for up to 8 months and disposed of when there is a favourable market price. Such barns should have complete treatment. Equally, maize suspected to have *P. truncatus* field infestation should have complete treatment to reduce losses as it has been observed that it is mostly *P. truncatus* and not *S. zeamais* that is responsible for the serious damage to stored maize.

The observations made here are based on on-station trials. It is important to determine whether farmers themselves can implement the method and grain benefit from its use. The extension of the targeted trial using farmer participatory methods forms the bulk of the next chapter where on-farm studies in rural maize stores in the Hohoe and Jasikan Districts of eastern Ghana are reported.

ZIMBABWE TRIALS

Methods

An eight-month trial was undertaken at the Institute of Agricultural Engineering in Harare, from July 2000 to February 2001. Four brick-built farm stores with thatched roofs were used. Each store had six compartments, measuring 2 m deep and 0.56 m square in cross section. The compartments were arranged in two rows of three separated by a 1.5 m-wide gangway. The inner surfaces of the stores were lined with cow dung 10 days before the start of the trial.

For the trial, 7 tonnes of white, dent, hybrid maize, from the 1999 harvest, was purchased from the Zimbabwe Grain Marketing Board. This grain was fumigated with phosphine for seven days under gas-tight sheet using two 3 g tablets of phostoxin/tonne then emptied from sacks and thoroughly mixed before allocation to each barn. Five samples of 0.5 kg were taken from these allocations for laboratory analysis and each divided into two using a riffle divider. Weight loss due to insect damage in these sub-samples was determined by count and weigh method (Adams and Schulten, 1978). When insect damage was slight, occasionally the loss values were negative. In these cases the loss was recorded as zero. Sub-samples of 30 g were taken from four of the samples for moisture content determination by placing the grain in an oven at 105°C for 16 h. This technique is adequate for a rough estimate of moisture content but may not be as accurate as the ISO standard method.

Each compartment of a barn was filled with 300 kg of grain (giving a grain depth of about 106 cm). Each of the treatments listed below was applied once in each of the four barns giving a total of four replicates for each treatment. When half the grain had been loaded into a compartment, ten 2-week old adult *Sitophilus zeamais* Motschulsky were added to simulate pre-harvest infestation.

Pesticide	Extent of treatment
1. Control	no treatment
2. Actellic Super dust	all grain treated
3. Protect-it	all grain treated
4. Actellic Super	top 10% and bottom 20%
5. Protect-it	top 10% and bottom 20%
6. Actellic Super	bottom 20%

Treatments were allocated to the compartments in each barn so that no treatment was next to or opposite another on more than one occasion. The Actellic Super dilute dust formulation (active ingredient confirmed at NRI by GC/analysis 1.62% pirimiphos methyl, 0.31% permethrin) was admixed at the manufacturer's recommended rate of 0.5 g dust/kg grain. The diatomaceous earth ('Protect-it') was admixed at 1g dust/kg grain.

At the end of the trial, the grain in each compartment was sampled using a 1.25 m brass compartmentalised sampling spear. The spear had three compartments which when inserted into the grain would extract a sample at the bottom (4.5 cm - 26 cm) middle (44 cm - 66 cm) and top (84 cm - 106 cm) layer of each barn compartment. The spear was inserted at nine equally spaced points across the surface of each compartment, giving a bulked sample of about 900g for each of the three layers. The samples were returned to the laboratory where they were weighed and then sifted for insects that were then identified and counted. The maize samples were subdivided to give two 250 g sub-samples from which weight loss due to insect damage were determined as before using count and weigh analysis. On the surface of each compartment there was a considerable amount of rodent-damaged grain. This was recognisable by the neat removal of the germ compared with insect-damaged germ that was irregularly bored and contaminated with frass. The rodent-damaged grains were subject to a separate count and weigh analysis. A separate sample, using the sampling spear, was taken from the centre of each compartment for grain moisture analysis.

Statistical analysis

Differences in weight loss according to treatment and position within the grain bulk (top, middle and bottom) were investigated by two-way analysis of variance, using a Generalised Linear Model (SPSS statistical package). The percentage data were subjected to an arcsin transformation prior to analysis so that they would meet assumptions of normality underlying analysis of variance. The standard error of the difference (SED) between two means was calculated in order to compare treatments; where the difference between two means was at least twice the SED then the means are considered to be significantly different at the 5% level ($p \leq 0.5$).

Results

At the time of loading no live insects were observed except for the *S. zeamais* that were seeded in the middle of the grain bulks. The average grain moisture content (± se) was 11.4% ± 0.98 and the mean grain weight loss (± se) was 0.05%± 0.01. After eight months storage the mean moisture content (±se) was 11.61% (± 0.09) and infestation by *S. zeamais* was prevalent, especially in the untreated control (Fig. 5.19) where numbers as high as 1000/kg were recorded. Other insect species observed were *Tribolium castaneum* (Herbst) and *Gnatocerus cornutus* (Fabricius) (Fig. 5.20). These were distributed throughout the bulk but at much lower numbers than *S. zeamais.* The moth *Plodia interpunctella* (Hübner) was also observed but confined to only the top layers.

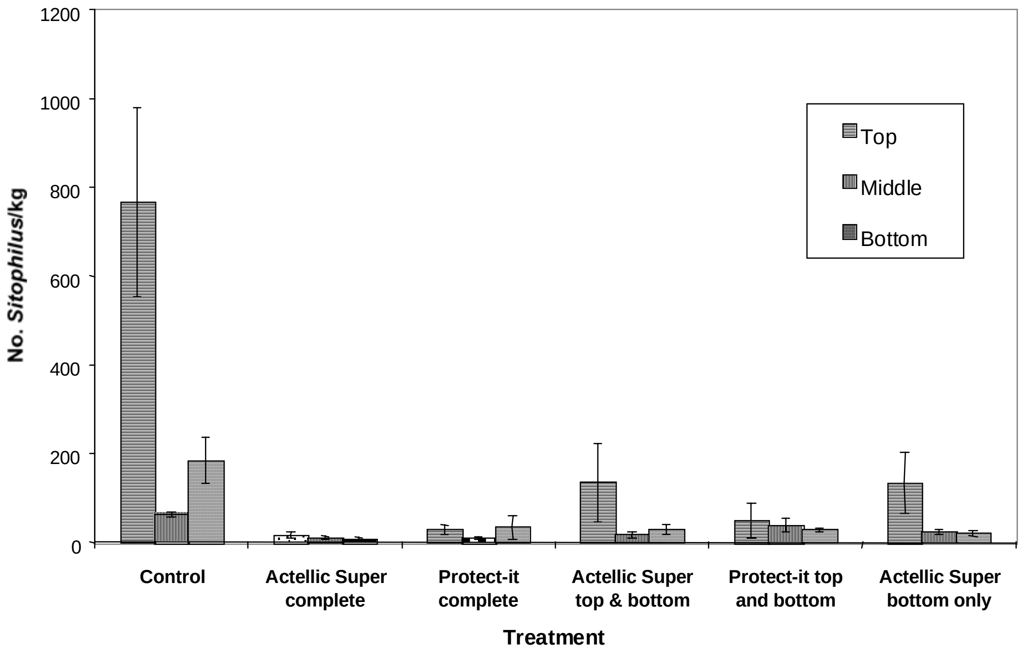


Figure 5.19: Mean numbers of **Sitophilus zeamais*****/kg ± se infesting maize grain at the top, middle or bottom of farm stores given various treatments (n = 4)***

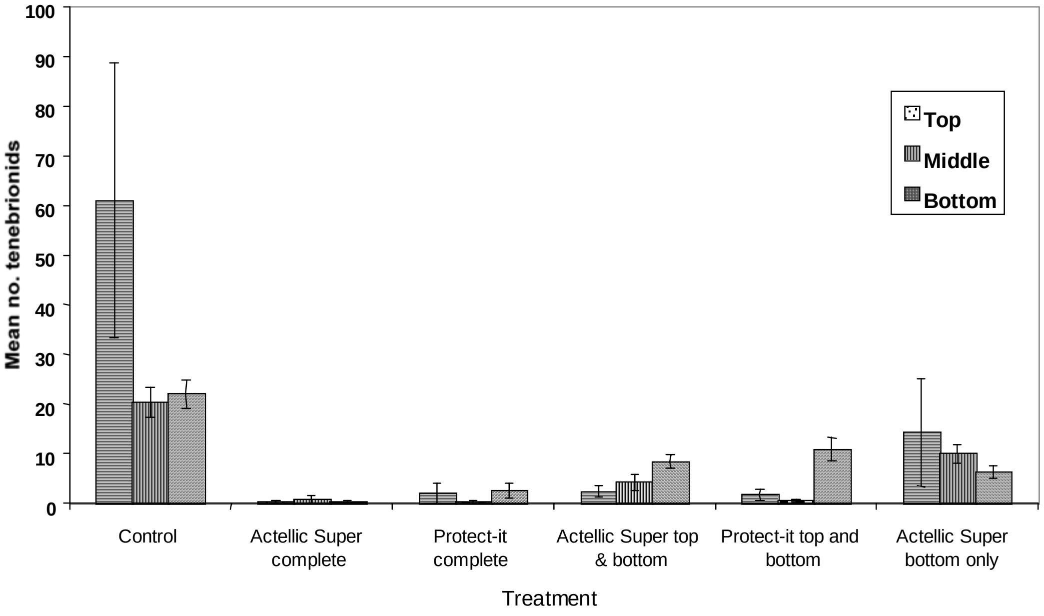


Figure 5.20: Mean numbers of tenebrionids (**Tribolium castaneum and Gnatocerus cornutus*****)/kg ± se infesting maize grain at the top, middle or bottom of farm stores given various treatments (n = 4)***

After eight months storage, weight losses and grain damage in untreated grain were much higher than in grain receiving any of the treatments (Table 5.5) and there was strong evidence that treatments limited the degree of loss ($F_{5,54} = 20.64$, $p<0.001$) and grain damage ($F_{5,54} = 38.29$, $p<0.0001$). All treatments were statistically significantly better than no treatment. There was a trend for losses to rise as the treatments became more reduced although the differences in weight loss and grain damage between complete treatment and the most reduced treatment was only 0.7% and 6.2% respectively.

Table 5.5: Mean % weight loss and % grain damage (transformed values in brackets) due to insect attack in farm stored maize grain given various pesticide treatments and stored for eight months

Treatment		Mean % weight loss ± se	Mean % grain damage
Control	no treatment	3.70 ± 1.5 (10.09)	21.07 ± 4.46 (27.27)
Actellic super	complete treatment	0.07 ± 0.04 (1.20)	1.23 ± 0.45 (5.70)
Protect-it	complete treatment	0.27 ± 0.14 (2.62)	2.66 ± 1.07 (8.83)
Actellic Super	top 10% bottom 20%	0.20 ± 0.11 (1.81)	3.40 ± 0.71 (10.08)
Protect it	top 10% bottom 20%	0.87 ± 0.34 (4.74)	5.37 ± 1.35 (12.61)
Actellic super	bottom 20%	0.83 ± 0.39 (4.15)	7.43 ± 1.63 (15.25)

SED between any two transformed means -weight loss = 0.29 -grain damage = 0.5

Position of grain in the bulk had a significant affect on both the degree of weight loss bulk ($F_{2,54} = 6.16$ $p<0.004$) (Fig. 5.21) and % grain damage ($F_{2,54} = 10.53$ $p<0.0001$). The middle layer had significantly lower losses than top or bottom layer (Table 5.6) and there was a significant interaction between treatment and position ($F_{10,54} = 2.05$, $p<0.045$). This pattern of loss was generally similar to the observed distribution of insects, especially of *S. zeamais* (Fig. 5.19).

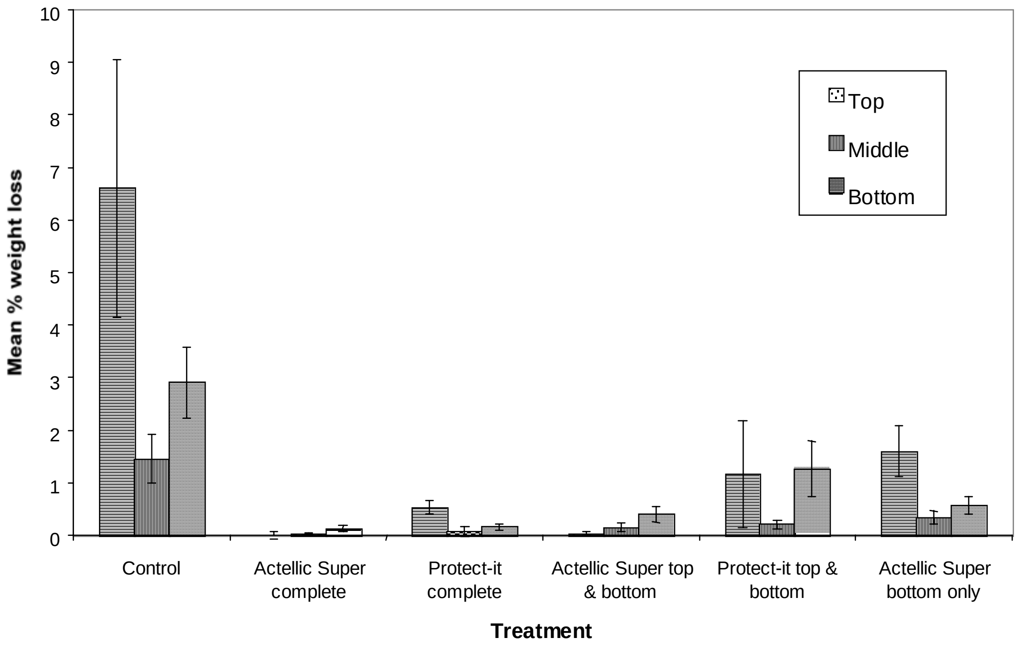


Figure 5.21: Mean % weight loss of maize grain at the top, middle and bottom of farm stores given various treatment (n = 4)

Table 5.6: Mean % weight loss and % grain damage (transformed values in brackets) at the top, middle or bottom of farm stored maize bulks given various treatments, due to insect attack

Position in bulk	Mean % weight loss	Mean % grain damage
Top	1.66 ± 1.02 (5.13)	9.38 ± 2.33 (15.68)
Middle	0.38 ± 0.22 (2.71)	4.17 ± 1.02 (10.20)
Bottom	0.90 ± 0.43 (4.46)	7.43 ± 1.70 (14.01)

SED between any two transformed means -weight loss = 0.25 -grain damage = 0.15

Rodent damage was prevalent on the top layer of the grain (Fig. 5.22). It was surprising to find that the extent of damage followed the same pattern of insect damage (Fig. 5.21) and it is not clear why this should be the case. It is possible that rodents may have been more attracted to the insect infested grain hence the more effective the pesticide treatment the less attractive the grain will have been to rodents.

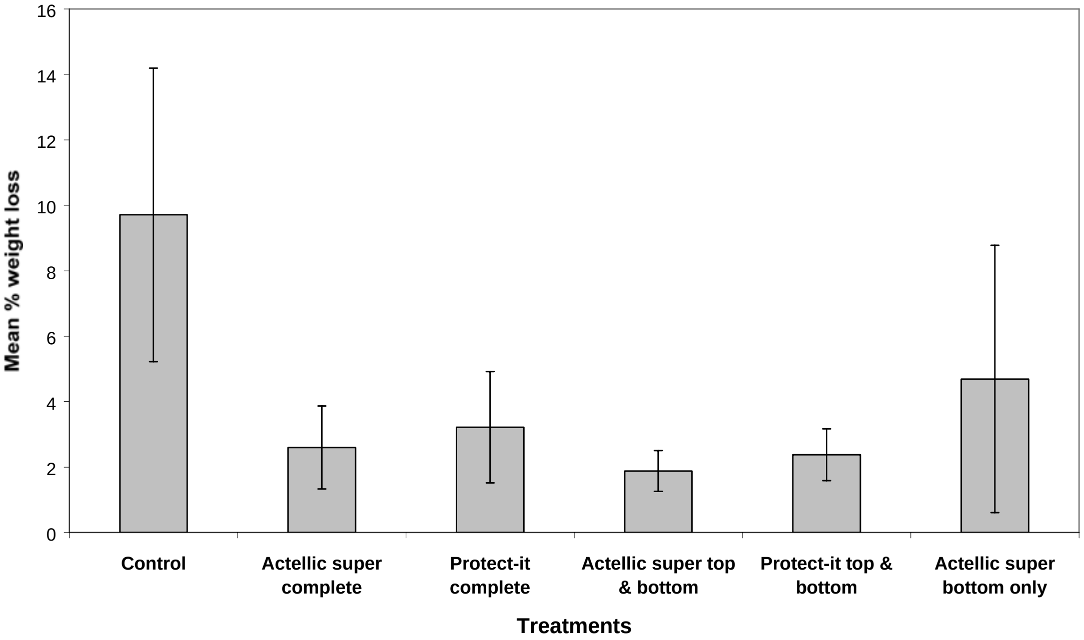


Figure 5.22: Mean % weight loss from maize grain due to rodent attack in the top 20% of grain stored in farm granaries for eight months and given various treatments (n = 4)

Conclusions for the storage of maize grain in bins

All the partial treatments used in this trial resulted in good protection of stored grain and all were statistically significantly better than the storage of untreated grain. Under the prevailing conditions of Harare, there was little or no difference in the degree of protection provided by a complete treatment of Actellic Super or the inert dust Protect-it. When pesticide applications were reduced by 70%, top and bottom only treatments of Actellic Super or Protect-it, both gave good protection. However, the overall trend was for Actellic Super to give slightly better results. The weight loss associated with the full Actellic Super treatment was only 1.8% of that experienced by untreated grain, this rose to 5.4% with the 70% reduction in treatment and to 22% with the 80% reduction.

On the basis of field observations and some laboratory investigations, it has been proposed (Hodges *et al.*, 1998) that the efficacy of bottom-only treatments results from the tendency of the initial colonising insects to migrate downwards and die in contact with the treated layer. As Actellic Super has been the pesticide used in all the previous tests, it has remained a possibility that vapour action from the pirimiphos methyl component might be repelling or killing insects at a distance from the treated layer. However, the good performance of Protect-it in this trial, which can have no vapour effect, suggests that downward migration of colonisers is indeed the most likely explanation. The middle layer of grain was the least affected by insect infestation despite the fact that this was the location used for seeding the bulks with *S. zeamais*. A possible explanation for the observed distribution is that the seeded insects migrated downwards and that a later generation of insects, subsequently distributing from the bottom, move to be as far away as possible, i.e. to the top, and may well have been joined there by insects migrating into the store.

If farmers are to adopt a partial pesticide treatment then the options are a top and bottom or bottom-only treatment. If they sell or consume the top layers of grain soon after storage then the bottom only option would seem most appropriate although a top treatment could be added in due course. For long periods of undisturbed storage the top and bottom option may offer the best results. Maximum benefit from the reduced pesticide method will be obtained by those farmers who previously had no protection for their grain because they could not afford the treatment. For those farmers who can afford the full treatment the benefits, aside from the health and environmental considerations, will be in proportion to the ratio between the cost of treatment and the price of maize. This relationship has to take into account the small additional losses that will result if a reduced treatment is adopted. Typical weight losses from untreated grain due to insect attack during storage would be 5% and if this is taken as the norm then losses associated with reduced treatment, observed in the current trial, become 0.3% for top and bottom and 1.12% for bottom-only. If these are the expected losses and it is assumed a full treatment costs 0.195 Zim$/kg, then there is a clear financial benefit even if maize prices rise to 9 Zim$/kg (Fig. 5). This relationship is probably reasonably reliable when farmers are consuming their own grain and the reduction in losses helps them avoid having to make maize purchases. For farmers who sell grain it is much less certain since the relationship between grain damage, rather than weight loss, and market value is not known.

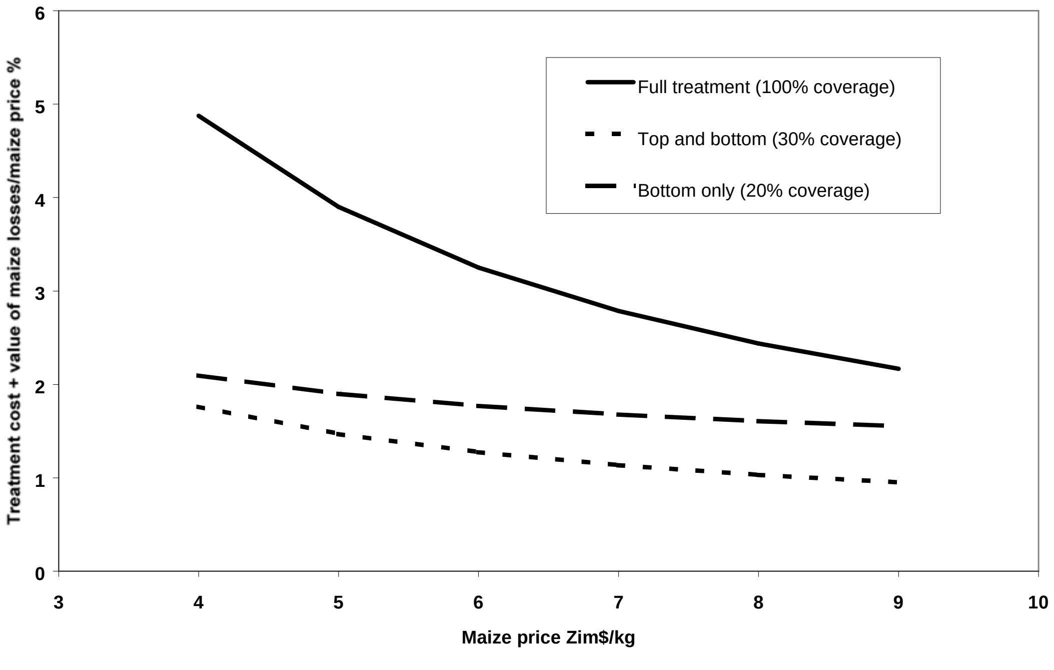


Figure 5.23: Changing benefit from different approaches to insecticide application as price of maize varies (assuming treatment cost of 0.195 Zim$/kg, and the following weight losses - no treatment 5%, top and bottom 0.3%, bottom-only 1.2%)

6. Farmer participatory research and stakeholder responses to targeted treatment

Addo S.

Introduction

To test farmers responses to targeted pesticide treatment, on-farm trials were undertake in 2001. It was considered that these participatory trials would empower farmers to test, develop and adopt their own findings and also help other farmer by encouraging farmer-to-farmer and village-to-village spread of knowledge. In this study, twenty farmers from four villages participated in on-farm targeted application of insecticide to their cob maize barns.

Besides accruing the advantages of farmer participatory trials listed above, there were objectives to

- assess the efficacy of the targeted methods when used by farmers to treat their own barns
- develop the most effective application/ management methods
- determine which issues may need to be stressed in any promotional material/assistance
- identify constraints to the farmer during the uptake of this package.

To further inform the process of disseminating the targeted treatment technology and obtain feedback from a broader range of stakeholders than just farmers, a stakeholder meeting was held. The main objectives of the stakeholder meeting was to -

- assess the wider acceptability of the targeted maize treatment and
- identify some of the constraints in its promotion,

FARMER PARTICIPATORY RESEARCH

Methods

Village selection

Farmers were selected from each of four villages in the Hohoe and Jasikan districts of the Volta Region for the participatory trial. These villages are in the transition zone between forest and woodland savannah and their selection also took into account their relative accessibility from Hohoe township. Another factor for the village selection was that they produced a sizeable quantity of maize, which could last for at least six months. The villages were also chosen because there had been previous research work in them so it was assumed that the farmers would be willing to work with the project. The villages selected are shown in Table 6.1.

Table 6.1: Farmer on-farm trial villages and number of farmers in each village.

Village	Number of farmers
Hloma	5
Amle	5
Chebi	5
Dzolu	5

Barn owner selection

The responsibility for the selection of participatory farmers was delegated to the local 'opinion leader' such as assemblymen or women, teachers, local village spokesperson (village secretary) or chief farmer. In Hloma, the village secretary and in Amle, an assemblywoman selected farmers. In Chebi, a chief farmer, who was also a clan chief selected participants for the trial. In Dzolu the Agricultural Extension agent made the selection. In the selection of the farmers the guiding principles were to

- give opportunity to two female farmers in each village
- have farmers with a range of different sized land holdings
- ensure that Ewe barns stores would be available for five months and ready at the time the trial is to start
- have farmers who would be willing to provide workforce for stacking the maize cobs

Villages contain a series of family groups, participants in the trial were chosen to be from different groups. The selectors picked more than needed, but those who weren't going to engage in long-term storage or who would shell their cobs and treat the grain were excluded. Few women were used because those owning barns often did not have husbands and were not able to have barns ready when the trial was set up. In households where there is a man and a woman the man is responsible for barn building and stacking. A good range of barn sizes were included in the trial. Very few farmers were smoking their maize; this contrasts with many other villages in southern Volta Region where building a cooking fire beneath the barn is common practice.

Timing of trial

The trial was timed to coincide with the loading of stores with maize from the minor harvest, which is usually at the end of December or January of the following year. The minor season was chosen because the storage period is usually longer as the maize coming from the field is very dry. The longer storage period increases the likelihood that barns will sustain *P. truncatus* damage.

Barn characteristics

The following information was collected at the start of the trial about the barns that were treated:

1. Roofing material (e.g. thatch or metal sheeting)
2. Store wood (new or old?) (What type e.g. bamboo?)
3. Moisture content of maize as loaded.

4. Diameter of stack
5. Height above ground
6. Whether or not there was a fireplace under the stack
7. Number of cobs around the circumference
8. Total number of layers up
9. Number of layers that were treated
10. Presence of *Dinoderus* spp and/or *P. truncatus* in the platform wood

Treatment of barns in villages

Hloma, Amle and Chebi villages were treated on the 22-23 of January 2001 whilst Dzolu village was treated on the 5-6 of February 2001.

Insecticide treatment of cobs

The emulsion used for the earlier on-station trials at Kpeve was applied at the dosage rate recommended by the manufacturer for the treatment of store surfaces. This is approximately 100 times the rate recommended for admixture to grain. It could be argued that an application of EC to the maize cob is a surface treatment with little EC ending up in the grain. However, one cannot be 100 percent sure of this (pesticide may migrate through the husk layers). In the Kpeve trial, a dust formulation of Actellic Super was also used. Since there was no recommended rate for surfaces, approximately that recommended for admixture was used. The dust treatments did not perform quite as well as the EC, but generally much better than the controls. It was therefore proposed that a concentration of diluted EC that would give a dose comparable to the recommended rate for admixture should be used. Even this posed a dilemma as to whether it should be per weight of grain or weight of whole cob. It was finally decided that 5ml of EC would be diluted in two litres of water and applied to 6kg of cobs (approx. 75 cobs or a large basketful). Cob weight was used here, as previously for the dilute dust, to calculate the application rate. For each farmer, a third of the barn was treated with the Actellic Super formulation.

After treatment a sample of the Actellic Super EC was taken to Natural Resources Institute (NRI), Chatham, for GC analysis. The concentration of the active ingredients was found to be four times those indicated by the recommendations on the packaging. The producers of this chemical were immediately informed and action was taken to re-label this stock. This means that village treatments had four times the intended concentration of active ingredients. However, the treatment rate was still much lower than the normal surface application, by a factor of at least twenty. In view of this low application rate, the efficacy for the insecticide was cross-checked by bioassaying the maize cobs, this is described later.

To treat a typical store required the preparation of 22 litres of emulsion. Of this volume, 2-4 litres drained into the metal bowl beneath the baskets used for application (and were subsequently diluted and disposed of in the bush far from the household). An estimated 1-2 litres of the emulsion were lost around the edge of the treating baskets and from drips from the basket as it was loaded onto the store.

Initial loss assessment of cobs

Thirty cobs were selected at random from the pile to be stacked by each farmers. These cobs were subjected to rapid loss assessment (Compton and Sherington, 1999).
The following variables were recorded in the field:

- size of cobs (large, medium or small),
- presence of earworm,
- damage class of cobs and
- number of adult *P. truncatus*, *S. zeamais*., *T. nigrescens*, *Dinoderus* spp., *Tribolium* spp., *Cathartus* spp. and *Carpophilus* spp.

Monitoring and P. truncatus activity

Participating farmers were visited every two weeks after the start of the trial.

At each visit, any *P. truncatus* or *Sitophilus* damage or dust on cob was noted. In addition, the total number of layers remaining in each barn was recorded and if layers were removed farmers were asked what they had used this maize for. If farmers were to break down their barns between visits, they were asked to retain forty cobs from the treated and forty cobs from the untreated layers for analysis by the project staff.

End of storage assessment (project team)

Most barns were broken down after 6 months but four farmers pulled down their barns after four months because of the high price for maize. Cobs were sampled as described below. The stack of cobs was divided into four sections as shown in the diagram.

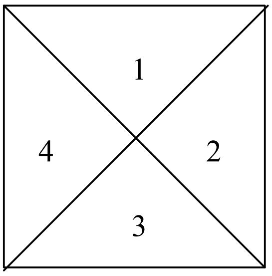


Figure 6.1: Pattern of cob selection from trial barns

Forty cobs were taken from the treated layers (excluding the treated layer adjacent to the untreated layers since this might actually be a mixture of treated and untreated cobs) with ten from each of the four sections, but within this constraint cobs were taken at random throughout the height of the stack. Untreated layers were sampled in the same way as treated, i.e. the layer nearest the treated section was excluded from the sampling. Of the

40 cobs selected, 30 of reasonable size from the treated area and 30 cobs from the untreated area were subjected to rapid loss assessment.

Besides sampling treated barns, about fifty maize cobs were selected from the barns of each of five farmers at Hloma. These cobs were used as a control and also subjected to the same rapid loss assessment method.

Farmer evaluation of trial.

Once the trial had been completed a day was arranged to meet with farmers. The meetings were held with farmers to assess the effectiveness of the targeted treatment and to identify constraints and ways of improving and sustaining this method. The maize cobs collected from farmer barns at the end of the trial were shelled separately and put in a sealed transparent polyethylene bags. These small bags were labelled and presented to farmers for ranking using the form shown in Appendix 2. Reasons for ranking were recorded and additional questions posed to explore farmers' views of the targeted treatment.

Assessment of insecticide residue efficacy by bioassay

The insecticide dosage used was considerably lower than that recommended by the insecticide manufacturer and determined by the safety considerations mentioned earlier. It was thus necessary to check on the efficacy of the treatment by bioassaying some cobs removed from barns after storage.

Cobs were obtained as follows :

1. After four months storage, treated cobs were collected in Hloma, Amle and Chebi villages. Four cobs were taken at random from the outside of the barns from ten of the twelve participating farmers and this sample was bulked. Twelve cobs were then selected randomly from this sample. The same procedure was repeated with cobs from five barns in Dzolu. However, these cobs were handled and tested separately from the other villages since they had been treated with insecticide two week later.
2. For the control, untreated local variety maize cobs were collected in Fodome in November 2000.

Each replicate consisted of three cobs tied together with string and placed in a wooded box (33cm x 33 cm x 33cm) lined with a fine wire mesh to prevent *P. truncatus* boring into the wood. Four replicates were prepared of the treated and untreated cobs. The boxes were placed on a shelf in one row with random ordering of treatments in the laboratory at the Ministry of Food and Agriculture in Ho.

Fifty *P. truncatus,* were introduced into each box in a Petri dish lined with brown paper, this allowed *P. truncatus* to walk easily in the dish. The unsexed adult *P. truncatus* were approximately one to three weeks old and taken from stock cultures initiated fifty days earlier with 100 insects trapped in Ho.

There was a daily count of how many *P. truncatus* remained in the Petri dish. By day three, approximately 5% insects remained in the dish so the cobs were sampled.
For each box the following variables were recorded:

- Number of dead and number of dead *P. truncatus* in the cobs
- Number of live and number of dead *P. truncatus* in the box

Results

Barn owners
Three of 43 original barn owners were women. All barn owners were over 30 years old. Only three of the participants had sources of income other than farming e.g. teachers in the village. All others were subsistence farmers. In Amle and Hloma most participants had more than one barn in the household but other barns may be responsibility of others in the household. At the start of the trial most farmers were not selling maize. Most farmers would sell small amounts of maize to buy other foodstuffs e.g. fish, salt and may be soap. All barn owners were storing local varieties of maize except for one individual who was storing an improved variety.

Most farmers were also growing cassava and plantain, which are preferred for fufu (made from pounding boiled cassava or plantain into sticky paste) preparation, but during the lean season when the cassava is not boiling soft then *kenkey* is prepared (a local porridge prepared from fermented maize dough). In all participating households there were more than five dependants on the maize and a maximum ten, mostly five or six dependants. Most of the participants would not use conventional chemical pesticides on their maize, usually nothing at all, although in this season one farmer was using neem leaves.

Loss Assessment of farmer barns
Weight losses of farmer cobs at the start and end of the trial indicate that untreated cobs have higher damage levels than the baseline or the treated cobs (Fig. 6.2). This is considerably greater than the damage experienced by farmers who did not take part in the trials. This supports the idea that targeted treatment although not quite as good as full treatment is similarly effective and its adoption by the subsistence farmer would lower damage at the end of the storage season.

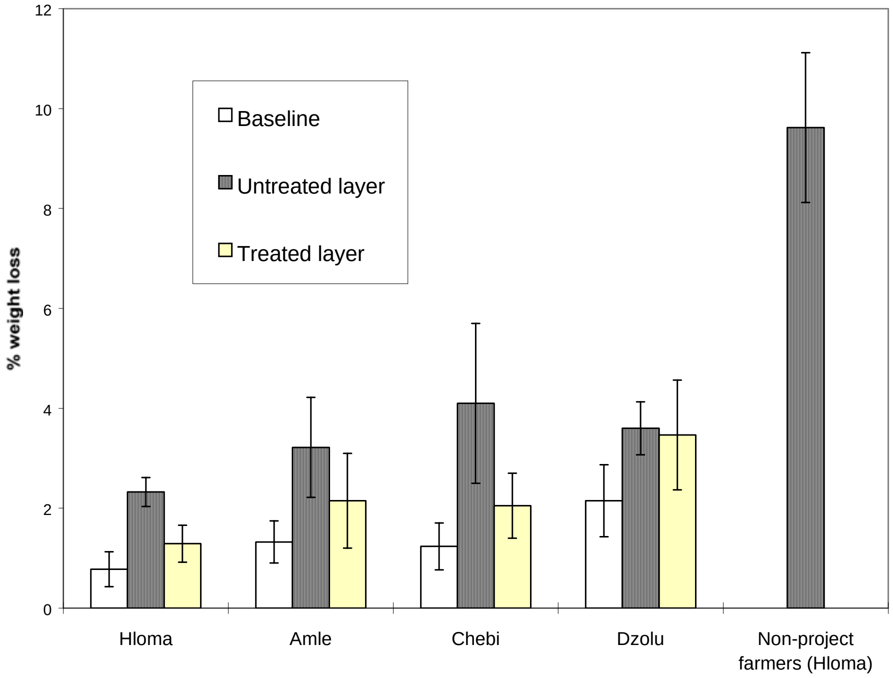


Figure 6.2: % Mean grain weight loss (+sem) from maize barns in 4 villages, showing baseline assessment and losses from treated and untreated portions of the barns after 6 months storage (4 months storage in the case of four barns). Also shown are losses from untreated (control) barns. (n= 5)

Monitoring and P. truncatus activity

Very little damage was observed in treated barns throughout the trial. In only one case was *P. truncatus* damage seen, it was in the treated layer first observed four weeks after loading. Two cobs had *P. truncatus* holes, but when these were withdrawn and observed, only dead *P. truncatus* adults (approximately 20) were seen in between the cob sheathing leaves.

Assessment of insecticide residue efficacy

By the third day of the trial to test insecticide efficacy, all *P. truncatus* in the boxes with maize cobs treated with insecticide were dead, while about 98% of the *P. truncatus* in the untreated boxes were alive. This shows that even after four months of maize cob storage the insecticide applied o cob surfaces was still potent.

Farmer evaluation of on-farm trial.

Three farmer assessment meetings were held. In all there were a total of 66 respondents (18 females, 48 males). Although meetings were at three different places on different occasions, 90% of farmers ranked shelled grains from the treated area of the stores as belonging to the best three quality categories. All the farmers suggested that maize in these categories would fetch a higher market price and could be used as seed maize. Their criteria for selecting the best shelled maize was based upon the number of insect holes present, level of dust present in grain and the level of mouldiness of the grain. Grains from the untreated areas had a lot of insect holes, dust and insects and were ranked as occupying lower categories. These maize characteristics agree with assessment made earlier by a maize trader panel (Compton *et al.*, 1998) where damage was related to lower acceptability.

Almost all the farmers stated that husk from their stores were burnt while the cobs were used to kindle fire or used as a toilet facility. A few however used the husk to wrap *kenkey*. On the ways in which the trial could be improved, farmers who said they could afford insecticide suggested treating the whole barn and those who could not afford it were satisfied with the low damage levels provided by the targeted treatment. Some farmers suggested covering the outside of barns with plastic sheet as a barrier to in-coming insects. Plastic sheet cover tested in an earlier targeted trial gave an added advantage but was not included in this farmer trial.

On ways to ensure safety during chemical treatment of stores, farmers came up with the following:

- Use the approved chemicals and the recommended dosage,
- Treat only maize that is for long-term storage and keep maize for home consumption untreated,
- Wash hands well before eating food or drinking water,
- Wash clothing used during treatment,
- Buy insecticide from the authorized dealers,
- Label insecticides and keep them out of the reach of people especially children.

Discussion

Farmer evaluation of on-farm trial.

Farmers agreed that the targeted treatment is as good as treating the whole barn especially for farmers who could not get money to treat large quantities of commodity. Some of the farmers who were not part of the trial complained that they had higher levels of damage in their stores than those farmers who participated in the trial. However, it is not certain whether this damage occurred during the period of storage or that their cobs were already in a worse state at the start of the storage period, since no loss assessment was made on these stores at the time of stacking. Farmers did not feel the effect of pre-harvest infestation since consumption of the top layers minimised the insect pressure on the lower and treated zones.

Although most farmers said they were happy with the insecticide treatment it is not clear if they could do it on their own or would have to seek the assistance of agricultural extension agents. Also, the treated husks were still potent with chemical and its use in wrapping *kenkey* may affect their health. Farmers who treat undehusked maize cobs should be strictly advised on good disposal methods.

A positive aspect of the trial was that farmers generally did not find a problem with the way insecticide was administered to the cobs in the store since this fitted into the traditional way of sprinkling water onto the cobs to dampen them for stacking. The only constraint for most farmers was the cost of insecticide which are only available in quantities much larger than they need and a reliable source since this is mostly in the hands of private agents. The problem of cost is, at least in part, solved if farmers form small groups and contribute to buy chemicals that they can share.

STAKEHOLDER ANALYSIS

Method

Maize storage

This meeting was attended by three maize sellers, three small-scale pesticide sellers, four Ministry of Food and Agriculture (MoFA) staff, three Larger Grain Borer project staff and nine subsistence maize farmers. The participants were introduced to the day's activities by asking them questions about the type of storage facilities in their locality, how maize cob barns are stacked, the types of insects found in their stores, how they deal with insect damage, insecticides used and how insect damage is prevented.

Demonstration of targeted treatment

Participants were then shown a simulated Ewe store (raised platform type) to illustrate how targeted treatments had been undertaken in on-station trials at Kpeve and on-farm trials in Hohoe and Jasikan districts (refer to details in farmer participatory work). This was followed by question and answer sessions on farmer observations, appraisals and recommendations of the targeted insecticide trials.

Results

Type of storage facilities

Almost all the participants agreed that the raised platform Ewe store is the type of storage facility used. Those who stored as loose grains in sacks at one time had the commodity on the platform. About five percent of farmers (elderly people) who cannot provide platforms store cobs in rooms.

Major insect pests found in maize stores

The participants through description and giving actual local names identified *S. zeamais*, tenebronids and earworms as the major insect pests they come across when dehusking and shelling maize. The maize farmers and maize traders among the group mentioned the *P. truncatus* as another pest, which is more destructive than the usual pests they have mentioned. Participants revealed that due to *P. truncatus* damage to maize it has been given a lot of local names such as 'caterpillar', 'corn miller' and 'molar teeth'.

Infestation in Ewe barns

The farmers among the stakeholders think insect infestations are heaviest at the bottom since that portion of the store stays for a longer period. The maize traders also say they pre-finance cultivation of maize and the maize infestation from the stores the farmers allocate to them starts from the bottom.

Control of maize pests

There were different schools of thought as to what is done to control pests of maize. The maize sellers/traders suggested sifting the damaged grains using baskets or winnow using bowls to remove insects. The farmers were of two categories: the first group include those who do not apply any insecticide but only sun dry their crop and the second are those who consult the Ministry of Food and Agriculture (MoFA) staff for advice.

Insecticides used by participants

Participants mentioned formulations such as Actellic EC, dichloro-diphenyl-trichloroethane (DDT), residue liquid from *akpeteshie* (a local alcoholic beverage), fresh neem leaves, solutions made from neem leaves, and some unidentified cocoa insecticides as preservatives. Some farmers insist on buying insecticides they have heard about from a relative or a fellow farmer (although it was evident that this was not always the recommended insecticide). Insecticides most farmers asked for include Actellic Super, 'Gastoxin' tablets (aluminium phosphide), Dursban and Sumicombi. The insecticide sellers present complained that farmers and traders used any chemical which kills the insects for protecting their maize and most often they had to advise them on what to buy.

Comments on the targeted treatment of maize cob barns

Dzolokpuita experience (by farmers)

Fire under the barn (that is smoking) is not able to control most insects but there should be some amount of smoking to dry the major season maize which comes into the store very wet. The Dzolokpuita farmers are also of the view that neither alcohol residues nor neem concoctions protect the maize against *P. truncatus*. They had a severe *P. truncatus* attack some six years ago and it was only Actellic Super EC that was able to control it. They are happy that the farmer is going to use a smaller quantity of insecticide to treat his barn for almost the same result. This they say has two advantages; less money to spend on insecticides and less insecticide used on food. Most rural farmers are concerned about the health implications of having insecticide on their food.

Trader comments

The maize traders who came had very interesting views about the treated maize that comes to the market. According to the maize traders, the treated grains looked mouldy and buyers complain about their low starch contents. The traders complained that maize shelled, treated and bagged do not appeal to their customers so they always look for farmers who have cob maize to buy. Some maize buyers even smell the grains and refuse to buy if they notice any trace of insecticide on them. They are therefore happy about the targeted treatment of cobs, which will not get to the grains, thus grains are insect-free and clean. Participants suspected that the mouldiness of grain stored in sacks might be due to it becoming dampened during treatment and not drying sufficiently before being placed in sacks.

Farmer from the on-farm trial

A farmer briefed the stakeholders about his personal experience from the targeted insecticide treatment to support the views expressed on protecting maize against *P. truncatus*. He advised other colleagues to embark on the trial owing to the laudable benefits derived by their group in Fodome. The farmer said that at first he thought targeted treatment would not be effective but after 5-6 months of storage his maize was in the same condition as if he had treated the whole barn. He felt that after treatment there should be no fireplace constructed under the platform of the barn since it may weaken the efficacy of the insecticide applied to the maize. He said an earlier experience with *P. truncatus* showed that the more you smoke to dry the cobs the more damage the beetle will do to the maize. This accords with earlier studies that showed similar negative effects in smoked stores (Boxall and Compton, 1996).

Cost and availability of insecticides

Participants (especially the traders and farmers) were happy with the advantages of targeted insecticide treatment but their main concern was the availability of insecticide and its affordability. Their appeal was that MoFA should procure the insecticide for them because the private dealers charged very high prices. Most farmers said they could afford to treat the whole store should prices of insecticides be slightly reduced. The MoFA staff present explained the government's policy of not selling insecticides. However, after a lengthy but fruitful discussion, it was agreed that farmers and traders should work through their local agricultural extension agents (AEAs), who will liase with chemical houses to obtain more favourable prices.

Maize husks and cob cores

A difficult issue was the disposal of maize husks and cob cores. Farmers agreed to treat cobs but at the close of the storage season maize husks are used to rekindle fire or used in wrapping kenkey. The cob cores are used for kindling or as a toilet facility. A farmer complained that even though farmers had been advised to discard the treated husks, one farmer still sold his treated husks which may then have been used as a wrap for kenkey. The participants were however of the view that husks fetched little money and should be destroyed. If husk is needed as a wrapper then large quantities could be stored at the start of the season before the remainder is treated.

Conclusions

The stakeholders agreed that it is a good method that will help the farmers and traders. They said the method would fit into the farmer's traditional method of sprinkling water in-between layers while stacking. They recommend that there should be training for Agricultural Extension Agents who will later train other farmers or opinion leaders in the villages. On what precaution farmer undertaking targeted treatment should take, they came up with the following;

- know the right chemical to use, seek professional advice,
- apply the right quantity of insecticide ; overdosing and under-dosing have their problems,

- store chemical in the right bottle (there was the Dzolokpuita story where DDT was stored in a paracetamol (analgesic) bottle and a child mistook it for a cough syrup,
- insecticides should be well labelled,
- insecticides should not be kept in rooms and places where children can reach them.
- people should not eat, drink or smoke when using insecticides, and
- wash hands, clothes and instruments used for treatment.

Technologies work best when stakeholder experiences and traditional ethics are discussed. These advantages came out clearly during the stakeholder meeting especially when it came to insecticide usage on cobs, effective way of treating maize barn, and what to do after using pesticide. Also farmer and trader understanding of the health hazards posed to them when using treated maize husks would help in the dissemination of the targeted methodology. The stakeholder meeting afforded the participants to establish organisational linkages. The lack of a close working relationship between national agricultural research and extension organisations, and with different categories of farmers and farm organisations, is one of the most difficult institutional problems confronting ministries of agriculture in many developing nations. Farmers know where and how to get their insecticides cheaper for trials, the extension would be part of the sustenance of the trial and the policy makers represented by the Ministry of Food and Agriculture are aware of a new technology. The Ministry of Food and Agriculture can now incorporate the targeted treatment into their basket of control options and even involve in other adaptive trials for other commodities and storage forms. The researcher after the stakeholder meeting is now adequately informed about constraints and other cultural practices that can be put into other modifications on targeted treatment.

Research Activities associated with output 3

Output 3 - The impact of Tn reinterpreted in the light of increased understanding of relationship with LGB
OVI - Further, Tn releases continue and backed-up with improved evidence of efficacy by 2002.

7. Understanding the impact of *Teretrius nigrescens* (Tn) on LGB

Birkinshaw L.A.

Two areas of work were proposed under this heading:.

1. Assessment of the potential ability of male LGB to prevent attack from Tn in plant hosts larger than maize grains.
2. Interpretation of the short-term correlation between Tn and LGB changes in trap catch.

Here we report exclusively on point one. Work undertaken to address point two was unsuccessful. The dispersal rates of Tn and LGB from an experimental system designed to distinguish between internal (e.g. crowding) and external (e.g. climate) factors was too low to gain meaningful data.

Assessment of the potential ability of male LGB to prevent attack from Tn in plant hosts larger than maize grains

Summary

We hypothesised that Larger Grain Borer males may be able prevent predation from the histerid beetle *Teretrius nigrescens,* in plant hosts that are large enough for the LGB to construct a guardable tunnel-system.

The presence of males was found to increase the net number of offspring produced in three weeks by fertilised females, both in the presence and absence of predators. The introduction of predators did, however, significantly reduce the net number of offspring produced, even when male and female LGB were occupying relatively large hosts. Observations of insect behaviour tunnel systems revealed that male LGB can exclude Tn. The data also suggested that males may increase their time spent in the tunnel entrance when exposed to high predation pressure. Therefore the drop in reproductive rate observed when predators were introduced into a system with males and females in a large host may be due to a trade-off between guarding behaviour and other paternal inputs such as nutritional contributions in ejaculates.

Introduction

The Bostrichidae are a coleopteran family composed mainly of wood-borers. There is evidence that LGB is relatively poorly adapted to the stored product environment (Hodges *et al.,* 1999) and aspects of its biology may make more sense when it is considered in a woody host. LGB has substantial populations both in the stored product environment (feeding mainly on maize and dried cassava) and in the natural environment, where it feeds on woody hosts (Borgemeister *et al.*, 1998b). It is therefore important for us to determine how LGB behave in potentially large wood hosts and to establish whether LGB has any behavioural adaptations that might protect it against predators such as its biological control agent *Teretrius nigrescens* (Coleoptera: Histeridae).

LGB construct tunnels within their plant hosts for feeding and egg laying (Hodges, 1986; Li, 1988). Preliminary observations of LGB adults within artificial plant hosts, sandwiched between glass slides, has indicated that males co-habit with just one female per gallery (monogamous), even when the sex ratio is female biased (Birkinshaw, 1998). Male LGB were observed to remain in the entrance to the gallery when not mating, in a similar manner to some scolytid species (Kirkendall, 1983), thereby possibly guarding against intrusion by either predators or other male competitors (Birkinshaw, 1998). Female LGB are relatively long-lived as adults and are reproductively active throughout this time. Estimates of rates of egg laying vary, but females can lay approximately four eggs per day, pausing only to construct new galleries (Hodges, 1986). Since LGB appear to be largely monogamous when in a host that is large enough to contain a tunnel gallery, it is likely that males make relatively high direct contributions to maximise their partner's reproductive rates. Direct benefits obtained by LGB females from males might include nutritional contributions in the ejaculate, assistance in tunnel construction, and protection from predators. All of these direct benefits have the potential to influence reproductive rates and might be favoured in long-term associations between a male and female co-habiting in a defendable gallery.

One potential influence of the presence of males on F1 production rates is the protection of developing offspring against predation. *Teretrius nigrescens* (Tn) is a relatively specific predator of LGB eggs and larvae, that has been released as a classical bio-control agent (Waage and Greathead, 1988) in Africa in an effort to suppress populations of LGB (Biliwa *et al.*, 1992). *Teretrius nigrescens* is spreading and establishing itself well in East and West Africa (Giles *et al.*, 1995; Borgemeister *et al.*, 1997b). Assessments of the impact of Tn on LGB populations are varied (Borgemeister *et al.*, 1997b; Birkinshaw and Hodges, 1999). Little is known about the behavioural interactions between these two insects in the stored-product environment. Nothing is known about how effective Tn might be in a larger plant host, where LGB may be able to protect against Tn predation by guarding an enclosed tunnel system such as is found in Scolytidae (Kirkendall, 1983). To investigate this subject further, net reproduction (numbers of eggs and larvae produced, minus any consumed by predators or conspecifics) were recorded for females allowed to reproduce under varying conditions of host size, predation pressure and with or without males available, to establish the potential influence of these factors. Direct observation using timelapse photography of insect behaviour within artificial hosts sandwiched between glass plates, were then made to aid the interpretation of the results obtained.

Methods

Net reproductive rate measurements

Source of insects and plant host

Prostephanus truncatus used in this experiment were originally collected from Tanzania and have been cultured on maize in CTH rooms in the UK. The *Teretrius nigrescens* used were also originally collected from Tanzania in 1994. All insects have been kept in a CTH room maintained at approximately 27°C and 60% r.h. All insects used in this experiment were taken from six-week old cultures as unknown age adults selected at random within the constraint that they appeared healthy and were not juveniles (light coloured and relatively inactive). LGB used were sexed by examination of genitalia as (Birkinshaw, 1998).

The cassava used in this experiment was collected as dried cassava, 'kokonte', from the Volta Region of Ghana and placed in a freezer for five days to kill any insects/mites, then conditioned in the CTH room for five days before being used in the experiment.

Experimental design

Each replicate was contained within a glass jar (capacity 375 ml). Approximately 30g of cassava were placed in each jar, made up of three pieces of approximately $6cm^3$. For treatments with large pieces of cassava these three pieces were left intact, but for treatments with small pieces of cassava the three large pieces were broken down into chunks of approximately $0.5cm^3$.

Initially eight replicates of six treatments were tested:

1. Three females on large pieces of cassava.
2. Three females with three males on large pieces of cassava.
3. Three females with three males on small pieces of cassava.
4. Three females with two *Teretrius nigrescens* on large pieces of cassava.
5. Three females with three males and two *Teretrius nigrescens* on large pieces of cassava.
6. Three females with three males and two *Teretrius nigrescens* on small pieces of cassava.

Later, treatments 1-3 were repeated with an additional treatment (also with eight replicates):

7. Three females on small pieces of cassava.

The treatments were set up as follows:

1. All LGB were placed on the cassava.
2. All Tn were introduced 48 hours later.
3. All treatments were then left to incubate in the CTH room for 19 days.

One replicate of each treatment was then dissected and number of LGB offspring (eggs and larvae) produced recorded immediately and the rest were placed in the freezer and scored for LGB offspring production within three weeks.

Observations of insect behaviour in tunnels

Host sandwiches:

A dough was made from a 6:4:1:1 mix of maize flour: water: wheat flour: cellulose (proportions quoted are by uncompacted volume). The wheat and maize flour had been passed through a 600 µm brass sieve (Endecotts Ltd., UK). The cellulose used was α-cellulose supplied by Sigma, UK. The wet dough was sandwiched between two glass microscope slides as shown in Figure 7.1. The sandwiches were then freeze dried over two days using an Edwards Freeze Dryer Super Modulyo.

Experimental design

One pair of LGB adults was placed on each sandwich in glass Petri dish lined with filter paper 24-48 hours prior to filming. Three such pairs were set up each day and as far as possible two pairs where the male and the female were occupying the same tunnel system were selected for filming. After two pairs had been selected they were ascribed to one of two treatments by flipping a coin.

1. No predators present
2. Two adult *Teretrius nigrescens* present

Nine replicates of each treatment were observed. Each pair of LGB within their sandwich were placed in one half of a square clear plastic container (see Fig. 7.2). The predators were released in one of the arenas, the container was sealed using tape and placed in a constant temperature room (27ºC ± 3ºC and 60% r.h. ± 10% r.h.) for filming. Beetle behaviour was recorded using a CCTV digital camera (Model: WVBP332E Panasonic, Matsushita Communication, Neuműster, Germany) connected to a time-lapse video recorder (Computar CTR-3024, UK). The sandwiches were filmed for 12 hours.

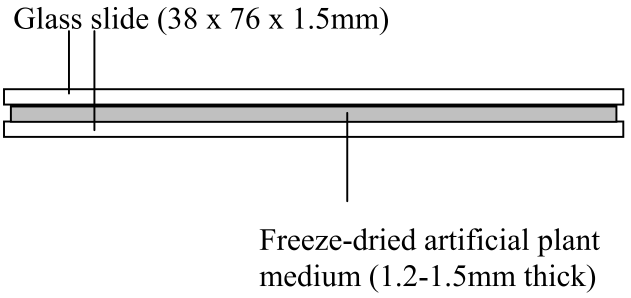


Figure 7.1: Cross-section through a glass/host/glass sandwich.

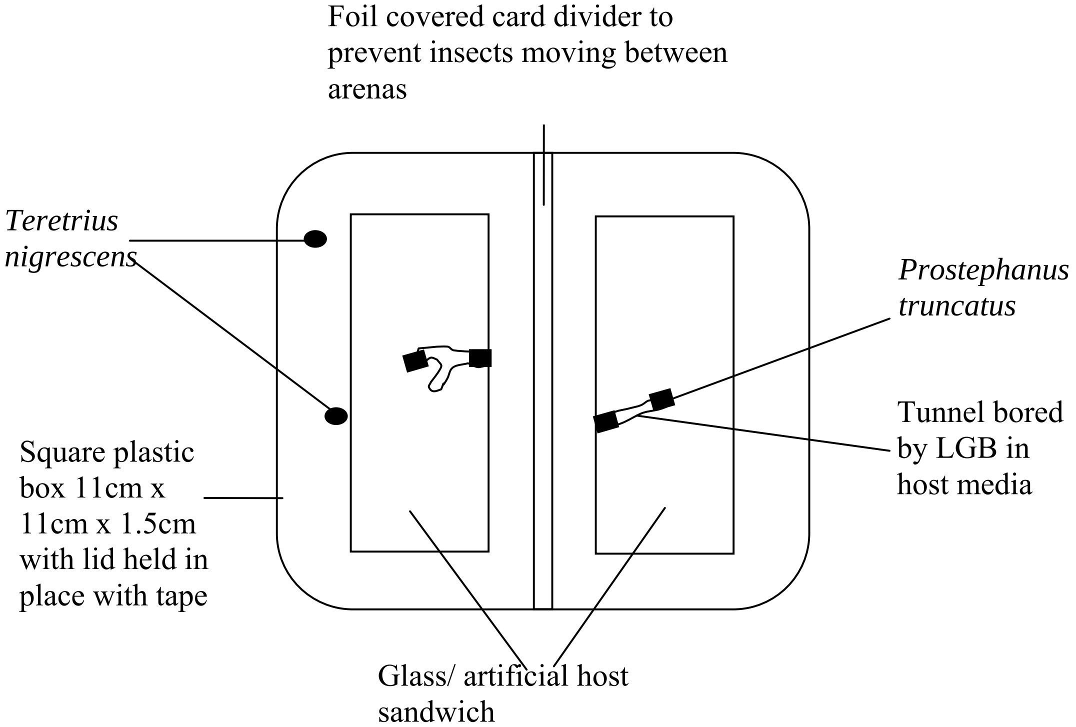


Figure 7.2: Plan view of test arena as arranged during filming.

For each replicate the following was recorded:

- Time that LGB pair co-habited within one tunnel and were clearly visible
- Time that LGB pair co-habited within one tunnel but were only partly visible
- Number of two-minute periods that the beetle in the entrance to the tunnel system (assumed male) left the entrance (at least one body length away) at least once

- Number of two-minute periods *Teretrius nigrescens* was present at the entrance of the LGB tunnel system
- Number of two-minute periods where at least one *Teretrius nigrescens* was within the LGB tunnel system

Results

Net reproductive rate measurements

Females produced approximately 50% more offspring when in the presence of males compared to lone females in both large and small pieces of cassava, but this difference was only statistically significant in large pieces (see Fig. 7.3 and Table 7.1). Females also produced significantly more offspring when the cassava was presented as large pieces compared to when it was divided into small pieces (Table 7.1). The presence of *Teretrius nigrescens* with females alone on large pieces of cassava (LT) resulted in the number of offspring recorded to be significantly decreased by an average of 68% of the mean without Tn (L)(see Fig. 7.3 and Table 7.1). A significant effect of the presence of *Teretrius nigrescens* on final offspring numbers was still recorded in the presence of males (ML vs. MLT) (Table 7.1) where the number of offspring was decreased by a mean of 50% of that without Tn (Fig. 7.3). The mean number of offspring produced in the presence Tn decreased by 66% where males and females were present in smaller pieces of cassava (MS vs. MST) (Fig. 7.3).

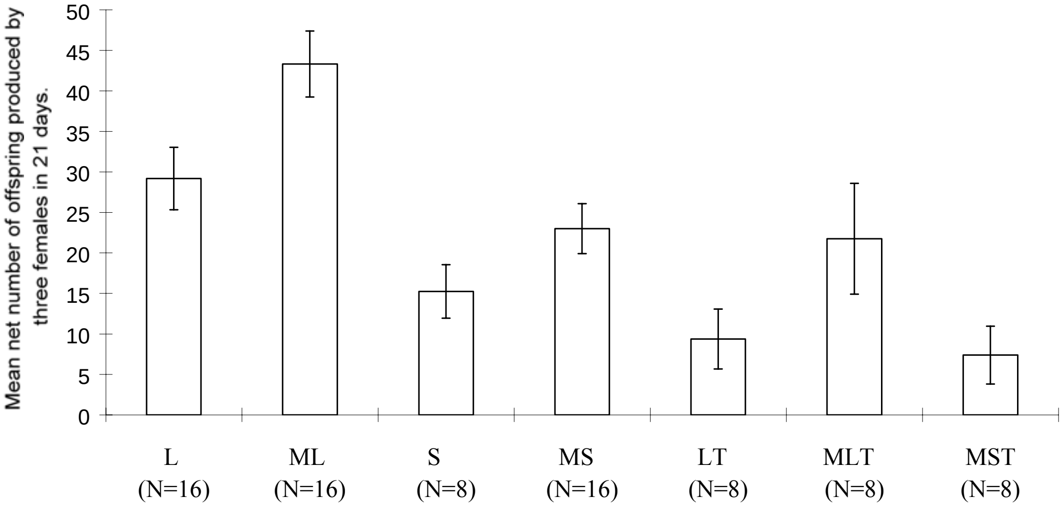


Figure 7.3: Means (±sem) of the number of offspring produced by three female **P. truncatus** *in 21 days across a range of treatments involving different sized plant hosts, presence or absence of males and presence or absence of the predator,* **T. nigrescens.** *M = three males present, L = large host, S = small host, T = two* **Tn** *present.*

Table 7.1. Summary of statistical analysis to test for differences between treatment groups. M = three males present, L = large host, S = small host, T = two Tn present

Comparison	Mann-Whitney test stat	p value	N for each treatment
L *vs*. ML	64.5	0.017	16
S *vs*. MS	41.5	0.170	8/16
L *vs*. S	28.0	0.027	16/8
L *vs*. LT	16.5	0.004	16/8
ML *vs*. MTL	27.0	0.023	16/8

Observations of insect behaviour in tunnels

Some of the biscuit/glass sandwiches containing LGB were incubated for six weeks after the experiment. Live, apparently healthy adult offspring were produced indicating the suitability of this media as a plant host for LGB. The biscuit media successfully cemented the glass slides together and none of the glass slides fell off. The biscuit media was generally solid enough to maintain the integrity of tunnel systems bored into it, but occasionally crumbled slightly at the tunnel entrance or where two tunnels were too close togetherΔ (Table 7.2a). The thickness of the biscuit enabled a clear view of insect behaviour within the tunnels in almost all cases (see H for exception in Table 7.2b).

Tn were able to move freely around the arena, but never managed to move from one arena to the other.

17 of 30 male/female pairs occupied the same tunnel system within 24 hours of being placed onto the host sandwich.

Where Tn visited the LGB tunnel entrance, the predator generally did not spend very much time trying to gain entry. There was only one occasion where a predator was persistently positioned next to the LGB at the tunnel entrance. Generally Tn made multiple short visits to the tunnel system. Tn moved past the LGB and gained access to tunnel systems in only two occasions and in one case the tunnel entrance had crumbled slightly making it easier for Tn to gain access.

In at least two replicates∴ (Table 7.2a) Tn visited the LGB tunnel entrance very few times. For the purposes of presenting the data, we have limited the replicates classed as high predation-pressure to those with more than 5% of the two-minute time-slots with at least one Tn visit.

In replicates where there were no predators (or low predator visitation rates), LGB showed very variable levels of ‘guarding’ behaviour (see Fig. 7.4).

There was no obvious instantaneous dramatic change in behaviour by LGB adults in the presence of Tn. There were five replicates where the LGB pair initially co-habited a tunnel system, were easily visible, and were classed has having high predation pressure. In three cases LGB showed very high levels of guarding behaviour, in one case Tn gained access to the tunnel system and in the fifth case neither of the LGB remained at the tunnel entrance, indeed one of the LGB completely left the tunnel system for some of the time.

Table 7.2a: Details of the number of two-minute periods that insects exhibited different behaviours for replicates of, 'high predation pressure'.

Tape/ date	**Visible, paired and no Tn in system**	**LGB at entrance**	**LGB not at entrance but in tunnel**	**LGB out of tunnel**	**Tn at entrance**	**Tn in tunnel beyond one LGB**	**Comments**
9/5 (7)	148	139	9	0	100	170	Diff to see if Tn past LGB so estimate given is upper limit
10/5 (8)	314	311	3	0	105	0	The few times that LGB left entrance was right at start before Tn encountered.
11/5 (9) ∴	317	199	115	3	15	0	Tn a bit rubbish especially in second half of observations
12/5 (10)	0			0		0	Tn never entered tunnel LGB always at tunnel entrance at night.
16/5 (11) ∴	311	20	291	0	13	0	Tn moving but not around tunnel entrance.
17/5 (12) Δ	118	1	117	192	52	226	Tunnel entrance quite broken up
18/5 (13) Δ	312	106	206	0	10	0	A lot of the time when male not at actual entrance, is at entrance to side tunnel near entrance.
19/5 (6)	313	2	284	27	278	0	Estimation of time at entrance may be underestimate as v.strict in defining ‘entrance’
24/5 (5)	331	282	49	0	185	0	

Table 2a: Details of the number of two-minute periods that insects exhibited different behaviours for replicates of, 'low or no predation pressure'.

Tape/ date	**Visible, paired and no Tn in system**	**Total periods LGB at entrance**	**Total periods LGB not at entrance but in tunnel**	**Total periods LGB out of tunnel**	**Comments**
9/5 (7)					unpaired
10/5 (8) H	316	261	55	0	Not visible so underestimation?
11/5 (9)	317	45	272	0	
12/5 (10)					unpaired
16/5 (11)	203	49	154	109	Female expelled male?
17/5 (12)					Pair too close
18/5 (13)	312	189	123	0	
19/5 (6)					unpaired
24/5 (5)	321	40	279	2	Male pushed up to entrance?

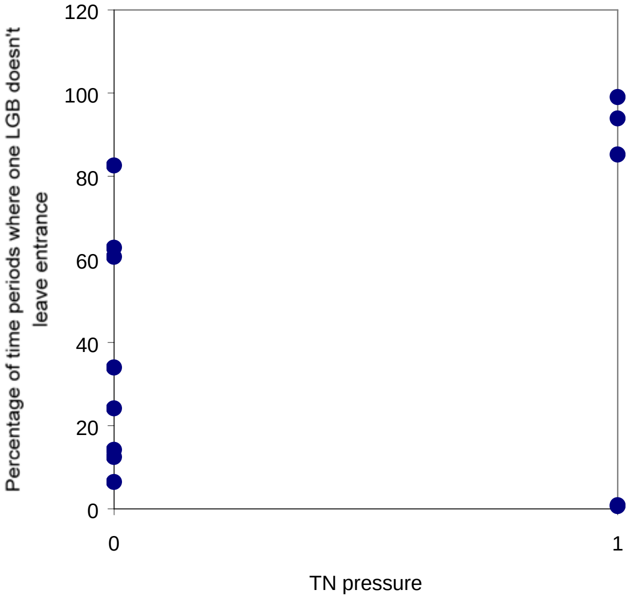


Figure 7.4: LGB presence in the tunnel entrance for replicates with low (0) or high (1) predation pressure from Tn

Discussion

Studies of net offspring production by females in different scenarios has shown that more offspring are produced in large hosts compared to small ones. In the absence of predators, the presence of males significantly increased net reproduction in large hosts only (although reproduction was numerically higher for females with males even in small hosts). This supports the hypothesis that males co-habiting with females in a tunnel system (only really possible in the larger hosts) may be particularly influential on female reproductive rates.

Rates of egg production are not likely to be limited by a lack of sperm for fertilisation (Hodges and Birkinshaw, 1999; Li, 1988). Higher reproductive rates of *P. truncatus* females when in the presence of males may result from an increase in nutritional intake derived from the ejaculate, if egg production rates are closely linked to female nutritional intake. Egg laying rates may, however be altered in response to egg-laying or maturing stimulants from the males (Wilson *et al*., 1999).

Net reproductive rates were always significantly reduced in the presence of the predator, Tn. There were three likely explanations for this:

1. Some of the females did not pair with a male.
2. Guarding males do not completely exclude predators from their tunnel system.
3. In order to exclude predators from the tunnel system, males invest more time or energy in guarding the entrance of the tunnel system and this time/energy is traded off against other possible paternal investments (such as numbers of matings or size of ejaculates)

The observations of beetle behaviour within tunnel systems with and without the presence of Tn were taken to assess the contribution of the two explanations given above. Generally guarding males did successfully exclude predators from the tunnel system. The cases where Tn did gain entry were when the entrance was unguarded or when the tunnel had crumbled slightly. Such crumbling may occur (although likely to a lesser extent) in dried cassava, but is very unlikely to prevent LGB from blocking the entrance to a wooden host. It is easy to imagine that an LGB posterior jammed in the entrance to such a tunnel system would be a very effective barrier. If this is the case, it might explain why, generally, Tn were not observed to engage in any kind of extended pushing matches with LGB since this would be futile.

There is some evidence that males either increase their guarding in the presence of predators or abandon the tunnel system altogether. No intermediate levels of guarding were observed when Tn predator pressure was high. More replicates of paired LGB in the presence of high predation rates would give us a clearer picture of whether LGB behaviour changes in response to predation pressure. Those males whose increase their guarding rates may incur a trade-off between guarding investment and other paternal investments (responsible for the increased reproductive rates of females in the presence of males in the absence of predators).

The host sandwich system used has some limitations. Many wood boring beetles do construct tunnel systems in two dimensions as the insects in this experiment are constrained to do by the glass plates. However, we do not know the physical nature of LGB hosts away from store, and LGB behaviour may be different in truly three-dimensional media. The new recipe for host media developed for this experiment is relatively solid and doesn’t crumble as easily as some artificial hosts used in the past (Birkinshaw, 1998), however it does still crumble more readily than wood.

Our assessment of the ability of LGB to exclude Tn by blocking tunnel entrances is likely to be an underestimate. We used moderately small host sandwiches to enable easy drying of the media and fairly high resolution of the beetles during filming. This prevented us from being able to leave the LGB on the sandwiches for very long periods prior to introducing the Tn. LGB tunnelled fast through the host, and the longer they are left the more likely the tunnel entrance will start to crumble away slightly, or the LGB might tunnel through the other side (although actually LGB seem to be able to avoid the edges of the media quite successfully). A slice of wood would be the best media to use, but this was not possible since samples of wood are notoriously variable in their suitability as a host for LGB (Christian Nansen, pers. com.).

Nang'ayo (1996) found that if Tn were added three weeks after LGB then Tn had a proportionally similar effects on LGB population growth in both wooden hosts and maize. However, Tn appeared to have proportionally more impact on populations of LGB on maize if added after six weeks. This piece of evidence supports the hypothesis that LGB can reduce the impact of Tn more effectively on larger hosts although this study has the confounding effect of different host type. We do not know why such an effect is only observed after six weeks and not after three.

Despite considerable effort, very few LGB have been observed in wooden hosts in the field (Nang'ayo, 1996). As yet, we know little of their location away from store or whether they indeed form monogamous pairs when building tunnel systems as suggested in the lab (Birkinshaw, 1998). Identification of the main hosts of LGB away from store will allow us to make a more definite appraisal of the likely impact of Tn on this part of the population.

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Outputs

Risk warning system (output 1)

The risk warning system has been developed to the point of field application. The current project in phase 1 and phase 2 succeeded in demonstrating that farmers are at greater risk when there are more LGB taking flight. This is technically very difficult to demonstrate and is a significant achievement since it supports the host selection hypothesis developed by earlier DFID funded research (Hodges *et al*., 1999). Even more important, it establishes that risk warning is an achievable objective by monitoring the number of flying beetles. The next step was to show that it would be feasible to estimate the numbers of flying beetles by observation of climate. A climate based model was successfully developed in Ghana. This was validated using data from Tanzania where the bad year in 1998 was clearly demonstrated.

Targeted pesticide treatment (output 2)

Targeted pesticide treatment was investigated in Ghana and Zimbabwe. The benefits of treating only a portion of the bulk of stored commodity was demonstrated in on-station trials. In Ghana, farmer participatory studies with maize cob barns and stakeholder meetings were used to explore the potential for the method to be used by farmers and its acceptability to a wider community. Similar work was planned for Zimbabwe and trials were established with farmers storing shelled grain in bins in collaboration with pesticide suppliers. Unfortunately, political disturbances prevented the completion of this part of the work although as far as it went the method appears to have been successfully applied by the farmers.

Impact of the biocontrol agent Tn (output 3)
Our own observations on 'bad years' for LGB have lead to the conclusion that Tn would be unable to offer little direct benefit in farm stores. Parallel research undertaken by IITA in Benin provided further evidence of this. Their modelling approach showed that strong density dependence effects on Tn would prevent it ever having a dense enough population to significantly reduce the depredation of LGB in stores. Furthermore, the low growth rate of Tn populations were unlikely ever to be sufficient for them to exert a controlling influence of an LGB population that has become established on maize. It remains a possibility that Tn may exert some influence in natural habitats were LGB may be present as a sparse population breeding slowly on a diet that is nutritionally relatively poor. However, this does not stop the incidence of bad years in those habitats that have been studied. The prospects for manipulating the farm storage environment in favour of a greater efficacy by Tn are thus slender. In view of this, the project reduced its emphasis on this output and increased efforts on the other two.

Contribution of outputs

Risk warning system and targeted pesticide-treatment
Both the risk warning system and targeted pesticide treatment have been publicised through CPHP printed leaflets and by workshops held in Ghana (Accra and Tamale) and in South Africa (Pretoria) where there were sixteen participants from S. and Eastern Africa. In Ghana, the LGB

risk warning system is now ready for implementation on a pilot basis and forms a component of a CPHP promotion project based in Northern Ghana. In S. Africa there was considerable interest judging by the statements made by country representatives as follows

***South Africa* (Mr F. Kirsten)**

A beneficial technique and less expensive than trapping. It will allow the potential distribution and abundance of LGB to be estimated in advance of the full establishment of the pest in RSA and so will be an important tool in awareness creation. The Plant Protection and Research Institute will be seeking financial support to implement the risk warning system.

Zimbabwe (Dr G. Chikwenhere)

LGB committee in Zimbabwe will consider implementing the model. Dr Brighton Mvumi will seek appropriate meteorological data and test the model in specific situations.

Zambia (Dr A. Sumani)

Zambia already has plenty of both LGB trap catch data and suitable meteorological data. These could be used to test how well the model will work in Zambia. It will be useful in explaining why in all provinces LGB can be captured in traps but in only three does it attack grain in store.

Malawi (Mr E. Muwalo)

The model is potentially very useful and could give warning of bad years and could be used to explain the differing abundance of the pest in various parts of Malawi. Mr Muwalo said that he would endeavour to locate suitable climate data to run the model.

Tanzania (Mr W. Riwa)

The model would be very useful if predicting the risk of bad years in Tanzania and the model has already shown it can do this for the area around Morogoro. Training is required so that the system can be operated.

Targeted pesticide treatments is also a component of a prospective CPHP project in northern Ghana and was strongly endorsed by the S. Africa Workshop where the following conclusions were reached.

1. It was agreed that the technique offered real potential to improve pesticide use by smallholder farmers. Delegates considered that further adaptive trials should be undertaken in various locations to determine how well the method might work with different storage methods including sacks, different commodities, different climates, different pest complexes etc. For example in Zambia, storage structures are arranged so that the maize cobs are removed from the middle of barns, so in this case treatment could be at base and top. Other differences in practice throughout the sub-region are likely to affect how the method can be applied.

2. The possible reaction of chemical companies to this method, which would involve individual farmers using less pesticide, was discussed. Experiences in Zimbabwe were mentioned. In that country, chemical companies had supported the technique since although farmers used less pesticide they would be less likely to under-dose the portion of grain that they treat so there would be fewer complaints about ineffective pesticide. Also, a greater number of farmers would

be able to afford the treatment of grain so the benefits of treatment would reach a larger group. It is clear that chemical companies can be supportive stakeholder of this technique and should be involved in its promotion.

3. It was noted that if there was extensive pre-harvest infestation in the grain stock then any benefits of targeted treatment might be seriously reduced. It is therefore important that good storage hygiene is practised, i.e. before being placed in stores, cobs or grain should be carefully inspected for signs of insect attack and any infested stock rejected. A further measure to limit pre-harvest infestation is to ensure that once the crop has reached physiological maturity there should be no undue delay in harvesting.

4. As with the use of any pesticides, proper precautions are required at the time of application. Although the amount of pesticide is reduced, because only a portion of the grain is treated, the risks at the time of treatment are no different from a conventional full application. In addition, where treatment of maize cobs is involved, proper disposal of the treated husk after storage is important, it should not be used as a wrap for food items.

The adoption of appropriate pest management by farmers affects their livelihoods. Decision making to achieve the most cost-effective action on the part of the farmers needs to encompass a range of factors, not least the aspirations of the individual farmer. In order to benefit from LGB risk warning and options like targeted treatment, a decision making framework must be developed that is directly applicable to the farming community in question. Such a decision framework is being proposed for development under the future CPHP project in northern Ghana. This could form the basis for frameworks for use elsewhere and so facilitate the spread of appropriate and effective pest management to maintain food security and food quality among small holder farmers.

List of project publications and other dissemination outputs

Peer reviewed papers

ADDO, S., BIRKINSHAW, L.A. and HODGES, R.J. (in press). Ten years after the arrival of Larger Grain Borer: Farmers' experiences and action against an exotic pest of stored maize in Ghana. *International Journal of Pest Management*.

ADDO, S., BIRKINSHAW, L.A. and HODGES, R.J. (in press). Biocharacteristics of *Prostephanus truncatus* attracted to flight traps baited with aggregation pheromone In E. Highley (ed.) *Proceedings of the 8th International Working Conference on Stored Products Protection. 22-26 July 2002, York (UK).*

BIRKINSHAW, L.A., HODGES, R.J. and ADDO, S. (in press). Flight behaviour of *Prostephanus truncatus* and *Teretrius nigrescens* demonstrated by a cheap and simple pheromone-baited trap designed to segregate catches with time. *Journal of Stored Products Research*

BIRKINSHAW, L.A., HODGES, R.J., ADDO, S. and RIWA W. (2002). Can 'bad' years for damage by *Prostephanus truncatus* be predicted? *Crop Protection* 21 (9), 783-791.

BORGEMEISTER C., HOLST, N. and HODGES R.J. (in press) Biological control and other pest management options for Larger Grain Borer *Prostephanus truncatus.* Biological Control in Africa, CABI Biosciences.

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BIRKINSHAW L.A. (2001) Can 'bad' years for Larger Grain Borer (*Prostephanus truncatus*) be predicted? Royal Entomological Society, Special Interest Group Meeting, Natural Resources Institute, Chatham, Kent, UK. 12 Sept 2001

BIRKINSHAW L.A. (2001) From beetle sex to food on the table. Exploiting the behaviour of *Prostephanus truncatus* to limit its damage in Africa. Association for the Study of Animal Behaviour. 'Interphasing animal behaviour with other disciplines'. Glasgow, Sept. 2001.

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Appendix 1

FARMER MAIZE STORAGE QUESTIONNAIRE

1. GENERAL

(a) Date:…………………………

(b) Region: ………………………

(c) District: …………………………

(d) Village: ……………………….

2. RESPONDENT/ HOUSEHOLD INFORMATION

(a) Sex M F

(b) Age Adolescent Middle age Elder

(c) Ethnic group Ewe Akan Kotokoli Buem Other

(d) Education none primary middle secondary/univ

(e) How many dependent on household maize? ………

3. HOUSEHOLD MAIZE PRODUCTION/STORAGE

Don't worry about major vs minor harvest, simply fill in largest area at any one time.

(a) Area farmed + ...

(b) Area farmed with maize ....

	MAJOR		MINOR	
c) When do you cultivate maize? I=Improved, L=local	I	L	I	L
d) Which season do you store your maize? I, L.	I	L	I	L
How long do you store (months) <3, 3-5, >5?				

f) Harvest/ later	g)Store type (same store type can be in more than one row	h) Major (kg)*	i) How many stores?	j) Minor (kg)*	k) How many stores?
	Raised platform				
	Room sacks				
	Room cobs				
	Inverted cone				
	Other				

*Circle maize that is sometimes treated (with **ANY** protectant)

4. MAIZE USES

What is the household maize used for?

(a) Tick		(b) Ranking 1=most important	(c) Approximate quantity (Kg)
	Food for family		
	Sale for cash		
	Food for those other than immediate family		
	Feed for animals		
	Seed		
	Payment to hired labour		
	Other		
	Other		

5. STORAGE PROBLEMS

(a) Have your storage problems changed over the years? yes / no / new (I haven't had this responsibility for long)

(b) What are the changes?

Harder to get construction material	
Harder to find people skilled in barn construction	
Larger Grain Borer	
Increased insect infestation	

(c) Have you changed your storage practice in response to this? (yes / no)
……………………………………………………………………………………………..

(d) What have you been doing differently?

	Tick	(e) Comment (useful/ not useful, how has this been adapted to your particular situation?)
Better store hygiene		
Replacing barn wood more often		
Using insecticide more often		
Inspecting the barn more often		
Shelling infested		
Sun drying more often		
Other ……………………………		

6. INSECT PESTS OF STORED MAIZE

Which insects have you ever found in your maize stores?

(a)	(b) (Y=yes I have this) (N=no I don't have this) (?=I don't know what this is)	(c) How important? VI (very important) I (important) NI (not important)	(d) Explain your answer to column (c)
Sitophilus species (weevils)			
LGB			
Other (please specify if possible)			

7. VARIATION IN INSECT DAMAGE BETWEEN YEARS

Do you remember which years were bad for damage from insects?

3 - higher than normal damage, 2- normal level of damage, 1- less than normal damage,, 0 can't remember/ can't be sure of insect type

(a)	(b) Year before last year 97/98	(c) Last year 98/99	(d) This year 99/00
Total insect damage (use this if unsure)			
Sitophilus damage			
LGB damage			

8. USE OF PROTECTANTS.

(a) Are any protectants (**local** or purchased) used? Yes No

(b) Who decides whether or not protectants should be used in the household maize stores?

I do woman farmer man farmer man and woman for separate

FLS Other……

(c) What are the main things that might prevent you from using commercial chemical protectants?

time knowledge doesn't work cost health hazard space

rodents other (please state) …...

(d) Protectant used (e.g. Actellic, other insecticide, wood ash, plant materials) ....

(e) Formulation (e.g. dust, EC, leaves, dip, other -please state)

(f) Approximately how many years out of five do you use this?

(g) When applied during storage?

as store is loaded after a set time time depends on damage

time depends on access to protectant time depends on other

(h) Monetary cost of protectant (cedis)

(i) Other monetary cost

(j) Availability of protectant (ignoring cost)

very easy to obtain   sometimes hard to obtain   very difficult to obtain

9. ACCESS TO INFORMATION

a)How do you find out about new storage ideas? Rank importance (1=most important)

	Rank
Radio/TV	
Friends/ Family/Fellow farmers	
Village specialists	
NGO’s	
Develop my own	
Extension officers	
Other (specify)	

(b) Comment on ranking of sources of info
……………………………………………………………………………………………..……

(c) How much direct contact do you have with the agricultural extension services?

Never   Hardly ever   Less than once a year

1-5 times a year   More than 5 times a year

(d) Would you like to be asked to be involved in any future work we are doing?
If yes, what is your name…………………….

Appendix 2

EVALUATION OF TARGETED TREATMENT OF EWE BARNS

Village: Date:

Number of farmers: Males = Females =

Recorder (s):

Section 1: Ranking of maize grains

Rank	Sample code	Reason for ranking	Remarks
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Section 2: Farmer questions

1. What can the various groups of maize be used for and which will fetch higher price. Give reason(s).
2. How will you dispose of the husk?
3. What will the cobs be used for?
4. What is your impression about treating barns?
5. How many would want to treat barns in future?
6. If not treating, what are your problems with treating with chemicals?
7. If you should repeat this work, what additions/subtractions would you make?
8. What have you learned from this trial?
9. How can we ensure safe use of insecticides?

Section 3: Attendance list

Males	Females