Recent advances in the biology and control of *Prostephanus truncatus* (Coleoptera: Bostrichidae)

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Abstract

Prostephanus truncatus (Horn) is a serious pest of farm-stored maize and cassava. It is indigenous to meso-America but was introduced into East Africa in the late 1970s. Since then it has spread to several countries in both eastern and western Africa and continues to spread. Currently, the main option for farmers to reduce losses is to admix pesticides with the stored crop. This implies an expansion of pesticide usage which may be undesirable financially and environmentally; it also involves changes to traditional farm practice which may be unacceptable. For these reasons there has been a considerable research to improve understanding of the biology of the pest and to generate a wider range of loss reduction options.

Recent studies on *P. truncatus* are described, particularly those undertaken as part of a U.K.-funded 'Integrated Pest Management Initiative'. Investigations have centred on essential aspects of pest ecology, the use of pheromone traps for monitoring the pest, and potential loss-reduction strategies including the release of a specific predator (*Teretriosoma nigrescens* Lewis). Mention is made of: a model of pest abundance in relation to climatic factors in Mexico that could be used to predict pest distribution and status in Africa; food losses and improved loss assessment methodology; host selection behaviour, which has enabled a tentative interpretation of the very discontinuous nature of *P. truncatus* infestations; the importance of the pest in the natural environment, away from stores; and the significance of the natural environment in relation to the likely impact of *T. nigrescens*.

Introduction

Prostephanus truncatus (Horn) is a serious pest of farm-stored maize and cassava. Its biology and control have been reviewed in detail by Hodges (1986) and Markham et al. (1991). The pest is indigenous to meso-America but was accidentally introduced into East Africa in the late 1970s and spread widely in the following years. In the period 1981–85 the use of contact insecticides for the control of *P. truncatus* was developed, in particular the admixture of a 'cocktail' of an organophosphorus and a synthetic pyrethroid insecticide to shelled maize (Golob 1988). However, although the use of contact insecticides is clearly effective against the pest, long-term control using this method would require a massive expansion in insecticide usage among rural African communities. For financial and environmental reasons this is an undesirable prospect and the shelling of maize before applying the pesticide may be an unpopular or unacceptable proposition.

Much of the research effort described in this paper was undertaken as part of an integrated pest management initiative against the larger grain borer, funded by the U.K.'s Overseas Development Administration. It has sought to increase understanding of the pest and broaden the range of options available for African farmers to reduce storage losses. For the future, it is planned that this knowledge will be developed into an extension methodology to ensure that farmers will receive the right advice depending on their circumstances, which will vary according to the pest status of *P. truncatus* within the relevant agro-climatic zone, storage methods and length of the storage period. Consideration of these factors can form the basis of 'range recommendations', a decision tree enabling extension workers to give specific and appropriate advice.

Current and Potential Distribution of *P. truncatus*

The current distribution of *P. truncatus* in Africa is shown in Figure 1 and its range in the continent is believed to be still expanding. Investigations of the pest in Mexico were undertaken to examine what factors influenced its importance and to glean clues as to its potential in Africa. An initial socio-economic survey in four states in Mexico did not reveal any obvious link between storage practices and levels of the pest but confirmed that across the selected regions and in different geographical areas *P. truncatus* is of secondary importance to *Sitophilus zeamais* (Motschulsky); only in the drier areas covered by the survey was there evidence that *P. truncatus* was commonly an important pest (J. Leslie, unpublished). Overall, it was concluded that levels of the pest were influenced more by the natural environment than by those maize production and storage systems found in the regions surveyed and that the presence of a specific predator, *Teretriosoma nigrescens* Lewis, and alternative host plants may have an important role in determining its pest status.

As the pest was shown to exist in Mexico in a wide range of climatic zones, from the hot humid tropical coast to cool highland areas (Tigar et al. 1994a), it will probably continue to expand its range throughout most of sub-Saharan Africa, wherever there are suitable food sources. A simple empirical relationship was found to exist between the numbers of the pest caught by pheromone traps and different climatic conditions across five regions in Mexico. The analysis was used to produce a predictive map of the Mexican distribution of the pest, and this suggested that there is higher abundance in cooler, more temperate areas, a relationship evident even from the raw data. This contrasts strongly with the predictions made by Haubruge and Gaspar (1990), based on laboratory observations of development and mortality. They suggested that the hotter humid areas would be most vulnerable to the pest. It is difficult to comment on this discrepancy until it has been confirmed that higher catches in pheromone traps actually

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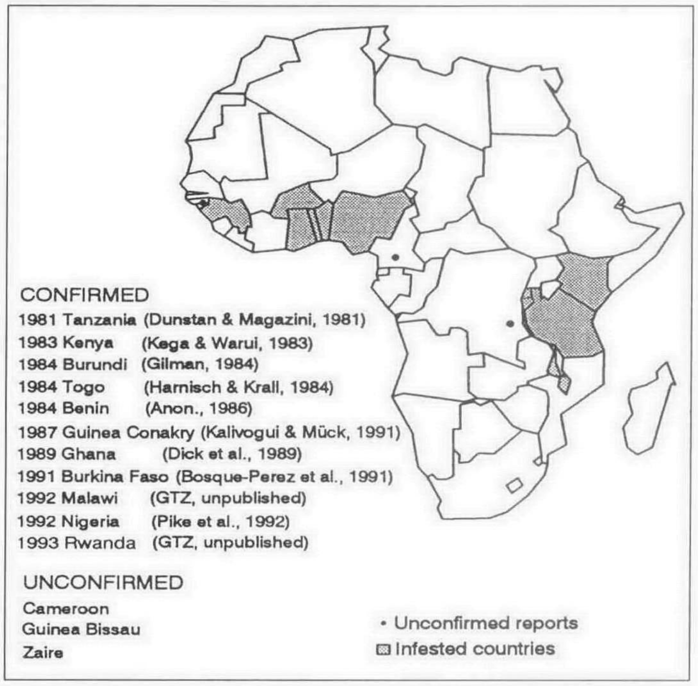

Fig. 1. Distribution of *Prostephanus truncatus* in Africa.

reflect higher abundance rather than, for instance, more active host-seeking behaviour. A further essential step in developing this approach is to establish that higher abundance is positively correlated with greater losses in farm stores. The Mexico model has also been used to prepare a predictive map for *P. truncatus* distribution in East Africa (Tigar and Osborne 1993). It is intended to verify this prediction and at the same time investigate the relationship between observed temporal and spatial abundance and storage losses.

Farm Store Losses and Incidence of *P. truncatus*

The pest is highly destructive of farm-stored maize and cassava. In those areas in Africa where the pest is well established, it is considered to have increased average losses of farm-stored maize from less than 5% to approximately 10% per year (Dick 1988). Unfortunately, most estimates of losses are not cumulative, i.e. do not take into account farmer consumption patterns. Although these estimates demonstrate the highly damaging nature of the pest, they do not accurately reflect the threat to the farmer. An exception to this is a study of dried cassava root losses in central Togo by Wright et al. (1993). They found that 25 farmers, in five villages, sustained average cumulative weight losses of 9.7% after three months of storage, rising to 19.5% after seven months. On a national basis it was estimated that these losses could amount to an average 4% of cassava production (which includes cassava products not infested by the pest) with a value of 0.05% of Togo GNP. However, these recorded weight losses may not represent the actual loss since nutritional analysis of cassava 'flour ' that accumulates in farm stores, as a result of *P. truncatus* infestation, demonstrated that this flour was not nutritionally inferior in oil, protein or sugars although it suffered a small reduction (4%) in starch content (Wright et al. 1993). When obviously free of taint, such flour is used as animal food or even human food (Compton 1991). The copious 'flour' produced by *P. truncatus* infestation of maize is apparently rejected by farmers (Compton 1991) and its nutritional value has yet to be investigated.

The estimation of losses during farm-store surveys has proved very difficult as samples have to be returned to the laboratory where time-consuming analysis is required. For maize this has largely been undertaken using a gravimetric method (count and weigh). Similar methodology has not been available for cassava, where instead loss estimates required knowledge of initial weights which are not normally available in typical survey work. These difficulties have been overcome in Togo by Compton et al. (1994) who devised a rapid loss assessment method. They developed visual scales, supported by reference photographs, which distinguish five or six categories of damaged maize cobs or dried cassava roots. It was found to be possible to calibrate the scales against conventional loss assessment techniques to permit the estimate of percentage weight loss in the field. In future, it may also be possible to devise other calibrations such as loss in market value or final food product. The more widespread use of this rapid method will greatly increase availability of loss data which may be used to give a more accurate reflection of the value of losses to the farmer. More recently, a rapid technique for estimating insect numbers has been devised based on the observation that, for *P. truncatus* and *S. zeamais*, the number of individuals dislodged when tapping a maize cob is on average half the number remaining within the cob (J. Compton, pers. comm.).

P. truncatus Outside the Storage System

P. truncatus can infest maize in the field before harvest although there is much variation in the extent to which this occurs. In Togo, there was little evidence of pre-harvest infestation (Wright et al. 1993), while 11% of stores in Arusha (Tanzania) were estimated to have received their infestation from this source (Henckes 1992). In Central Mexico, after maize has matured it is often left in the field to dry for a period of three to four months. At maturity, Tigar et al. (1994b) observed that less than 1% of fields showed signs of infestation by *P. truncatus* or *S. zeamais*, although after several months of drying, 50% and 60% of fields had these pests respectively. In the case of *P. truncatus*, cob infestation rates varied from 0.7% to 4% compared with 1 to 13% for *S. zeamais*.

With the advent of pheromone baited flight-traps to monitor the pest, it was observed that there are large populations of *P. truncatus* in the natural environment, away from stores or maize fields. Traps have made large catches in woodland areas of Mexico (Rees et al. 1990) and the pest is widespread in the vegetation of the Tsavo national park in Kenya (Nang'ayo et al. 1993), where to date two species have been shown to support populations of the pest, *Commiphora riparia* and *Commiphora africana* (G. Hill, pers. comm.). However, many tree species may be involved, as laboratory investigations in Togo (Helbig et al. 1990) and Kenya (Nang'ayo et al. 1993) have shown that the pest is capable of developing and reproducing on the dried twigs of a range of trees. In Kenya, this includes no less than 15 tree species from the families Leguminosae, Burseraceae and Anacardiaceae. As the conditions required in wood for the development of *P. truncatus* become better known then the list of possible hosts may continue to grow.

The large and widespread populations of *P. truncatus* in the bush, at least in Mexico and Kenya, suggest that the major reservoir for the pest is probably wood. However, wood appears to be a relatively deficient food medium as it generally supports smaller, slower-growing populations of the pest than would be expected in maize or cassava. Ramirez et al. (1991) speculated that in Mexico *P. truncatus* occupies a transient niche created as branches die and dry out. Observations in

Kenya of population dynamics in relation to seasonal die-back in trees, and of breeding being restricted to wood of lower moisture content, has supported this hypothesis (Nang'ayo et al. 1993).

The role of wood as an alternative host may have considerable importance in the infestation cycle of the pest. The construction of stores from unsuitable types of wood may enable rapid infestation of the fresh harvest. Recommendations to use alley farming systems in Africa, where crops are planted in strips between rows of trees, may encourage greater exchange of the pest between wood and the mature crop. These possibilities need to be investigated further.

Host Selection

Over short distances, *P. truncatus* is attracted to maize grain (Detmers 1990) and dried cassava (Wright et al. 1993); the volatiles concerned have been extracted and shown to attract the pest in a laboratory bioassay (Pike, these proceedings). However, field studies both in Mexico (Tigar et al. 1994b) and Togo (Wright et al. 1993) suggest that there is no long-range attraction of adult *P. truncatus* to maize grain or cobs or to dried cassava. This may not be surprising for a pest believed to have evolved as a wood borer (Chittenden 1911) and for which wood is probably still the major host, as already described. One can thus speculate that host selection, particularly in the case of maize and cassava, may occur largely by chance.

A tentative hypothesis for the process of host selection is presented in Figure 2. Adults (probably mostly males) disperse and on arrival at a suitable site make test burrows in search of food. Test burrows have been observed in a wide variety of materials such as soap, plastic, wood, leather, etc. and they may be 1–2 cm long (Hodges 1986). If no suitable food is located the beetles back out of their burrows and try again elsewhere. However, once suitable food is found the male secretes a pheromone attractive to females and other males (Dendy et al. 1989, Cork et al. 1991). Once the male is joined by a female, pheromone production is stopped in response to a non-volatile compound produced by the female (J. Smith, unpublished), but before this happens other males may also respond to the pheromone and arrive to exploit both food and mates. In this way aggregations of both male and female *P. truncatus* may occur. However, as a male stops releasing pheromone on the arrival of a female, it is probable that the secretion is released as a sex attractant and production ceases as soon as possible to limit competition with other males. The aggregation pheromones secreted by males of several long-lived storage Coleoptera (Burkholder 1985) may be worth reviewing in this light since if their purpose, rather than their result, was to cause aggregation this would imply evolution by 'group' rather than by 'individual' selection.

The type of host-selection behaviour suggested here for *P. truncatus* may help to explain relatively frequent field observations where, of two adjacent stores, one becomes very heavily infested and the other appears to escape without attack. If a male arrived by chance at the first store and attracted other adults using its pheromone secretion, the closely-located second store containing maize, which by itself is relatively unattractive, may escape infestation. Storage workers have not reported such stark discontinuities of distribution in *Sitophilus oryzae* or *Sitophilus zeamais*, which suggests that the host-seeking behaviour in these species may be rather different: this would not be surprising as *Sitophilus* spp. (except some unusual strains of *S. oryzae*) are specialist cereal feeders and are known to be attracted over long distances to wheat (Barrer 1983) and at least over short distances to maize (Trematerra and Girgenti 1989). More detailed comparisons of the host-selection behaviour of *P. truncatus* and *Sitophilus* spp. would be useful.

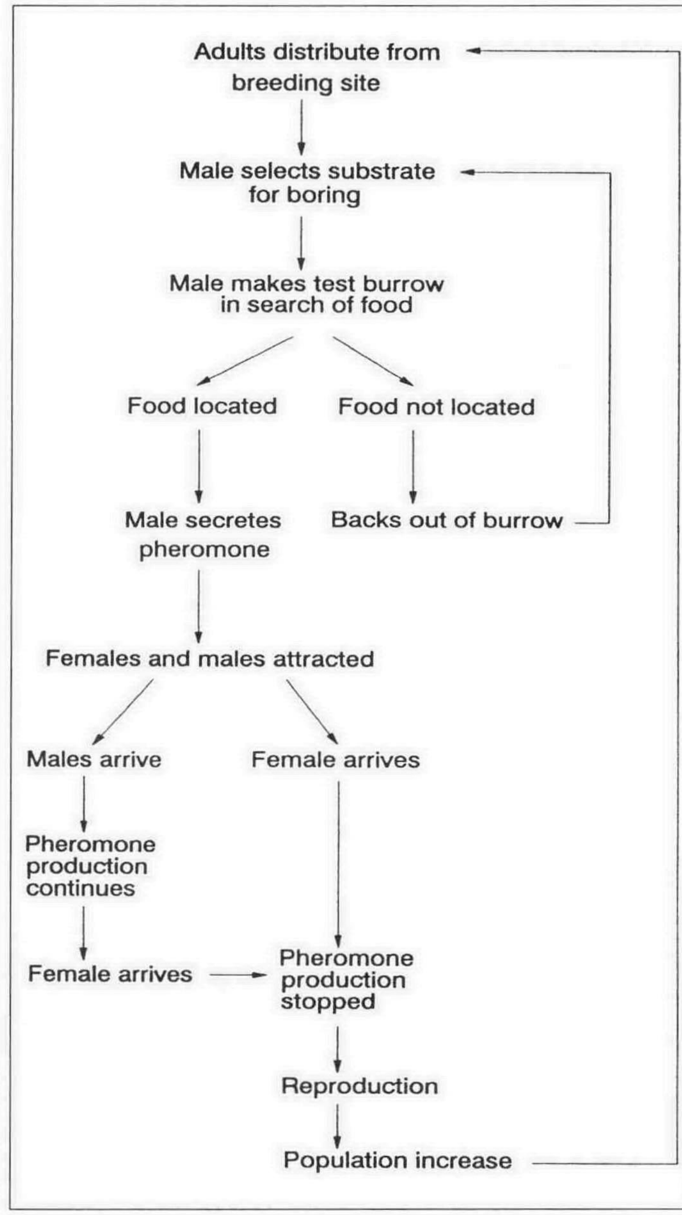

Fig. 2. Host selection hypothesis for *Prostephanus truncatus*.

Pheromone Trapping

Studies by Pike (1993), in Mexico, have shown that once present in a suitable food source, even at relatively high population density, the pest is not attracted from the food into nearby pheromone-baited traps. At present, the factors that lead to the distribution of *P. truncatus* populations and the change to a positive pheromone response remain unknown.

Pike (1993) was also able to show that pheromone-baited crevice traps, in simulated maize stores, attract few of the pests actually present in the maize but instead attract those, from outside the store, that are actively dispersing. Thus traps placed in stores may not give reliable data on actual store infestation rates and may result in uninfested stock becoming infested. To avoid this happening, it is now recommended that pheromone traps be placed at least 100 m from maize stores and fields. Pheromone-baited flight traps used in this way have proved very successful and have been used in several African countries to monitor the distribution and spread of *P. truncatus*. Recent studies on the use of these traps have provided more background information on their performance. Farrell and Key (1992) working in central Mexico have demonstrated a dispersal of *P. truncatus* to pheromone traps by upwind flight of a maximum of 340 m in 24 hours, of which about 100 m was directional flight apparently in response to the pheromone. This is broadly in agreement with observations by Rees et al. (1990) in the Yucatan in a more densely vegetated area where dispersal occurred over 250 m in a period of 72 hours, and of Novillo (1990) in Honduras, where dispersal occurred over a maximum of 300 m in 48 hours. However, this should not suggest that the pest is a poor flier since studies of flight capability on a 'flight mill' have shown that over a period of 45 hours distances of about 25 km can be covered (Pike 1993).

Studies by Novillo (1991), in Honduras, indicate a bimodal pattern of flight activity according to time of day, with a major peak at 06.00–08.00 h and a minor peak at 18.00–20.00 hours. A similar pattern was observed by Tigar et al. 1993 in Central Mexico except that the major peak was associated with dusk. Novillo (1991) and Tigar et al. (1993) both investigated the effective life of the standard pheromone bait, a plastic capsule loaded with 2 mg of attractant (ratio of Trunc-call 1 and 2 1:1 by weight). Both found the baits to be maximally attractive for the first eight days of use and the majority of catches were made within 14 days. These results support similar observations in Tanzania (Dendy et al. 1991).

The use of pheromone traps over long periods has demonstrated that there are strong seasonal variations in trap catch (Nang'ayo et al. 1993; Novillo 1991; Tigar et al.1994a; Wright et al. 1993) which are probably related to climatic and vegetational variables. Thus trap-catch values are both site and season-specific. However, at least in Kenya where the pest is well established, variations between years at the same site are relatively small (G. Hill and F. Nang'ayo, unpublished data). Thus long-term trapping studies, at sites away from the more explosive population fluctuations associated with stored maize or dried cassava, may offer a useful means of monitoring the effects of pest control activities on *P. truncatus* populations, particularly the effects of the predator *T. nigrescens* Lewis.

Use of Insecticides Against *P. truncatus*

The adoption of the admixture of dilute-dust insecticide cocktails for *P. truncatus* control involves most subsistence farmers in a considerable change in farming practice since the storage of maize cobs, usually with husk intact, is generally preferred. Consequently, attention has focused recently on the treatment of maize cobs, with or without husk cover, in Togo (Berg and Biliwa 1990) and Tanzania (Golob and Hanks 1990) and Kenya (P. Giles, unpublished). In Togo, where both store structure and cobs were sprayed, and cobs forming the outside of the store sprayed twice, good protection was achieved over a period of 10 months with deltamethrin or a mixture of fenvalerate and fenitrothion. The results from Tanzania were less promising, although only a single treatment was applied to the cobs. The results from detailed studies in Kenya on the treatment of maize cobs with and without husk cover, with or without heat and smoke from a kitchen fire, will be available soon and should give further clarification on the advantages or otherwise of cob treatment.

Cob treatments generally require the farmer to use a sprayer and make dilutions of concentrated insecticide. For these reasons they may ultimately be impractical. Laboratory observations by Hodges and Meik (1984) suggest an alternative treatment for cobs, involving selective treatment of the cut stalk of the cob. In a field study of this, excellent control was achieved for 40 weeks when the cut ends of cobs were dipped in one of two permethrin formulations, 25% wettable powder (applied dry) or 25% emulsion (Golob and Hanks 1990). The use of these materials may also be impractical for farmers, but further research on the method, involving the use of dilute dusts prepared at higher than normal concentration (e.g. in the case of permethrin, higher than 0.5% but lower than 25%) and formulated with a carrier that has good adhesion to maize stalk/husk, may give an effective and practical alternative treatment.

Successful protection of cassava chips has been achieved by both dipping in insecticide emulsion (Berg and Biliwa 1989) or dusting with dilute dust (Wright et al. 1993), using the same active ingredients as on maize. However, although the insecticide residues on the cassava were below those recommended by the Codex Alimentarius for cereals, they exceeded the much more stringent limit for root crops: the limit for deltamethrin on cereals is 1 ppm but on root crops only 0.01 ppm. However, it should be noted that the maximum recommended level for root crops is based on the fresh rather than dried product. As the nearest 'similar use' commodities to dried cassava are cereal grains then it may be acceptable to adopt the higher maximum recommended level, but this requires the guidance of the World Health Organisation.

Biological Control Options

Various potential methods of biological control have been described by Markham et al. (1991). Of these, only classical biological control using a specific predator from Central America, the histerid beetle *T. nigrescens* Lewis, has shown practical potential so far. The predator was successfully released in southern Togo in January 1991 (GTZ, unpublished data) and southeastern Kenya in May 1992 (P. Giles, unpublished). In Kenya, the releases have been in a relatively cool highland habitat, averaging 1700 m, and a lower warm habitat at 900 m. The fact that the pheromone of *P. truncatus* is a kairomone for *T. nigrescens* (Boeye et al. 1992) has meant that the spread of the predator has been easy to monitor with pheromone traps. In Kenya, at the lower altitude, the predator spread at least 16 km from the release site within nine months although numbers captured even 2 km from the release site were relatively low. At the higher altitude release site, the spread has been very much slower.

It is unlikely that *T. nigrescens* will have much direct impact in stores where pesticide is used, as the insecticide susceptibility of the predator is considerably greater than its prey (Golob et al. 1990), or where there is an established and hence fast-breeding pest population which will cause severe losses before the predator can have any significant impact. However, the predator may significantly reduce pest populations that are present in wooden store structures and on maize residues and so limit the rate of carryover of the pest between storage seasons. There may be ways for farmers to encourage the survival of *T. nigrescens* in this situation, so increasing the response rate of the predator against the pest. This possibility remains an area for further study. Another important situation where the predator may have a significant impact on the pest is in the natural environment, where it may reduce slow-breeding populations on wood. A reduction in this pest reservoir may limit cross-infestation rates to maize and cassava, as suggested by Markham et al. (1991), and so decrease food losses. It is clear that a better understanding is needed of the relationship between predator and prey in the wider environment and to this end studies in the natural environment are currently underway in Kenya.

Programs in both Togo and Kenya include efforts to demonstrate the impact of the predator on reduction of losses in store.

To date, impact assessments have been largely experimental or semi-experimental in nature, while data from 'real' stores are sparse. Most emphasis has been placed on observing losses in infested stores, with and without the predator. The frequency with which stores actually become infested does not appear to have been studied, although it might be expected that lowered *P. truncatus* populations, especially in the natural environment, would result in fewer infested stores. Studies planned for Kenya and Ghana will attempt to detect changes in this parameter. The investigations will be supported by long-term pheromone trapping to detect pest population reductions.

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