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Developing an Integrated Pest Management approach in rural Maize stores: Experimental studies in Benin and Togo

By

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Declaration

I, Cyrille Gnidoté ADDA, hereby declare that the work presented in this thesis is my own and has not been submitted for a degree in any other University.

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In loving memory of my dear father ADDA Aigla Cakpo Valère.

May I inherit part of your wisdom and strength...?

Abstract

Developing an Integrated Pest Management approach in rural maize stores: Experimental studies in Benin and Togo.

Cyrille Gnidoté ADDA

The importance of maize as one of the major staple foods in Africa substantiates the need to search for adequate methods to protect this crop, mainly against storage pests like the Larger Grain Borer, *Prostephanus truncatus* (Horn) (Col.: Bostrichidae), or the maize weevil, *Sitophilus zeamais* Motschulsky (Col.: Curculionidae). An IPM strategy for storage pests, developed by the Larger Grain Borer project of the International Institute of Tropical Agriculture (IITA) in Benin, was tested in the field. The strategy comprises of the use of local maize varieties (or varieties with good husks cover characteristics) in combination with timely harvest of the maize, sorting of cobs for visual damage prior to storage and general store hygiene, carried out in a collaborative manner, involving different stakeholders, i.e., local farmers and representatives of the national plant protection services (SPV) of Benin and Togo. Large scale field trials in Benin and Togo were conducted in a 'competitive' manner that is, the three different storage regimes, the IPM developed by IITA, the storage systems recommended by SPV, and the local storage practices of the farmers were directly compared in a collaborative manner.

After a general introduction, the second chapter of this document deals with the experiment conducted in Togo. Data on insect infestation and maize losses revealed the high efficiency of the IPM approach compared to the traditional storage methods of the farmers although the low yield of the local variety led to important shortcomings of the IPM package at the farm level. On the store level, no significant differences were recorded between the IPM approach

and the recommendation by SPV. These results suggest that sustainable stored product protection through an IPM approach is a sound alternative to the use of chemicals.

The third chapter is devoted to the IPM studies in two contrasting agro-ecological regions of Benin. The low infestation levels, particularly by *P. truncatus* during the experiments coupled with the use of the same variety (local variety Gbogbe) for both the IPM approach and the traditional storage system in the southern part of Benin lead to no detectable differences between those two storage systems. The use of the recommended insecticide provided relatively better result. However, in spite of the low density of *P. truncatus* in the northern part of Benin, both the IPM approach and the SPV storage system showed equally higher efficiency compared to the farmer's traditional method at the end of the experiment. However, maize losses at the end of the storage period in the farmers' treatment were comparatively low. The northern part of Benin, with its hotter and drier conditions compared to southern Benin, offers better conditions for maize storage. This explains why hardly any pests were recorded and no losses occurred during the first six months of storage.

The reduction of post-harvest losses due to pest attack represents a substantial contribution to food security. Our research showed that integrated approaches in maize storage although necessarily site-specific, could provide solutions that are more effective, sustainable and competitive compared to the conventional methods of post-harvest protection. Not only must losses be reduced but, in addition, this must be accomplished in an ecologically, economically and socially acceptable manner.

Population dynamic data of *P. truncatus* and its natural enemy the predator *T. nigrescens* from 1995 to 1997 in southern Benin proved the successful biological control of LGB by its predator, thereby also confirming results from other countries where biological control programs against LGB had been initiated.

Zusammenfassung

Entwicklung von integrierten Schädlingsbekämpfungsverfahren in bäuerlichen Maislagern: Experimentelle Untersuchungen in Benin und Togo.

Cyrille Gnidoté ADDA

Auf Grund der großen Bedeutung von Mais als Grundnahrungsmittel in Afrika müssen adäquate Methoden zum Pflanzenschutz entwickelt werden, insbesondere gegenüber Vorratsschädlingen wie dem Großen Kornbohrer *Prostephanus truncatus* (Horn) (Col.: Bostrichidae) und dem Maisrüsselkäfer *Sitophilus zeamais* Motschulsky (Col.: Curculionidae). Ein integriertes Bekämpfungsverfahren, entwickelt im Rahmen des "Larger Grain Borer" Projekts des International Institute of Tropical Agriculture (IITA) in Benin wurde in Feldversuchen getestet. Das Bekämpfungsverfahren basiert auf der Gebrauch lokaler Maissorten (bzw. Sorten mit guten Lieschblatteigenschaften), in Kombination mit einer frühzeitigen Ernte, einer Selektion der zu lagernden Kolben nach der Ernte (visuelle Schadsymptome) sowie einer allgemein verbesserten Hygiene in den Maislagern. Die Untersuchungen wurden in Kooperation mit Bauern der Region sowie Vertretern der nationalen Pflanzenschutzdienste (SPV) in Togo und Benin durchgeführt. Die Lagerversuche wurden in beiden Ländern einem ‚kompetitiven' Ansatz folgend angelegt so dass, drei unterschiedliche Verfahren der Lagerhaltung, d.h. das integrierte Bekämpfungsverfahren des IITAs, die von beiden Pflanzenschutzdiensten empfohlene Lagerhaltung sowie das von Bauern der jeweiligen Region üblicherweise verwandte Verfahren, von allen Beteiligten (Bauern, IITA Wissenschaftlern und Pflanzenschutzberatern) direkt miteinander verglichen werden konnten.

Nach einer allgemeinen Einleitung werden in Kapitel 2 die Ergebnisse der Untersuchungen in Togo vorgestellt. Daten zur Abundanz der wichtigsten Lagerschädlingen sowie zu den

Maistrockengewichtsverlusten zeigten eine Überlegenheit des integrierten Lagerhaltungsverfahrens des IITAs gegenüber den von den Bauern üblicherweise verwandten Lagerhaltungstechniken. Wenn allerdings der Ertrag der eingesetzten Maissorten mit berücksichtigt wurde, mußten in der IITA Variante auf Grund des geringen Ertrages der hier eingesetzten lokalen Maissorte beträchtliche Defizite konstatiert werden. Betrachtet man jedoch nur die Verlustsituation in den Lagern, so konnten keine Unterschiede zwischen dem integrierten Verfahrens des IITAs und dem von SPV empfohlenen Einsatz von Insektiziden nachgewiesen werden.

In dem 3. Kapitel werden die Ergebnisse der Untersuchungen in zwei kontrastierenden agrarökologischen Zonen Benins vorgestellt. An dem südlichen Versuchsstandort führten die allgemein sehr niedrige Abundanz von *P. truncatus* und der gleichzeitige Einsatz der selben lokalen Maissorte ('Gbogbe') in der IITA sowie der Bauern-Variante nur zu geringen Unterschieden zwischen beiden Lagerhaltungsverfahren. Der Einsatz eines Insektizids zum Lagerschutz (SPV-Variante) führte zu vergleichsweise besseren Ergebnissen. Trotz des geringen Befalls durch *P. truncatus*, zeigten sowohl das integrierte Lagerhaltungsverfahren des IITAs sowie der von SPV empfohlene Einsatz von Insektiziden eine gewisse Überlegenheit im Vergleich zu der bäuerlichen Variante, obwohl selbst hier die Maisverluste zu Ende der Lagerhaltungszeit relativ gering waren. Das heiße und trockene Klima im Norden Benins ist allgemein besser geeignet für eine langfristige Maislagerung. Dies ist auch der Hauptgrund warum im Laufe der durchgeführten Lagerversuche nur sehr geringe Schädlingsdichten und zu vernachlässigende Maisverluste verzeichnet wurden.

Eine Reduzierung von Nachernteverluste stellt einen gewichtigen Beitrag zur Nahrungssicherung dar. Die hier vorgestellten Ergebnisse zeigen, daß standortspezifische integrierte Lagerhaltungsverfahren effektive und nachhaltige Verfahren des Nachernteschutzes darstellen, die mit dem konventionell-chemischen Nachernteschutz durchaus konkurrieren können. In Zukunft sollte das Augenmerk nicht nur auf einer Verringerung der Lagerverluste liegen, sondern diese sollten in einer ökologisch, ökonomisch und sozial vertretbaren Art und Weise erreicht werden.

Daten zur Populationsdynamik von *P. truncatus* und seines natürlichen Feindes, der räuberischen Histeride *Teretrius nigrescens* Lewis im Süden Benins belegten eine erfolgreiche biologische Schädlingsbekämpfung des Großen Kornbohrers und bestätigten so Ergebnisse aus anderen afrikanischen Ländern, in denen ebenfalls biologische Schädlingsbekämpfungsprojekte gegen *P. truncatus* initiiert wurden.

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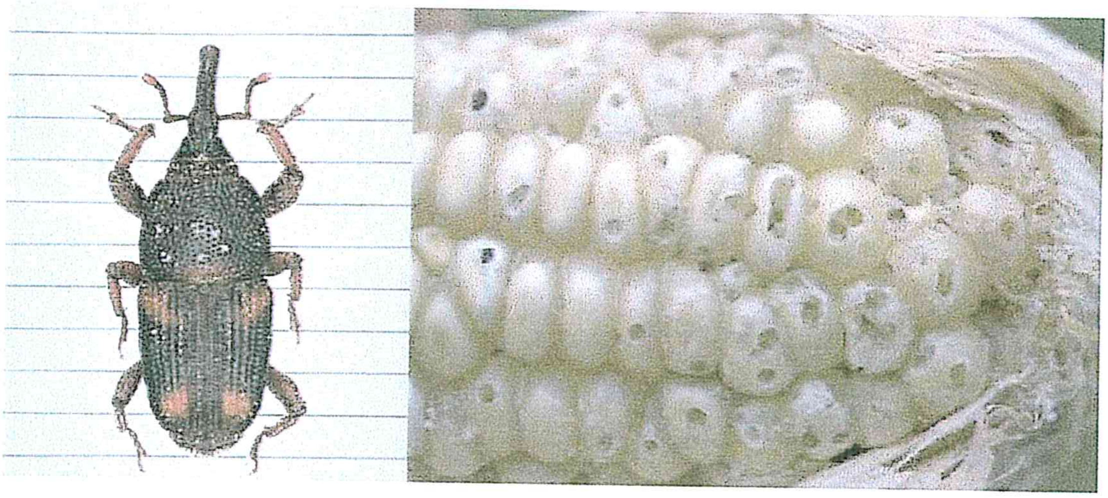
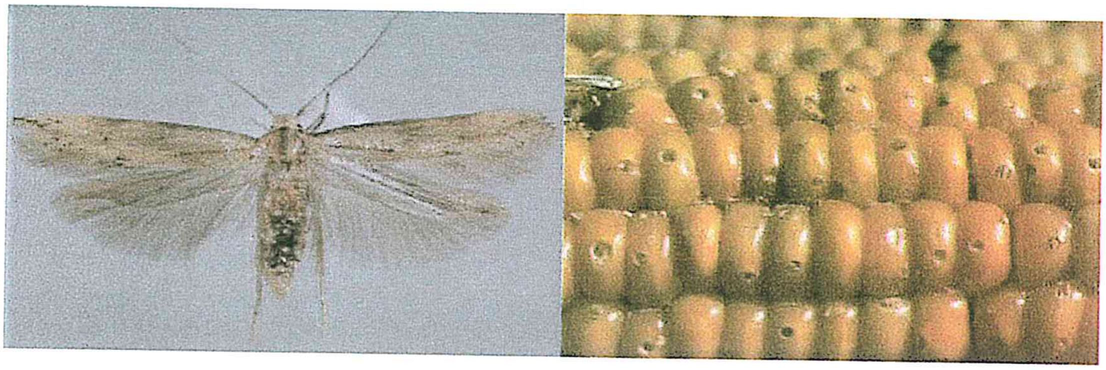
1 Introduction

Maize (*Zea mais* L.) originated in the Americas (CIMMYT, 1990) and is grown world wide both as a subsistence and as a commercial crop. It is the most important cereal crop in West Africa, providing a source of income for both small- and large–scale farmers. From the production of maize, through its storage up to consumption, many problems are encountered by farmers, traders and consumers, i.e., mainly insect, bird and rodent attack, plant diseases, fungal infections and subsequent toxin contamination of stored commodities. These factors pose an inherent danger to food security for millions of people (FAO, 1992). While the maize weevil *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) (Picture1.1 (A)) and the angoumois grain moth *Sitotroga cerealella* Olivier (Lepidoptera: Gelechiidae) (Picture 1.1 (B)) are two important maize storage pests cosmopolitan in their distribution, a third one, the Larger Grain Borer (LGB) *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) (Picture 1.1 (C)), native to Mexico and Central America (Markham et al., 1991), became established in East and West Africa during the 1980s. The accidental introduction of LGB into Africa (Dunstan and Magazini, 1981; Harnisch and Krall, 1984) led to a sudden increase in maize and cassava losses, the farmers' most important staple food crops (Hodges et al., 1983; Pantenius, 1988; Borgemeister et al., 1994). The presence of the beetle has been confirmed to date in at least 15 African countries (Hodges, 1994; Adda *et al.*, 1996; Sumani and Ngolwe, 1996; Roux, 1999; Anonymous, 2000a). Conventional methods for control of this insect and associated pests, based on insecticide treatment of the grain, have not been widely adopted in West Africa, mainly due to socio-economic constraints, e.g. the distribution of pesticides (Adda, 1991; Agbaka, 1996). Moreover pesticides pose serious health hazards to users and consumers (Anonymous 2000b).

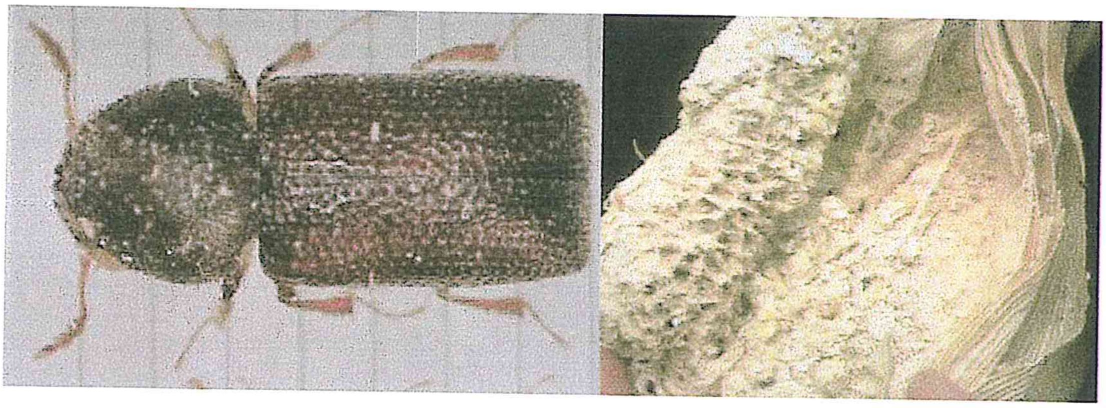
A more sustainable solution is urgently needed. The recent establishment, spread and impact (Picture 1.2) of the natural enemy of LGB, the predator *Teretrius nigrescens* Lewis



(A)- *Sitophilus zeamais* and its damage on maize cob (source: GTZ, 1988)



(B)- *Sitotroga cerealella* and its damage on maize cob (source: GTZ, 1988)



(C)- *Prostephanus truncatus* and its damage on maize cob (source: GTZ, 1988)

Picture 1.1 Adult of three primary insect pests and their damage on maize cob

(Coleoptera: Histeridae), introduced from the pest's area of origin in the early 1990s, is providing an good control of LGB populations in maize stores in West and East Africa (Mutlu, 1994). The predator has been released so far in Togo, Benin, Ghana and Kenya (Biliwa et al., 1992; Anonymous, 1992; Compton and Ofusu, 1994; Giles et al., 1995) and impact data from Kenya, Togo and Benin showed its efficiency in reducing the population density of LGB and subsequent losses (Giles et al., 1995; Böye et al., 1997; Borgemeister et al., 1997; Schneider, 1999). However, high damage is sometimes noticed in stores with low density of LGB and is attributable to a whole complex of insects, mainly *S. zeamais*.

Picture1.2 Adult *T. nigrescens* feeding on larvae of *P. truncatus* (source: GTZ, 1988)

In order to complete biological control of *P. truncatus*, compatible control measures, based especially on appropriate farmers' management practices, which avoid pesticide use as much as possible, need to be combined into integrated control strategies, acceptable to farmers. Previous experiments of the LGB Project of International Institute of Tropical Agriculture (IITA) had demonstrated the possibility of reducing insect infestations in rural maize stores through the following practices: (i) the use of local maize varieties, (ii) early harvest of the maize (approximately three weeks after physiological maturity), (iii) selection of maize cobs prior to storage (i.e., removing all visually damaged cobs before storage).

Investigations on maize resistance to insects attack revealed that grain hardness and size can considerably affect the bionomics of LGB (Li, 1988). Moreover, phenolic acids in certain Mexican maize varieties are considered as resistance factors against *S. zeamais* and *P. truncatus* (Arnason et al., 1992 & 1997). However, field and laboratory experiments at IITA showed that resistance in maize to *P. truncatus* and *S. zeamais* is more likely associated with husk cover than with grain characteristics (Meikle *et al.*, 1998). The number of husk leaves, leave thickness and the husk tip extension constitute physical barriers for any penetrating insect pest. In most breeding programs, the yield of the crop is primary objective. However, in maize this leads to a reduction in the number of husk leaves in high-yielding varieties, resulting in poor storability of such varieties (J. Kling, IITA, personal communication). Therefore we mainly focused on the use of so-called local varieties, with good husk characteristics and hence a good performance in store. Field infestation of maize by *S. zeamais* leads to higher population levels of maize weevils in the store (Markham, 1981). There is equivocal evidence for the importance of field infestation of maize by *P. truncatus* for the subsequent population dynamics of the beetles in stores (Henckes, 1992; Wright *et al.*, 1993). Previous experiment at IITA demonstrated that leaving the maize in the field for extended periods after physiological maturity results in severe grain losses, mainly due to *P. truncatus,* during the storage period (Borgemeister *et al.*, 1998). Early harvest of the maize was thus a second interesting component to consider in our IPM approach. At the beginning of storage, the distribution of *P. truncatus* is extremely clumped (Meikle *et al.*, 1999). Moreover, even small colonies of *P. truncatus* at the beginning of the storage period can lead to extremely high population densities eight months later (Scholz *et al.*, 1997). In another field experiment previously conducted at IITA, selecting the cobs for visual damage prior to storage had a direct and substantial effect on the initial infestation levels of maize cobs by *P. truncatus* and *S. zeamais* (Borgemeister *et al.*, 1994). Therefore, the removal of cobs visibly infested by insects at harvest was incorporated as the third component into our IPM package.

The efficiency of the IPM package was compared with existing storage protection systems, i.e. the farmers' traditional methods of storage and the storage systems recommended by the national agricultural extension services, in our case represented by the plant protection services of Benin and Togo (SPV). Farmers' traditional methods of storage vary according to region, agro-ecological zones and particular socio-economic considerations. However, one common feature was that most of the farmers stored their maize without thorough storage practices. Hence most of the farmers' storage systems were characterised by lack of storage hygiene, ineffective or no protection measures, abuse of non recommended chemical products (insecticides) etc.. The officially recommended storage protection systems in Benin and Togo favour the use of a binary insecticide called 'Sofagrain', applied using a 'sandwich' technique where layers of non-treated cobs are separated by layers of cobs treated with the insecticide (Gwinner et al., 1996). Sofagrain constitutes of two active ingredients: pyrimiphos methyl and deltamethrin which ensure adequate control of the whole complex of storage insects. The pyrethroid Deltamethrin is particularly effective against *P. truncatus* (Golob *et al.*, 1990; Biliwa, 1988), whereas the organophosphate pyrimiphos methyl is less toxic to LGB but very well controls the other important post-harvest pests of maize, for instance *S. zeamais*.

SPV agents and farmers participated in the establishment of the experiments and in the evaluation of the results. A rapid and accessible method of evaluation was developed, mainly to help farmers to draw their own conclusions, by arranging the experiments in a competitive manner (i.e., the three different treatments had to compete with regard to farmers' acceptance and appreciation).

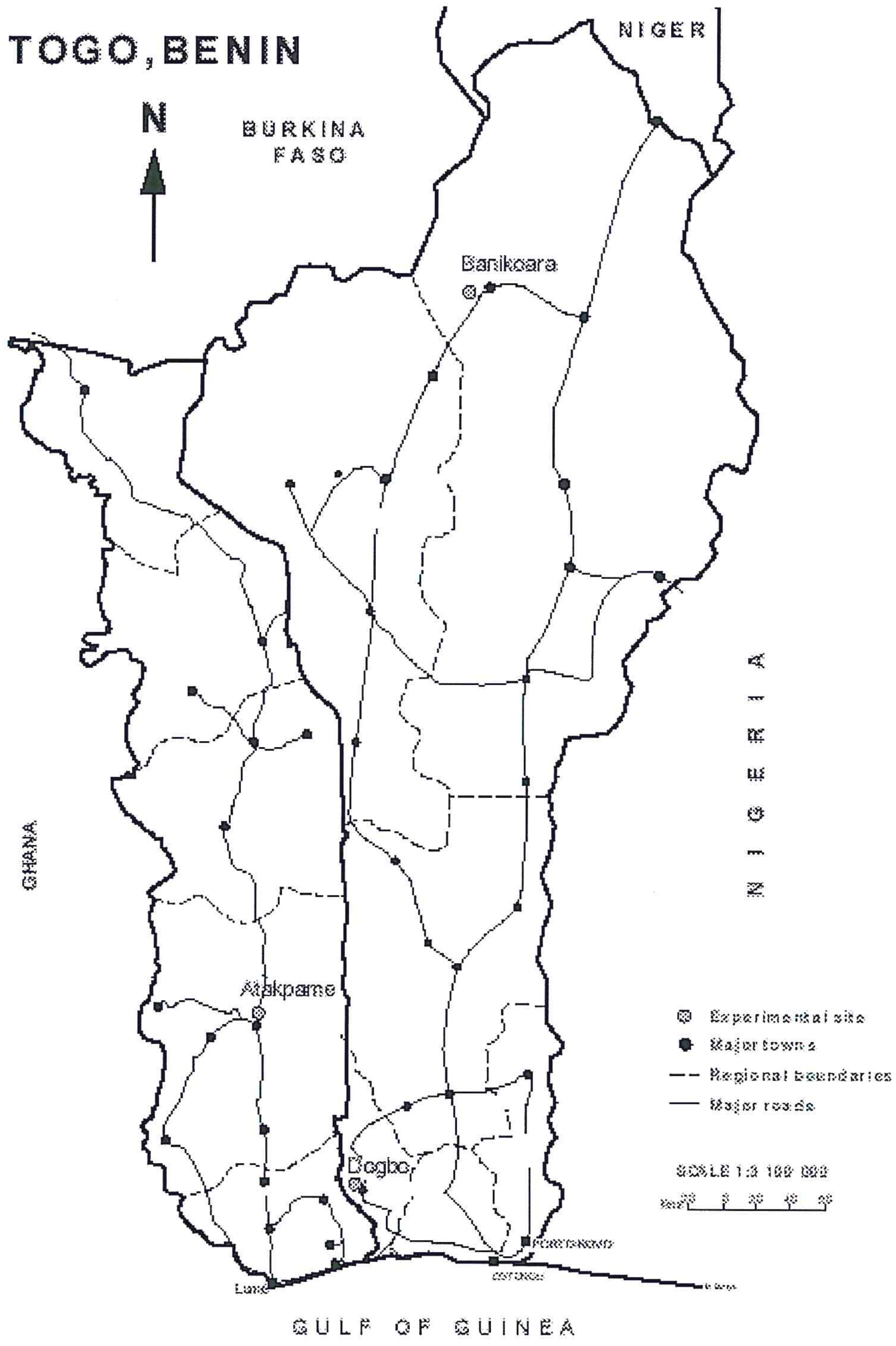


Figure1.1 Experimental sites in Benin and Togo (West Africa)

Prior to the development of sustainable IPM packages, it is important to gather as much as possible, information on farmer's traditional methods of farming and storage. Such an approach improves the acceptability and success of any IPM proposition. Therefore before the actual experiments, rapid surveys were carried out (using questionnaires and interviews) with farmers randomly selected throughout each area of research. With this we intended to elucidate the major agricultural practices and post-harvest constraints in the particular regions. It is important to note that maize varieties sown, storage equipment used, mode of storage, infestation levels by insects, especially in the case of *P. truncatus*, and agricultural practices in general, vary according to agro-ecological zones. Therefore, the experiments were conducted in two agro-ecologically-contrasting zones in Benin and in Togo, two West African countries seriously threatened by LGB.

2 Assessment of an Integrated Pest Management approach in post-harvest maize: a case study from Togo (West Africa)[1].

2.1 Abstract

A large-scale experiment on maize storage systems was carried out in Atakpamé (Plateaux region of Togo), between autumn 1996 and spring 1997. An integrated pest management (IPM) approach based on research findings at the International Institute of Tropical Agriculture (IITA) and intended to control storage pests in rural maize stores was compared with (1) the locally-prevalent methods of storage of farmers from the Plateaux region and (2) with the storage system recommended by the National Plant Protection Service in Togo (SPV). Two storage systems were designed based on IPM principles, one using a local variety (chosen mainly for its excellent husk cover characteristics), the second including an improved variety (with higher yield and moderately good husk cover characteristics), and both depending on visual selection of cobs at harvest to reduce initial insect infestation. The experiment was conducted in a collaborative manner, including representatives of the SPV, farmers from the Plateaux region, and researchers from IITA. Population dynamics of major insects and associated losses to stored maize were monitored monthly over an 8-month period, while an on-site evaluation of pest infestation and losses was conducted, with the collaborators, after six and eight months of storage. The performance of the different storage systems was evaluated according to pest densities, grain weight losses and cost-efficiency.

The IPM-based systems were as effective as the pesticide-based SPV system in reducing infestation and grain losses.

[1]To be published as C. Adda, C. Borgemeister, A. Biliwa, W.G. Meikle, R.H. Markham, H.-M. Poehling: Assessment of an Integrated Pest Management approach in post-harvset maize: a case study from Togo (West Africa). To be submitted to *Agriculture, Ecosystems and Environment.*

When only the incremental net return from the storage practices were considered, both the IPM approach and the recommendations of the SPV performed better than the farmers' methods of storage, mainly because of lower pest densities and associated grain weight losses. However, when the yield (per ha) of the different maize varieties used in the respective storage systems were included in the cost and return analysis, the IPM storage systems using the local variety was not competitive, mainly because of the low yield of the variety advocated.

2.2 Introduction

In sub-Saharan Africa, maize, *Zea mays* L., has become one of the most important staple foods (Fanou *et al.*, 1991; FAO, 1992; Markham *et al.*, 1994; Lutz, 1994; Compton, 1997; World Bank, 1997). As the main cereal grown in Togo, maize is produced almost exclusively by small-scale farmers (Albert, 1992; IDRC, 1998) and is stored generally in traditional granaries both for food, feed and for sale (Richter *et al.*, 1997, 1998). In West Africa, losses caused by post-harvest pests like the maize weevil *Sitophilus zeamais* Motschulsky and the Angoumois grain moth *Sitotroga cerealella* (Olivier) constitute a major constraint to increasing maize production through the introduction of improved varieties (Markham et al., 1994). Since the accidental introduction of the larger grain borer *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) to East Africa in the late 1970s and to West Africa in the mid 1980s, the situation has deteriorated further (Hodges, 1994). Originating from Central America and Mexico (Markham *et al.*, 1991), the beetle to date has spread to fifteen African countries (Hodges, 1994; Adda *et al.*, 1996; Sumani and Ngolwe, 1996; Roux, 1999; Anonymous, 2000a). These countries include Tanzania (1981), Kenya (1983), Burundi (1984), Togo (1984), Benin (1984), Guinea (1987), Ghana (1989), Burkina Faso (1991), Nigeria (1992), Malawi (1992), Rwanda (1993), Niger (1996), Zambia (1996), Namibia

(1998) and South Africa (1999). In Tanzania, dry weight losses of maize in excess of 30% over a short storage season have been recorded locally (Hodges *et al.*, 1983; Keil, 1988; Henckes, 1992). With the introduction of *P. truncatus*, average dry weight losses of farm-stored maize in Togo were estimated to have risen from 7 to 30%, for a storage period of six months (Pantenius, 1987, 1988; Helbig, 1995; Richter *et al.*, 1997).

Chemical control strategies based on the application of a binary insecticide, combining a synthetic pyrethroid to control *P. truncatus* with an organophosphate to protect the commodity against other storage pests, especially *S. zeamais*, were introduced with considerable success in East Africa (Golob, 1988). Due to socio-economic constraints, such strategies, however, have not been widely adopted in several West African countries where farmers often use inappropriate cotton insecticides to protect their stored commodities (Adda, 1991; Albert, 1992; Agbaka, 1996; Meikle *et al.*, 1999). Recent reports of high death tolls in Benin due to misuse of Endosulphan clearly highlight the inherent health hazards both for farmers and consumers (Anonymous, 2000b). These factors have stimulated the search for biologically based alternatives (Böye *et al.*, 1988). As an outbreak pest, causing spectacular losses in its new area of distribution in Africa but being of minor importance in Central America and Mexico, classical biological control was considered as a promising approach for sustainable control of *P. truncatus* (Markham *et al.*, 1991). During exploratory surveys, the histerid predator *Teretrius nigrescens* (Lewis) was identified as the key natural enemy of *P. truncatus* in Central America and Mexico (Haines, 1981; Rees, 1985; Böye *et al.*, 1988). The predator was first released in Togo in early 1991 and its subsequent establishment has been confirmed throughout the country (Biliwa *et al.*, 1992; Agounke and Biliwa, 1999). The ability of the predator to control *P. truncatus* in rural storage conditions in Togo was demonstrated by Mutlu (1994). Moreover, impact assessment studies in Togo (Richter *et al.*, 1997, 1998), Kenya (Giles *et al.*, 1995, 1996), and Benin (Borgemeister *et al.*, 1997;

Schneider, 1999) showed that *T. nigrescens* can substantially reduce *P. truncatus* infestations. However, despite the considerable success of biological control of *P. truncatus*, in certain regions in East and West Africa larger grain borer infestations in rural maize stores are still a persistent problem for small scale farmers (Mück and Bell, 1999).

Previous experiments by researchers from the International Institute of Tropical Agriculture (IITA) investigated the usefulness of several integrated control techniques, compatible with the use of natural enemies, for reducing *P. truncatus* and *S. zeamais* infestations in maize stores. These included: removing all visually damaged maize cobs prior to storage (Borgemeister *et al.*, 1994); early harvest of maize (two to three weeks after physiological maturity) (Borgemeister *et al.*, 1998); and the use of varieties with good husk cover characteristics (strong and thick husks, and long tip extension) (Meikle *et al.*, 1998a).

The main objective of our present study was to combine these control options into an integrated pest management (IPM) strategy for post-harvest protection of maize and evaluate it, with farmers, under realistic conditions, by monitoring the population dynamics of the primary pests, and by quantifying the economics of such an IPM strategy. We chose a collaborative research approach, where in a competitive manner, different post-harvest protection strategies, specifically, the common practice of small-scale farmers of the region where the trial was carried out, the maize storage protection system recommended by the Togolese National Plant Protection Service (SPV) and the IPM approach developed by our research team, were jointly tested and compared by the stakeholders most closely concerned: local farmers, agents from SPV and researchers from IITA.

2.3 Material and Methods.

The storage experiment was conducted in a village near Atakpamé, in the Plateaux region of Togo, approximately 190 km north of the capital Lomé, located in the southern guinea savannah. The Plateaux region was particularly affected by the introduction of *P. truncatus* (Wright *et al.*, 1993), and high infestation levels of larger grain borer and *S. zeamais* still persist in maize and cassava stores (A. Biliwa, SPV Togo, pers. comm.).

2.3.1 Exploratory survey

An important prerequisite for the successful development and implementation of a sustainable post-harvest IPM strategy, is to gather as much information as possible on farmers' traditional methods of farming and storage (Markham *et al.*, 1994; Compton, 1997; van Huis and Meerman, 1998). Hence, prior to the onset of the actual storage experiment, rapid surveys were carried out (involving questionnaires and interviews) with 50 farmers opportunistically selected (by chance encounter) throughout the Plateaux region. By this means, we intended to elucidate the major agricultural practices and post-harvest constraints faced by farmers in this region. Survey results revealed that the great majority of farmers in the region predominantly intercrop maize with cowpea (*Vigna unguiculata* (L.) Walpers (Fabaceae)), which necessitates an early harvest of the maize crop. Three maize varieties were largely used by farmers: the local variety Gbade, the improved variety Ikenne (introduced in Togo by the Sasakawa Global 2000 extension project), and the hybrid NH1. Moreover, in the region around Atakpamé, farmers stressed that *P. truncatus* is the major pest in their maize stores. Three major trends in post-harvest protection in maize were observed: Some farmers treated their maize with cotton insecticides, whose use on other crops is officially prohibited (A. Biliwa, SPV Togo, pers. comm.); the next largest category of farmers stored their maize without any specific protective measures while only a small proportion of the interviewed farmers applied the binary insecticide Sofagrain (0.05% deltamethrine + 1.5% pirimiphos methyl), recommended by SPV, or local products such as ash or neem leaves (*Azadirachta indica* A. Juss. (Meliaceae)). Nearly all farmers stored their maize as cobs with the husk intact. The most commonly used storage structure in the Plateaux region is the 'Awa' store, similar to the 'Ava' type described by Borgemeister et al. (1994) in southern Benin.

2.3.2 Assessment of the yield of maize varieties

Some days before harvest, the yield (dry weight of maize grain per ha) of the different varieties involved in the experiment (the local variety Gbade, and the two improved varieties, Ikenne and NH1) was assessed together with the farmers and representatives of SPV. Six 5 m $\times$ 5m plots of each variety were selected at approximately equal distance along the main diagonal of the respective fields. Subsequently the plots were harvested and the following parameters were recorded: Number of cobs, weight of the cobs with and without husks, average grain weight, and the grain moisture content. The latter was determined in the laboratory, using a standard oven-drying technique (ISO, 1980). The mean grain weight value per plot ($25m^2$) of each variety was then extrapolated to 1 ha to estimate the yield of the different varieties.

2.3.3 The treatments

In all treatments 'Awa' stores were used. An 'Awa' store consisted of eight strong wooden posts supporting a 2 x 2 m split teak platform on which maize cobs with husks intact were carefully stacked horizontally to form a circular wall, with loose cobs placed within; the walls of maize were then wrapped with creepers, and finally covered with a thatched roof held by a central stick. Chicken wire was used to divide the store into eight equal vertical sections, radiating from the central post. All maize used in the experiment was purchased from local farmers immediately before harvest. Five storage systems were designed comprising different combinations of maize varieties, maize handling and the use (or otherwise) of the recommended insecticide Sofagrain (table 2.1). Due to the common practice of intercropping

Table 2.1 Synopsis of the experimented storage systems in Togo (West Africa)

Treatments	Maize Varieties			Post-harvest management of maize		
	Local	NH1	Ikenne	No handling	Selection of cobs	Insecticide
T1		•			•	
T2			•	•		
T3	•				•	
T4			•		•	
T5			•			•

NB: Horizontally distributed points (•) belong to the same storage system maize with cowpea in the Plateaux region, all maize varieties were early harvested (two to three weeks after physiological maturity), to allow a better development for the cowpea crop. The experiment was arranged in a randomised block design, with five treatments (storage systems), each replicated three times. The stores were sited in a farmer's compound and the minimum distance between two stores was 15 m. Each store was loaded with 500 kg of maize cobs, estimated using a local bowl with a capacity of approximately 25 kg of maize cobs, previously determined using a hand-held balance (Salter, Kansas, US Model 233). The storage systems were described as followed:

- Treatment 1: 'NH1 + selection of cobs', referred to as 'T1':

The improved variety NH1, with hard grains, long production cycle (120 days), poor husk cover and comparatively high yield potential (3-4 $t.ha^{-1}$) was used. Because of high initial infestation of the cobs by lepidopteran and coleopteran pests, maize cobs had to be sorted prior to storage. For each store (replicate), approximately 800 kg of maize was harvested, from which 500 kg of the selected cobs were finally stored. The remaining 300 kg of attacked cobs were immediately de-husked, shelled, cleaned, sun-dried for some days, and then sold although at a relatively low price. This treatment resembles some farmers' storage practice in the Plateaux region.

- Treatment 2: 'Ikenne without pre-storage handling', referred to as 'T2':

In this treatment the improved variety Ikenne was used. Ikenne is more floury than NH1, reaches physiological maturity within 90 days and has better husk cover properties than NH1. With these characteristics Ikenne very much resembles a local variety, though Ikenne has a higher yield potential (3-4 $t.ha^{-1}$). Approximately 500 kg of cobs were harvested and stored without any sorting or chemical treatment, reflecting the traditional methods of storage by a large majority of farmers in the Plateaux region. This means that storage hygiene is poor or absent, and that no significant protective measures against post-harvest pests are applied.

- Treatment 3: 'Gbade + selection' referred to as 'T3'

The variety Gbade, a local, short cycle (approx. 90 days) and floury variety, with good husk cover characteristics, but yielding less than 1.5 $t.ha^{-1}$, was used. Approximately 600 kg of cobs were harvested. The selection procedure (for visual damage) resulted in 500 kg of sorted maize for storage. The remaining 100 kg were immediately processed, shelled, sun-dried for some days, and sold at a relatively low price. In spite of its low yield potential, this local variety was chosen for the trial because of its good husk characteristics. This treatment was one of the storage systems designed by the collaborating researchers as the basis for an IPM approach, based on the previously-demonstrated importance of good husk cover as the starting point for sound store management.

- Treatment 4: 'Ikenne + selection' referred to as 'T4'

The improved variety Ikenne was used because of its high adoption rate by Togolese farmers (A. Biliwa, SPV Togo, pers. comm.) and its comparatively good husk cover, particularly with regard to coverage of the apex of the cob. Approximately 700 kg of cobs were harvested, from which, 500 kg of maize cobs were selected (based on visual inspection) for storage. The remaining 200 kg were immediately processed, shelled, sun-dried for some days and then sold. This treatment was the second storage system chosen by researchers, based on IPM principles.

- Treatment 5: 'Ikenne + insecticide' referred to as 'T5'

In this treatment the improved variety Ikenne was used. Approximately 500 kg of maize cobs with the husk on were treated with Sofagrain, applied as a multi-layer 'sandwich', in which layers of cobs are separated by layers of the insecticide (Gwinner et al., 1996). The insecticide was applied at a rate of one packet of 50 g Sofagrain per 100 kg maize cobs. An additional packet of Sofagrain was used to treat the platform supporting the cobs and the outside layer of the cobs. Thus, a total of six packets of Sofagrain (for a total of 300 g of insecticide) were applied per store. The combination of the use of a high yielding improved maize variety and the use of a binary insecticide during storage is essentially what SPV recommends to Togolese farmers.

2.3.4 Cob sampling and data collection

At monthly intervals one of the eight vertical sections, selected at random, from each store was destructively sampled. Sampled cobs were immediately replaced by identically treated cobs taken from a nearby bulk store to assure the physical integrity of the grain in the experimental store. Maize cobs were sampled for two purposes: Sampling for a detailed evaluation of the storage systems in the laboratory referred, to as 'monthly recorded samples', and sampling for an on-the-spot collaborative evaluation with the farmers and representatives of SPV.

- Monthly recorded samples

Each month for a total storage period of eight months, four samples of 25 cobs per store were taken from the upper, middle, and bottom part as well as from the surface layer of each sampled sector of the store. In the laboratory, these samples were used to assess damage and losses, using the standard count and weigh method (Harris and Lindblad, 1978; Boxall, 1986). Moreover, the moisture content of the grains was recorded, using the standard oven-drying technique (ISO, 1980), from a pooled sample of the shelled grain. Finally, the cobs were used to quantify insect population densities, focussing on the two primary pests, *P. truncatus* and *S. zeamais*, and on *T. nigrescens*, the natural enemy of larger grain borer. The shelled grains were thoroughly sieved, and then the beetles were carefully collected, identified and counted.

- On-farm evaluation of stores

On-farm evaluation with local farmers and SPV representatives took place after six and eight months of storage. A total of nine samples of 100 cobs were selected per treatment (from top, middle and bottom layers of each of three replicate stores), de-husked and classified according to the following two categories: 'intact' and 'attacked or destroyed'. For each category of cobs, data on cob and grain weight (after shelling) were recorded. Thereafter, grains were sieved and the beetles quickly collected. The percentage of intact cobs and the approximate number of pests were used to rate the performance of the storage systems under consideration. Although less precise than the assessment in the laboratory, this technique allowed a rapid evaluation by farmers and SPV representatives, and permitted them to evaluate directly and on-site the different storage systems.

2.3.5 Statistical analysis

Prior to the statistical analysis of the data from the monthly-recorded samples, the means of data on insect density and losses for each replication across all treatments were rank-transformed. Afterwards, a multiple endpoint analysis, based on the sum over the ranks, within the blocks (replications), for each storage system (treatment) and over all time points, was conducted. Subsequently, the General Linear Model (GLM) procedure for a univariate randomised block design was performed (SAS Institute, 1992), and an adjusted all-pair comparison Tukey test was used to assess differences between the storage systems (treatments).

Stepwise multiple regression analyses (Sokal and Rohlf, 1995) were used to evaluate for each storage system the impact of maize weevil and larger grain borer on the percentage of losses after eight months of storage.

Data from the assessment with farmers and representatives of SPV was analysed by means of ANOVA. Means were separated using the Student Newman Keuls sequential mean comparison (Zar, 1974). Because of the great difference in 100-cobs weight of the varieties involved in the experiment, the statistical mean comparison of the 'grain weight parameters' was run only for the storage systems T2, T4 and T5 in which the same variety, Ikenne, was used. To normalise variances for analysis, insect densities, and cob and grain weight parameters were log (x+1) transformed, while percentage of losses, moisture content and cob infestation levels were arcsin-transformed.

2.3.6 Cost and return analysis.

A farm-level economic analysis of the five storage systems was performed. In the analysis we assumed that the 500 kg of maize cobs per store (the capacity of a typical 'Awa' store) were kept for a total storage period of eight months. The cost and return analysis of the different storage systems was conducted after eight months of storage, when maize prices on the regional and urban markets are at their highest level (A. Biliwa, SPV Togo, pers. comm.). Farmers and representatives from IITA and SPV valued the maize according to the current prices and quality categories observed on four markets in the vicinity of the experimental site. Conducting an economic analysis in rural maize stores as in our case implies certain compromises. Hence, the initial loss at the onset of storage was considered equal for the different treatments installed. Thus, the initial value of the maize in all stores was assumed to be the same. As our analysis aimed at assessing and comparing the additional return provided by post-harvest storage practices in the different storage systems, costs for pre-harvest agronomic interventions like ploughing, sowing, weeding, applying fertiliser, harvesting etc. were not considered in the analysis.

The cost and return analysis of different storage systems was run using variables such as the 'net return from storage in store' (NRS), the 'value of the maize rejected by the cob selection procedure' (VMR) at the beginning of storage and the 'net return including the yield of the maize variety' (NRY). The latter parameter was based on the output of 1 ha. The NRS values were calculated using the initial value of the stores at the beginning of storage, the costs related to post-harvest care and the final value of the store determined by the dry weight losses of the individual stores in the respective treatments at the end of the storage period. For each storage system, the NRS and VMR values derived from a given quantity (Qh) of harvested maize. The separation and immediate processing and selling of the 'attacked' cobs could be considered a sound decision given that all maize belonging to this category would probably have become worthless by the end of the storage period (unless treated with recommended insecticides and stored in bags).

Table 2.2 Comparison of treatments (storage systems) based on multiple endpoints analysis (performed on the sum of the ranks over means for losses and insect densities and over all time points); General Linear Models followed by least square means Tukey post hoc tests, P < 0.05

Treatments[1]	Ranks	P-value (Tukey-adjustment)				
		T1	T2	T3	T4	T5
T1	111.83	-	0.500	0.055	0.061	0.004*
T2	113.33		-	0.042*[2]	0.046*	0.003*
T3	90.00			-	0.500	0.160
T4	90.50				-	0.145
T5	74.33					-

[1]T1, T2, T3, T4 and T5 stand respectively for 'NH1 + selection', 'Ikenne no-handling', 'Gbade + selection', 'Ikenne + selection', and 'Ikenne + insecticide'.
[2] significant differences are indicated by an asterisk

We assumed then that the VMR as obtained here is a 'gain' to be taken into account based on (or arising from) the decision to consider the output of an experimental unit equal to 1 ha in the cost and return analysis. The NRY values were the extrapolated sums of the NRS and the VMR when we included the yield (i.e., the quantity of maize harvested from 1 ha).

2.4 Results

2.4.1 Population dynamics of insects and subsequent losses

According to data from the monthly-recorded samples, the tested storage systems significantly affected pest numbers and grain losses (F=9.42; DF 4, 2; P=0.0041). Significant differences were recorded between the storage systems T1 and T5, T2 and T5, T2 and T3 and T2 and T4. No significant differences were observed for any other comparisons of storage systems (Table 2.2). Densities of both *P. truncatus* and *S. zeamais* in all storage systems were relatively low until the 7th month of storage (Fig. 2.1B, 2.1C) with T1 having almost constantly the highest densities of both primary pests followed to some extent by T2.

In both T3 and T4 *P. truncatus* was absent (or present in extremely low numbers) throughout the storage period, but *S. zeamais* densities reached higher levels during the last three months of storage, particularly in T3 (Fig. 2.1C). *T. nigrescens* (Fig. 2.1A) followed the same pattern as its prey (Fig. 2.1B). Throughout the storage period, the lowest pest densities were recorded in the insecticide-treated SPV treatment T5. Due to the low pest infestation levels in all treatments, losses remained relatively low until the 7th month of storage. The massive outbreak of *P. truncatus* in both farmers' treatments led to a considerable increase in dry weight losses between the 7th and the 8th months of storage (Fig. 2.1D) and it was only then that the impact of different management strategies became apparent. When considering only the three treatments where the improved variety Ikenne was used, i.e. T2, T4, and T5, both the insecticide treatment and the cob selection procedure led to substantially lower *S. zeamais*

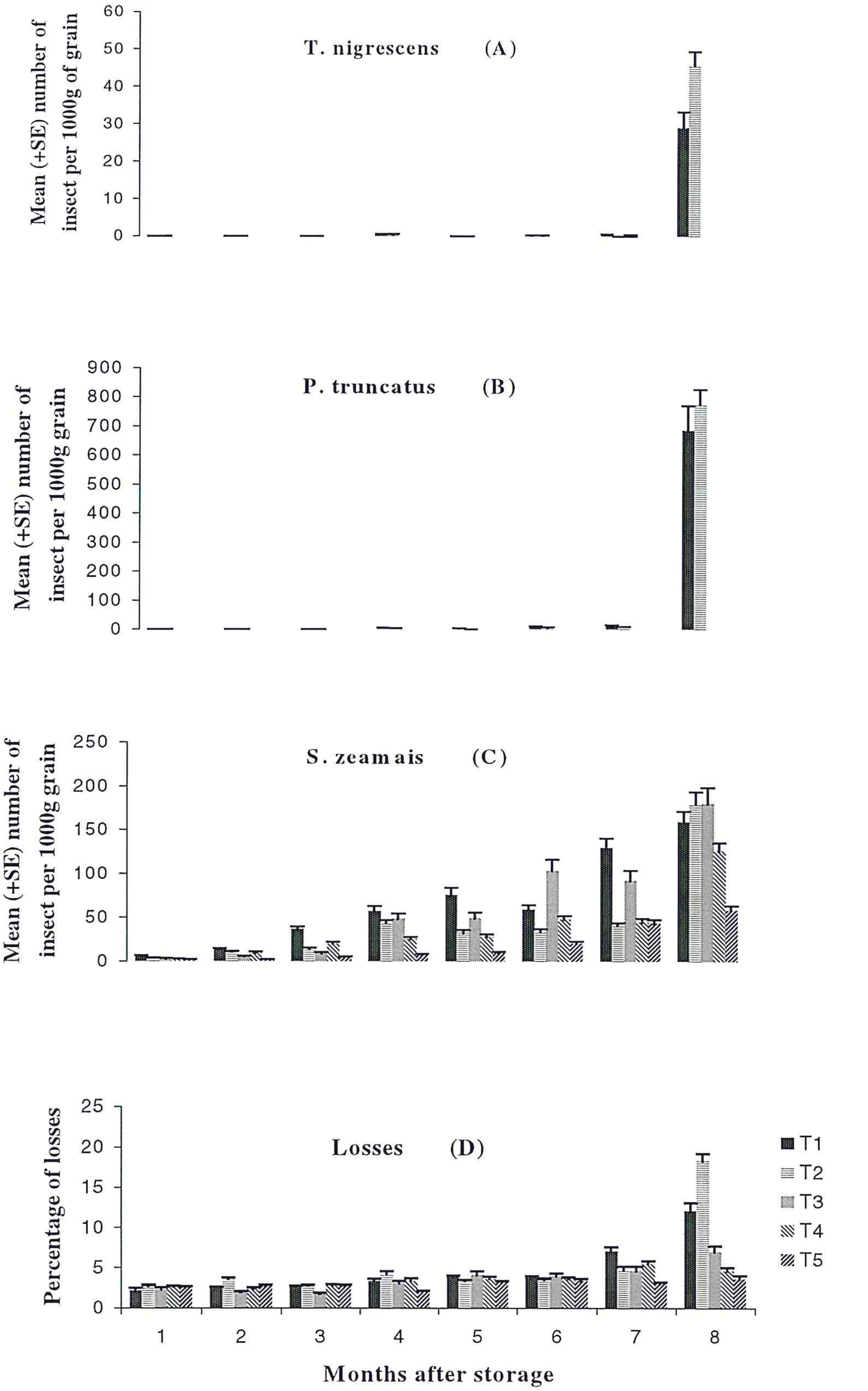


Figure 2.1 Assessment of the monthly recorded samples: insect population dynamics and subsequent losses to the stored maize.

densities compared to the 'no-handling' T2 treatment (Fig. 2.1C). Moreover, a high *P. truncatus* infestation was recorded only in T2 (Fig. 2.1B).

In terms of grain losses after eight months of storage, 61% of the variance for T1 could be explained by the multiple regression model, with both *P. truncatus* and *S. zeamais* contributing significantly to the model (Table 2.3A). Similar results were obtained for T2 (Table 2.3B). In both treatments the partial regression coefficients for *S. zeamais* were higher than those for *P. truncatus*, indicating that the latter pest had a lesser impact overall on grain losses, despite its higher mean density. For the T3, T4, and T5 treatments, 42%, 40% and 36% of the variance could be explained by the regression models, respectively (Table 2.3C, 2.3D, 2.3E), with only *S. zeamais* significantly contributing to the models.

2.4.2 Collaborative comparison of storage systems

The significantly higher number of cobs per plot (25 m^2) in the local variety Gbade compared to the improved varieties Ikenne and NH1 did not compensate for the significantly higher derived cob and grain weight (in kg of maize per 25 m^2) of the two improved varieties; hence the extrapolated maize yield (expressed as tons of maize per ha) was considerably higher in Ikenne and NH1 than for Gbade (Table 2.4).

After six months of storage the 'percentage of attacked or destroyed cobs' (PAC) did not differ significantly between T1 and T2 (Table 2.5). However, in these two storage systems significantly higher PAC values were recorded than in T3, T4, and T5 (Table 2.5). The PAC values in T5 were significantly lower than in T4 but not lower than in T3. At the sixth month of storage, *P. truncatus* and *T. nigrescens* were only recorded in T1 and T2. The density of *S. zeamais* in T5 was significantly lower than in all other storage systems (Table 2.5). Despite the generally low pest densities after six months of storage, the different store preparation regimes (cob selection and the use of insecticide) in the three treatments where the improved

Table 2.3 Multiple regression analyses of percentage dry weight loss on densities of main insect pests at the 8th month of the storage period.

		[1]B	[2]SE	t	P	[3]Mean ± SE
[4] **(A)- (T1)**						
Dependent variable	Y % loss[5] (dry weight)		0.98			12.11 ± 0.98
Independent variables	Intercept	2.99	0.91	3.29	0.001	-
	X1 density *Sz*	4.88	0.53	9.30	< 0.001	158.1 ± 12.5
	X2 density *Pt*	2.44	0.50	4.83	< 0.001	681.8 ± 85.6
Adjusted-R^2 = 0.61; No Cobs = 298						
(B)- (T2)						
Dependent variable	Y % loss		0.94			18.30 ± 0.94
Independent variables	Intercept	3.44	1.30	2.67	0.008	-
	X1 density *Sz*	4.43	0.65	6.87	< 0.001	180.1 ± 13.5
	X2 density *Pt*	3.10	0.60	5.61	< 0.001	773.5 ± 53.9
Adjusted-R^2 = 0.60; No Cobs = 298						
(C)- (T3)						
Dependent variable	Y % loss		0.78			6.98 ± 0.78
Independent variables	Intercept	3.39	0.65	5.21	< 0.001	-
	X1 density *Sz*	5.63	0.39	4.51	< 0.001	180.0 ± 18.2
Adjusted-R^2 = 0.42 ; No Cobs = 296						
(D)-(T4)						
Dependent variable	Y % loss		0.32			4.68 ± 0.32
Independent variables	Intercept	2.91	0.62	4.66	< 0.001	-
	X1 density *Sz*	4.70	0.34	3.80	< 0.001	126.5 ± 8.9
Adjusted-R^2 = 0.40; No Cobs = 299						
(E)- (T5)						
Dependent variable	Y % loss		0.39			3.66 ± 0.39
Independent variables	Intercept	4.47	0.414	10.80	< 0.001	-
	X1 density *Sz*	3.80	0.30	12.90	< 0.001	57.9 ± 5.7
Adjusted-R^2 = 0.36; No Cobs = 297						

[1] B-values are partial regression coefficients
[2] SE = Standard Error
[3] Mean values of the different variables (yield loss and insect densities, i.e number of insects per 1000 g maize) represented means of untransformed data
[4] Regression A), B), C), D) and E) represent relationships between pests and losses considering different storage systems (T1, T2, T3, T4, T5 respectively) at the eighth month storage. T1, T2, T3, T4 and T5 stand respectively for 'NH1 + selection', 'Ikenne no-handling', 'Gbade + selection', 'Ikenne + selection', and 'Ikenne + insecticide'.
[5] Prior to analysis, percentage values were arcsin-, and densities of insects ✓ (x+1)-transformed.

Table 2.4 Assessment of the yield of maize varieties

	[1]Parameters						
Varieties	No of cobs per plot (25 m^2)	Cobs weight with husks per plot (25m^2)	Cobs weight without husks per plot (25m^2)	Grains weight (kg) per plot (25m^2)	moisture content (%) per variety	Yield per plot (kg grains/25 m^2)	[3]Estimated Yield (tons of grains /ha)
NH1	92.33 a [2] ± 5.67	18.52 a ± 1.62	16.55 a ± 1.69	12.10 a ± 1.48	27.25 a ± 0.45	8.78 a ± 1.04	3.5
Ikenne	97.17 a ± 6.88	19.10 a ± 1.64	16.87 a ± 1.61	13.15 a ± 1.32	31.85 b ± 0.56	8.98 a ± 0.94	3.6
Gbade	119.33 b ± 8.22	6.12 b ± 0.39	5.02 b ± 0.30	4.05 b ± 0.24	26.45 a ± 0.51	2.98 b ± 0.2	1.2

[1] expressed as mean (± SE) of six replicates (i.e. plots of 25m^2 each).
[2] Means within a column followed by the same letter do not differ significantly; Student Newman Keuls test ($P > 0.05$)
[3] Extrapolation of the mean value per plot (25m^2) for each variety to 1 ha

Table 2.5 On-farm assessment of maize stores after six months of storage

Treatments[1]	[2]Cob parameters		[3]Grain parameters		[4]Insect densities			
	Samples Weight (100 cobs)	% attacked or destroyed cobs (PAC)	Intact grains weight	Attacked grains weight	T.n	P.t	S.z	Others
T1	9.46 b[5] ± 0.24	45.67 c ± 2.33	3.86 ± 0.13	2.78 ± 0.20	0.6 a ± 0.3	3.1 b ± 1.5	55.5 c ± 10.3	60.6 b ± 11.9
T2	13.39 c ± 0.47	46.33 c ± 4.57	5.87 a ± 0.61	4.03 a ± 0.30	0.2 a ± 0.2	2.6 b ± 1.2	23.8 b ± 4.5	30.0 ab ± 6.3
T3	6.19 a ± 0.23	30.56 ab ± 1.67	3.24 ± 0.20	1.13 ± 0.07	0.0 a ± 0.0	0.0 a ± 0.0	39.0 bc ± 8.0	37.2 ab ± 6.1
T4	12.50 c ± 0.31	36.89 b ± 2.33	6.28 a ± 0.34	3.05 b ± 0.22	0 a	0.0 a ± 0.0	27.5 bc ± 5.7	35.4 ab ± 6.6
T5	12.01 c ± 0.72	24.89 a ± 3.75	6.78 a ± 0.57	1.88 c ± 0.30	0 a	0 a	14.8 a ± 5.6	24.6 a ± 5.3

[1]T1, T2, T3, T4 and T5 stand respectively for 'NH1 + selection', 'Ikenne no-handling', 'Gbade + selection', 'Ikenne + selection', and 'Ikenne + insecticide'.

[2] expressed as mean (± SE) of nine 100 cobs samples. The weight parameters are in kg.
[3] mean grains weight derived from the participatory evaluation were statistically compared only for the storage systems using the same variety, i.e. Ikenne (T2, T4, and T5)
[4] mean number of insects ((± SE) per 1000 g (dry matter) of maize. Tn, Pt, and Sz stand for Teretrius nigrescens, Prostephanus truncatus, and Sitophilus zeamais, respectively; others insects include Tenebrionidae (Tribolium castaneum, Palorus spp.), Silvanidae (Oryzeaphilus spp., Cathartus quadricollis), Cucujidae (Cryptolestes spp.), Nitidulidae (Carpophilus spp.) etc..
[5] means within a column followed by the same letter do not differ significantly; Student Neuman Keuls test (P>0.05)

Table 2.6 On-farm assessment of maize stores after eight months of storage

Treatments[1]	[2]Cob parameters		[3]Grain parameters		[4]Insect densities			
	Samples Weight (100 cobs)	% attacked or destroyed cobs (PAC)	Intact grains weight	Attacked grains weight	Tn	Pt	Sz	Others
T1	11.28 b[5] ± 0.36	52.89 b ± 3.84	3.31 ± 0.33	3.99 ± 0.26	14.3 b ± 6.3	329.2 b ± 139.5	116.0 ab ± 27.5	77.8 b ± 19.7
T2	15.20 c ± 0.51	63.56 b ± 8.91	3.96 a ± 1	6.18 a ± 0.90	8.6 b ± 3.6	177.4 b ± 65.2	75.0 ab ± 9.2	84.6 ab ± 16.2
T3	6.98 a ± 0.54	32.00 a ± 4.34	3.50 ± 0.36	0.93 ± 0.25	0.3 a ± 0.2	0.8a ± 0.7	171.2 a ± 30.6	145.3 a ± 25.3
T4	16.22 c ± 0.54	35.44 a ± 6.58	7.93 b ± 0.83	4.16 b ± 0.89	0.1 a ± 0.1	0.6 a ± 0.3	79.5 ab ± 12.6	96.0 ab ± 21.2
T5	14.53 c ± 0.66	24.56 a ± 2.82	7.63 b ± 0.41	3.04 b ± 0.47	0.01 a ± 0.01	0.3 a ± 0.2	43.75 b ± 4.16	45.8 b ± 7.5

[1]T1, T2, T3, T4 and T5 stand respectively for 'NH1 + selection', 'Ikenne no-handling', 'Gbade + selection', 'Ikenne + selection', and 'Ikenne + insecticide'.
[2] expressed as mean (± SE) of nine 100 cobs samples. The weight parameters are in kg.
[3] mean grains weight derived from the participatory evaluation were statistically compared only for the storage systems using the same variety, i.e. Ikenne (T2, T4, and T5)
[4] mean number of insects ((± SE) per 1000 g (dry matter) of maize. Tn, Pt, and Sz stand for Teretrius nigrescens, Prostephanus truncatus, and Sitophilus zeamais, respectively; others insects include Tenebrionidae (Tribolium castaneum, Palorus spp.), Silvanidae (Oryzeaphilus spp., Cathartus quadricollis), Cucujidae (Cryptolestes spp.), Nitidulidae (Carpophilus spp.) etc..
[5] means within a column followed by the same letter do not differ significantly; Student Neuman Keuls test (P>0.05)

variety Ikenne was used (T2, T4, and T5), were reflected in significant differences in the PAC values and the weight of attacked grains (Table 2.5). Also, after eight months of storage the PAC values and the weight of attacked grains in the 'no-handling' treatment were significantly different from the ones in the 'cob selection' and 'use of insecticide' treatments. No significant difference in those parameters was noticed between the two latter treatments. Although the maize in T1 had been sorted prior to storage, high infestation levels of both primary pests were recorded (Table 2.5 and 2.6), confirming the results from the monthly assessment of stores (Fig. 2.1). After eight months of storage, the PAC values were not significantly different between the storage systems T1 and T2. Also no significant difference could be detected between T3, T4 and T5. Both the proportion of 'attacked or destroyed' cobs and the numbers of *P. truncatus* and *T. nigrescens* were higher in T1 and T2 than in T3, T4 and T5. Significantly higher densities of *S. zeamais* were observed in T3 compared to T5 (Table 2.6).

2.4.3 Cost and return analysis of storage systems

No significant differences in the NRS values of the five different treatments were recorded, although the respective values in the storage systems T3, T4 and T5 were considerably higher than the ones in T1 and T2 (Table 2.7). The high variability of the NRS values in the two latter treatments was due to great differences in losses between the individual stores (i.e. replicates) in the respective treatments, which were almost entirely attributable to variation in the infestations level of *P. truncatus*. By considering the difference in percentage between all other treatments referring to T2 the 'typical' farmers' storage system we can notice that the gain provided by the decision to store the maize following the latter system is respectively 78 %, 74% and 86 % lower than in T3, T4 and T5. T1 showed a difference of approximately 25% (Table 2.7).

Table 2.7 Cost and return analysis of the storage systems: Calculations of the net return from storage at store level

[1]Parameters	Storage systems				
Initial value of the store at the beginning of storage	T1	T2	T3	T4	T5
Quantity of maize in stores (in kg cobs)	500.0	500.0	500.0	500.0	500.0
[2]Quantity of maize in stores (Q_0) (in kg grains)	368.0	368.0	368.0	368.0	368.0
Price (P_0)	0.4	0.4	0.4	0.4	0.4
Values (V_0)	**147.2**	**147.2**	**147.2**	**147.2**	**147.2**
Costs related to post-harvest care					
Labour (workers) involved	2.0	-	1.0	2.0	-
Daily wage	15.0	-	15.0	15.0	-
Cost for sorting the cobs	**30.0**	**-**	**15.0**	**30.0**	**-**
Number of insecticide sachets used	-	-	-	-	6.0
Price per sachet	-	-	-	-	3.0
Cost for insecticide treatment	**-**	**-**	**-**	**-**	**18.0**
Final value of the store after eight months of storage					
Laboratory-derived losses per store ($L_{8\text{-}i}$)					
Replicate1 ($L_{8\text{-}1}$)	5.04	5.02	3.51	3.69	3.51
Replicate2 ($L_{8\text{-}2}$)	25.88	26.36	9.66	4.35	3.40
Replicate3 ($L_{8\text{-}3}$)	5.42	23.52	7.77	5.99	4.08
[3]Quantity of marketable maize in stores ($Q_{8\text{-}i}$)					
Replicate1 ($Q_{8\text{-}1}$)	349.4	349.5	355.0	354.4	355.0
Replicate2 ($Q_{8\text{-}2}$)	272.7	271.0	332.4	352.0	355.4
Replicate3 ($Q_{8\text{-}3}$)	348.0	281.4	339.4	345.8	353.0
[4]Price of the maize ($P_{8\text{-}i}$)	(0.8 , 1.2)	(0.8 , 1.2)	1.2	1.2	1.2
[5]Values (V_8) of the maize (mean ± SE)	**351.66**	**287.06**	**410.68**	**420.86**	**425.33**
	± 66.75	± 66.18	± 8.03	± 3.02	± 0.93
Net return from storage in store (NRS)	**174.46**	**139.86**	**248.48**	**243.66**	**260.13**
	± 66.75	± 66.18	± 8.03	± 3.02	± 0.93
Difference (in %) of the NRS in comparison to T2.	**24.74**	**0.00**	**77.66**	**74.22**	**86.00**

[1] The prices, values, wage and cost parameters are expressed in French Francs (FF).

[2] The maize was sold as grain. The 'quantity as grain' was derived from the 'quantity as cobs' using the conversion factor $\beta = 1.359$. ($Q_{grain} = Q_{cobs} / \beta$)

[3] $Q_{8\text{-}i} = [Q_0 (100 - L_{8\text{-}i})] / 100$

[4] $P_{8\text{-}i}$ had two different values according to the degree of losses: $P_{8\text{-}i} = 0.8$ for $L_{8\text{-}i} > 10\%$ and $P_{8\text{-}i} = 1.2$ for $L_{8\text{-}i} < 10\%$. The prices were defined by all participants to the evaluation and reflected the current situation on four markets in the region.

[5] $V_8 = [\sum(P_{8\text{-}i} \times Q_{8\text{-}i})] / n$; ($V_8$ is the mean value of the n = 3 stores representing each storage system)

Table 2.8 Cost and return analysis of the storage systems: Calculations of the net return including the yield

[1]Parameters	[2]storage systems				
	T1	T2	T3	T4	T5
[3]Yield (Y) in kg grains per ha	3500.0	3600.0	1200.0	3600.0	3600.0
Quantity of maize (Qh) harvested and (or not) subjected to the selection procedure)	800.0	500.0	600.0	700.0	500.0
Quantity of residual maize after cob selection (in kg cobs)	300.0	-	100.0	200.0	-
[4]Quantity of residual maize (in kg maize grains)	222.0	-	75.0	147.0	-
Price per kg grains	0.2	-	0.3	0.3	-
Value of the maize rejected by the cob selection procedure (VMR)	44.4	-	22.5	44.1	-
Net return from storage in stores (NRS) (see table 8)	**174.46**	**139.86**	**248.48**	**243.66**	**260.13**
Total net return deriving from Qh (NRS + VMR)	218.86	139.86	270.98	287.76	260.13
[5]Net return from storage including the yield (NRY) i.e., kg maize grains from 1 ha	**1301.26**	**1368.50**	**736.52**	**2011.20**	**2545.32**

[1] The price, value and net return parameters are expressed in French Francs (FF).
[2] T1, T2, T3, T4 and T5 stand respectively for 'NH1 + selection', 'Ikenne no-handling', 'Gbade + selection', 'Ikenne + selection', and 'Ikenne + insecticide'.
[3] Mean of six plots of $25m^2$ extrapolated to 1 ha.
[4] The selection procedure led to varying quantities of maize that was subsequently shelled, sun-dried and sold at the beginning of the storage period.
[5] $NRY = [((NRS+VMR)/Qh) \times Y \times \beta]$; $\beta = 1.359$ is the conversion factor between grain and cob weight. ($Q_{grain} = Q_{cobs} / \beta$)

By incorporating the actual maize yield per ha in the cost and return analysis, the situation observed at the store level completely changed. For instance, the NRY value of T3, where the use of the local maize variety Gbade was advocated, was lower than in all other tested storage systems, solely due to the very low yield of this variety (Table 2.8). In all treatments except T3, only improved maize varieties were used, and hence the yield on a per ha basis was more or less the same. However, the NRY values for both T4 and T5 were substantially superior to those of T1 and T2 (Table 2.8)

2.5 Discussion

Compared to previous studies conducted in southern Togo (Pantenius, 1988; Wright *et al.*, 1993; Helbig, 1995, Richter *et al.*, 1997), larger grain borer and maize weevil densities were relatively low until the 7^{th} month of storage, as shown by data both from the on-farm assessment and from the monthly-recorded samples processed in the laboratory. However, estimated pest densities based on the analysis in the laboratory were always higher than those obtained from the two on-farm assessments. The collaborative assessment with farmers is less accurate than the assessment in the laboratory, but is quicker and may also be more convincing to the farmers than providing them with more detailed figures at a later date. In the 'no-handling' T2 treatment, considerably higher densities of *P. truncatus* than of *S. zeamais* were observed. In most studies, the damage potential of *P. truncatus* exceeds that of *S. zeamais* (Pantenius, 1988; Markham *et al.*, 1991; Albert, 1992; Borgemeister *et al.*, 1997; Compton *et al.*, 1998). Strikingly, larger grain borer was found almost exclusively in T1 and T2 treatments, a finding supported by both the on-farm assessments with farmers and by the monthly-recorded data. Apparently, the cob selection procedure, in combination with the use of a local or less susceptible varieties in T3 and T4 treatments, had similar effects on the population dynamics of *P. truncatus* to those of the insecticide application in the T5 treatment.

Although cobs in T1 had been sorted prior to storage, one store in this treatment was heavily attacked by *P. truncatus*. A possible reason for the serious infestation could have been the choice of the hybrid variety NH1. Maize hybrids may be particularly susceptible to post-harvest losses due to insect pests (Pantenius, 1988; Albert, 1992; Helbig, 1995).. Moreover, the usefulness of visually selecting 'good' cobs prior to storage may be limited in varieties that are already too heavily attacked in the field. Laboratory and field experiments by Scholz *et al.* (1997), and subsequent modelling by Meikle *et al.* (1998b), revealed that small initial populations of *P. truncatus* in stores at the beginning of the storage season suffice to cause high infestation levels at the end of the storage period. Male *P. truncatus* produce a pheromone highly attractive to both male and female conspecifics (Dendy et al., 1989b; Cork et al., 1991, Hodges and Dobson, 1998). Possibly cobs already infested by *P. truncatus* were overlooked during the selection procedure, resulting in the tremendous beetle densities in one store of T1.

In the analysis of pest impact on the percentage of grain weight losses, only in T1 and T2 were both *P. truncatus* and *S. zeamais* found to contribute significantly to the regression models. In all other treatments, only *S. zeamais* densities were important. However, as indicated by the respective partial regression coefficients, even in T1 and T2, *S. zeamais* densities had a greater impact on grain losses than *P. truncatus* numbers. At the end of the storage season, numbers of *P. truncatus* in these two treatments far exceeded those of *S. zeamais*. However, *S. zeamais* infestation was already recorded at the beginning of storage, whereas *P. truncatus* was only detected at the end of the storage season. The duration of an insect infestation has a strong influence on the extent of losses in stored maize (Holst *et al.*, 1999). Moreover, high *P. truncatus* numbers were only recorded in one store in T1 and in two stores in T2. Highly aggregated infestation patterns of *P. truncatus* in rural maize stores were recorded in several other field studies (e.g., Wright *et al.*, 1993; Helbig, 1995; Borgemeister *et al.*, 1998, Adda *et al.*, 1999). Moreover, Adda (1991) observed in the Mono Department of Benin that 40% (14 out of 35) of the stores sampled were not infested by *P. truncatus.*

In summary, T1 and T2, the two treatments intended to simulate farmers' storage systems in the Plateaux region of Togo, performed the most poorly because of the detrimental impact of *P. truncatus* on grain quality and grain losses. This can be attributed to the choice of a hybrid that proved too susceptible to pre-harvest infestation and to lack of pre-harvest selection of cobs, respectively.

Although the adoption rate of improved maize varieties is rising, particularly because of their superior yield characteristics, many African farmers continue to grow local varieties. Local varieties are often considered by consumers to taste better than improved ones (Compton *et al.*, 1998). Moreover, local varieties may be better able to resist adverse agro-climatic conditions such as drought (Carsky et al., 1998). Our results showed that the local variety Gbade could withstand an insect attack better than the improved ones. Superior husk properties in local maize varieties have been shown to be the main reason for lower pest infestation levels (Kossou *et al.*, 1993; Meikle *et al.*, 1998). In our experiments, we did not directly measure the husk characteristics of the tested varieties. However, deducing the proportion of husks from the data presented in Table 4, it seems that the husks represented on average 18% of the cob weight in the local variety, versus 11.7% and 10.6% in Ikenne and NH1, respectively. In addition, it was noted that the apex of the cobs was often inadequately covered in the hybrid NH1.

In the cost and return study the final value of the maize was based on maize prices after eight months of storage, assuming that farmers had kept their cob stores for such an extended period. However, West African farmers often continuously utilise part of their maize harvest for home consumption, while other parts are stored for later selling, at times when maize prices are at their highest level. The net return from stores (NRS) of T1 and T2 were considerably lower than the ones of the other three treatments, a result consistent with the data on insect infestation and losses. Thus, the NRS figures might indicate that an insecticide treatment was not necessary to assure a profitable return after storage. T1 and T2 were less preferred during the 'on-farm' evaluation with the farmers, than T3, T4 and T5 although some farmers pinpointed the difficulty associated with the selection procedure in case of several tons of harvested maize to be stored, especially at a period overlapping with other urgent farming activities.

When the net return including the yield (NRY) was calculated, T3, which included the use of the local variety Gbade, performed the most poorly. T1 and T2 yielded intermediate NRY values that are relatively lower than the one in T4 our IPM package that included the use of an improved variety, whereas T5 the officially recommended SPV treatment performed the best. Farmers using the two latter treatments on average earned approximately 700 FF and 1200 FF respectively per ha of maize more than the ones using the farmers' practices (T1 and T2).

2.6 Conclusions

Experimental data from the Togo study proved the high efficacy of the IPM approach compared to traditional storage methods. However, the low-yield potential of the local variety Gbade results in considerable shortcomings. With regard to pest infestation and maize losses, little differences were observed between the officially recommended post-harvest protection approach by SPV, which is solely based on the application of a binary insecticide, and the IPM approach in this study. These results suggest that non-chemical stored product protection based on our IPM packages is a feasible alternative.

This study, conducted in the Plateau region of Togo, provided a realistic, on-farm evaluation of two store management strategies devised by researchers, based on previous detailed ecological studies of the maize storage system in coastal West Africa. Both strategies used sorting of cobs at harvest, rather than insecticides, to reduce the initial infestation, and relied on good husk cover to provide continued protection to the grain in store. These 'IPM strategies' were tested against two treatments that simulated practices used by the majority of farmers in the area and one, based on a prophylactic insecticide treatment, that simulated the recommendation of the national plant protection service. The comparison underlined the importance of good husk cover as a barrier to infestation by both maize weevils and larger grain borer, pre-and post harvest, although when the costs and returns were analysed it was evident that the value of protection provided by the heaviest husks (on a traditional variety) did not outweigh the disadvantage of low yield associated with such material. The contradiction between good storage performance on one side and low yield potential on the other needs to be addressed by the breeders. The cob-selection/moderate husk cover IPM strategy was found to be competitive with pesticide treatment and so might be preferred on the grounds of the reduced health risk to farmers and consumers.

3 Comparative studies of IPM packages for the control of maize storage pests in two different agro-ecological zones in Benin (West Africa)

3.1 Abstract

Large-scale experiments were conducted in two different agro-ecological zones in Benin between autumn 1995 and spring 1997. The Larger Grain Borer project of the International Institute of Tropical Agriculture (IITA) had previously developed an Integrated Pest Management (IPM) approach based on the results obtained from several field experiments. The IPM concept consisted of the use of the local variety 'Gbogbe' in combination with a timely harvest of maize, the sorting of cobs before storage and a generally good storage hygiene. The IPM concept was compared with (1) the locally-prevailing methods of storage of farmers from Dogbo and Banikoara, two villages in the south (Mono province) and north (Borgou province) of Benin, respectively, and (2) with the storage system recommended by the National Plant Protection Services in Benin (SPV). SPV mainly advocates the use of improved high-yielding maize varieties and the application of a binary insecticide, whereas farmers in both regions did not apply any specific post-harvest protection interventions. The experiments were conducted in a collaborative manner, including representatives of the SPV, farmers from the two different villages, and researchers from IITA. Population dynamics of major insects and associated losses to stored maize were recorded monthly over an 8-month period. The low pest incidence, especially that of *P. truncatus* during the two years of study in Dogbo, probably coupled with the use of the local variety 'Gbogbe' in both the IPM approach and the farmers' storage systems did not permit to detect any differences between those two storage systems. Applying an insecticide, as recommended by SPV, did not lead to any major gains in the 1995-1996 experiment in Dogbo. Despite the low incidence of pests, particularly that of *P. truncatus* in Banikoara after eight months of storage, both the IPM and the SPV treatment had a higher efficiency compared to the traditional storage method of the farmers.

The low population dynamics of *P. truncatus* revealed by studies carried out in the Mono province is probably due to the impact of the natural enemy of the larger grain borer, the predator *T. nigrescens*.

3.2 Introduction

Maize (*Zea mays* L.) is one of the major staple food grains grown throughout both the developed and the developing world (FAO, 1992; Macdonald and Chapman, 1997). The increasing importance of maize in West Africa (Assongba, 1984; Kpodo, 1996) explains its trade between countries (Lutz, 1994). If maize is cultivated for different purposes (food, feed, and industrial uses), more than 70 % of the crop in sub-Saharan Africa is produced for human consumption (FAO, 1992).

In Benin, three production areas are distinguished by the Ministry of Rural Development, each having its particular features regarding production and consumption: (1) The coastal areas of Atlantic, Mono and Ouémé departments, (2) the intermediate zone of Zou department, and the Sudan Savannah of Borgou and Atacora departments (Lutz, 1994). Maize yield in Benin, particularly by small scale farmers, are generally very low, mainly due to factors like socio-economical constraints, over-exploited soil resources especially in the southern regions, climatic hazards etc. In addition, in Benin severe damage is inflicted to maize in the field mainly by lepidopteran grain borers (Sétamou, 1996). Moreover, losses of farm-stored maize exceeded 20 % after six months of storage (Adda, 1991; Anonymous, 1992; Borgemeister et al., 1994), particularly since the accidental introduction of the larger grain borer (LGB) *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) from its area of origin in Central America to East and West Africa (Markham *et al.*, 1991). Principally, small-scale farmers (the great majority of maize producers) suffered seriously from the occurrence of the larger grain borer (LGB) that heavily destroys their maize in many regions of the country (Toko and Bokonon-ganta, 1999).

Nevertheless, because of socio-economic constraints small-scale farmers did not follow the chemical control advocated by the plant protection services. Therefore, beside biological control of LGB through releases of its natural enemy, the predator *Teretrius nigrescens* (Lewis) (Coleoptera: Histeridae), additional and compatible protection measures with biological control are needed to cope with the recurrent spots of infestation that still occur in parts of Benin. In order to evaluate the before mentioned IPM approach developed by researchers of IITA, two sites in contrasting agro-ecological zones in Benin were selected for two large field trials.

3.3 Material and Methods

The studies were conducted at Dogbo in the south (Mono Department) and at Banikoara in the north of the country (Borgou Department). Dogbo lies in the forest mosaic savannah, characterised by a hot and humid climate, bimodal rainfall pattern and consequently two cropping seasons. In Benin, larger grain borer was first recorded in the Mono Department in 1984 (Krall, 1984). At Banikoara, serious infestations of maize stores by *P. truncatus* have been reported since 1996. The Borgou Department is situated in the Sudan savannah, characterised by a hot and dry climate, with unimodal rainfall pattern, and thus only one cropping season. The following maize varieties were used in the experiments:

-The local variety 'Gbogbe', common in the south-west of Benin, is a floury variety with good husk cover characteristics that reaches physiological maturity within 90 days. Its yield capacity (approx. 2 $t.ha^{-1}$) is though lower than the ones of improved varieties.

-The improved variety 'DMR' (Downy Mildew Resistant) has a hard grain and is promoted by the national agricultural extension service of Benin. It also reaches physiological maturity in 90 days, but has less good husk cover characteristics than 'Gbogbe'. Its yield capacity is about 2.5 $t.ha^{-1}$.

-The improved variety 'TZSR-W' (Tropical *Zea mays* Streak Resistant - White) is an improved IITA variety with a long development cycle (120 days). It has poor husk cover characteristics but a high yield potential (3-4 $t.ha^{-1}$).

3.3.1 The trials in Dogbo

In May 1995, 2 ha of 'Gbogbe' and 1 ha of 'DMR' were planted at a density of approximately 50,000 plants/ha. NPK fertiliser (15:15:15) was applied 21 days after planting (d.a.p.) at a rate of 150 $kg.ha^{-1}$. The maize was harvested beginning of August, two to three weeks after physiological maturity (considered as an early harvest).

The same store type as in the experiments in Togo was used. A total of 12 stores were constructed. Nine of them (three treatments with three replicates) were used as experimental stores, and the remaining three were used for replacement purposes. The latter contained identically treated maize as in the respective experimental stores. Each experimental store was divided into four equal sections by chicken wire. The chicken wire provided the necessary support to completely remove a section of the store without affecting the integrity of the store during sampling. Each experimental store was loaded with approximately 500 kg of husked maize cobs. Maize was sampled after two, four, six and eight months of storage. Each section was sampled only once and sampled maize was replaced using cobs from the replacement stores. Stores were covered by a thatch roof.

The trial was arranged as a randomised block design with three storage systems (treatments) and three replicates. The treatments (summarised in Table 3.1) were defined as follows:

- 'Treatment 1' referred to as 'Tm1':

'Gbogbe', a local variety (stored with husks on) was early harvested (two to three weeks after physiological maturity), and prior to storage cobs were sorted (for visual damage). This treatment reflected the IPM approach of IITA.

- 'Treatment 2' referred to as 'Tm2':

'DMR', an improved variety (stored with husks on) was early harvested (two to three weeks after physiological maturity), and cobs were treated with the binary insecticide Sofagrain, using the sandwich technique (Gwinner *et al.*, 1996). This treatment followed the recommendations of SPV.

- Treatment 3 referred to as 'Tm3':

'Gbogbe', a local variety (stored with husks on) was late harvested (seven weeks after physiological maturity), and cobs were not treated prior to storage (i.e., no sorting and no insecticides were applied). This treatment represented the typical farmers' storage practices of the region.

In 1996, the experiment in Dogbo was repeated, using the same methodology.

Table 3.1 Synopsis of the experimented storage systems in District of Dogbo South western Benin

Treatments	Maize Varieties		Maize handling			Time of Harvest	
	Local	DMR	No Handling	Selection of cobs	Sofagrain	Early	late
Tm1	•			•		•	
Tm2		•			•	•	
Tm3	•		•				•

Table 3.2 Synopsis of the experimented storage systems in District of Banikoara North western Benin

Treatments	Maize Varieties			Maize handling			Time of Harvest	
	Local	DMR	TZSR	De-husked cobs	Selection of cobs	Sofagrain	Early	late
Tb1	•				•		•	
Tb2		•				•	•	
Tb3			•	•				•

NB: Horizontally distributed points (•) belong to the same storage system

3.3.2 The trials in Banikoara

During a preliminary survey in June 1995 in the region around Banikoara baseline data on farmers' practices, particularly with regard to maize storage systems, were gathered. On July 20, 1995, 1 ha of 'Gbogbe', 'DMR', and 'TZSR-W', respectively, was planted at an approximate planting density of 50,000 plants.ha^{-1}. NPK (15:15:15) fertiliser was applied 21 d.a.p. at a rate of 150kg.ha^{-1}. Additionally, urea fertiliser was applied on 'TZSR-W' plot 45 d.a.p. The 'Sourou' store structure, used in the experiment, is very common in the north of Benin. A 'Sourou' store constitutes of four strong forked-sticks (40 cm in height) used as support, and several vertical sticks fixed in the soil in a circular form. Horizontally disposed sticks were also used to build the platform. Stems of *Andropogon* spp. were woven into a sort of basket-type carpet, a so-called 'Seko'. One 'Seko' was used to cover the platform. Another much bigger 'Seko' was wrapped around the store, forming the wall of the 'Sourou' store. Stores were covered with thatch roofs. To facilitate sampling, *Sorghum* spp. stems were used to separate the interior of each store into four equal sections. Each experimental store was loaded with approximately 500 kg of husked maize cobs. Maize was sampled after two, four, six and eight months of storage, respectively. Each section was sampled only once, and sampled maize was replaced using cobs from replacement stores. A total of 12 stores were constructed. Nine of them (three treatments with three replicates) were used as experimental stores, and the remaining three were used for replacement purposes.

The trial was arranged as a randomised block design with three storage systems (treatments) and three replicates. The treatments (summarised in Table3.2) were defined as follows:

- 'Treatment 1' referred to as 'Tb1':

'Gbogbe', a local variety (stored with husks on) was early harvested (two to three weeks after physiological maturity), and prior to storage cobs were sorted (for visual damage). This treatment reflected the IPM approach of IITA.

- 'Treatment 2' referred to as 'Tb2':

'DMR', an improved variety (stored with husks on) was early harvested (two to three weeks after physiological maturity), and cobs were treated with the binary insecticide Sofagrain, using the sandwich technique. This treatment followed the recommendations of SPV.

- 'Treatment 3' referred to as 'Tb3'

'TZSR-W', an improved variety was harvested late (six weeks after physiological maturity), de-husked and cobs were not treated prior to storage (i.e., no sorting and no insecticides were applied). This storage system reflected the traditional storage practices by most of the farmers in the region around Banikoara.

3.3.3 Cob sampling and data collection

On each sampling occasion, three samples of 30 cobs were removed from each section. In Banikoara three holes were cut in the 'Seko' to access the top, middle and bottom section of each 'Sourou' store. Thereafter the 'Seko' was closed again. Twenty-five cobs per sample were individually kept in small paper bags and later analysed on a cob-by-cob basis, while the remaining five cobs (in total 15/store) were used to record the moisture content of the grain, using the standard oven-drying technique (ISO, 1980). For the cob-by-cob analysis, the cobs were individually weighed, then de-husked, shelled and sieved. Subsequently, insects were collected, counted and later identified. Only data on the two primary pests, i.e., larger grain borer and maize weevils, and on *T. nigrescens* were recorded.

As in the trials in Togo, additional cob samples were taken for the collaborative evaluation of the different storage systems, jointly executed by the local farmers and representatives of IITA and SPV. The evaluations took place after six and eight months of storage. At each evaluation occasion, three samples of 100 cobs were taken per treatment, de-husked, and cobs were then jointly classified into the following three categories: intact, attacked, and destroyed cobs. For each category, data on cob and grain weight were recorded. Thereafter, the grains were sieved and the number of pests recorded. The percentage of intact cobs per sample and the number of pests were used to jointly rate the performance of the different storage systems.

3.4 Results

During the storage period 1995-1996, *P. truncatus* occurred in the two contrasting sites only towards the end of the storage period and only in low densities (figure 3.1 (A) and (B)). In Banikoara, *P. truncatus* was only recorded in the Tb3 treatment, while in the south both Tm1 and Tm3 were weakly infested by LGB. In the 1996-1997 trial, no LGB infestations were recorded (fig 3.1 (C)). In both years, the population trend of the predator *T. nigrescens* followed almost the same pattern as that of its prey (figure 3.2). In Banikoara, *S. zeamais* was quasi absent throughout the storage period 1995-1996 (figure 3.3 (A)), whereas in Dogbo high weevil numbers were recorded (figure 3.3 (B) and (C)). The absence of *P. truncatus* in Dogbo in the second year of the study seemed to have favoured the development of *S. zeamais*. The "other insects", including mainly all secondary insect pests of stored maize, followed a similar pattern as *S. zeamais* during the 1995-1996 trial in Banikoara, where less than one 'other insect' per cob was recorded (figure 3.4 (A)).

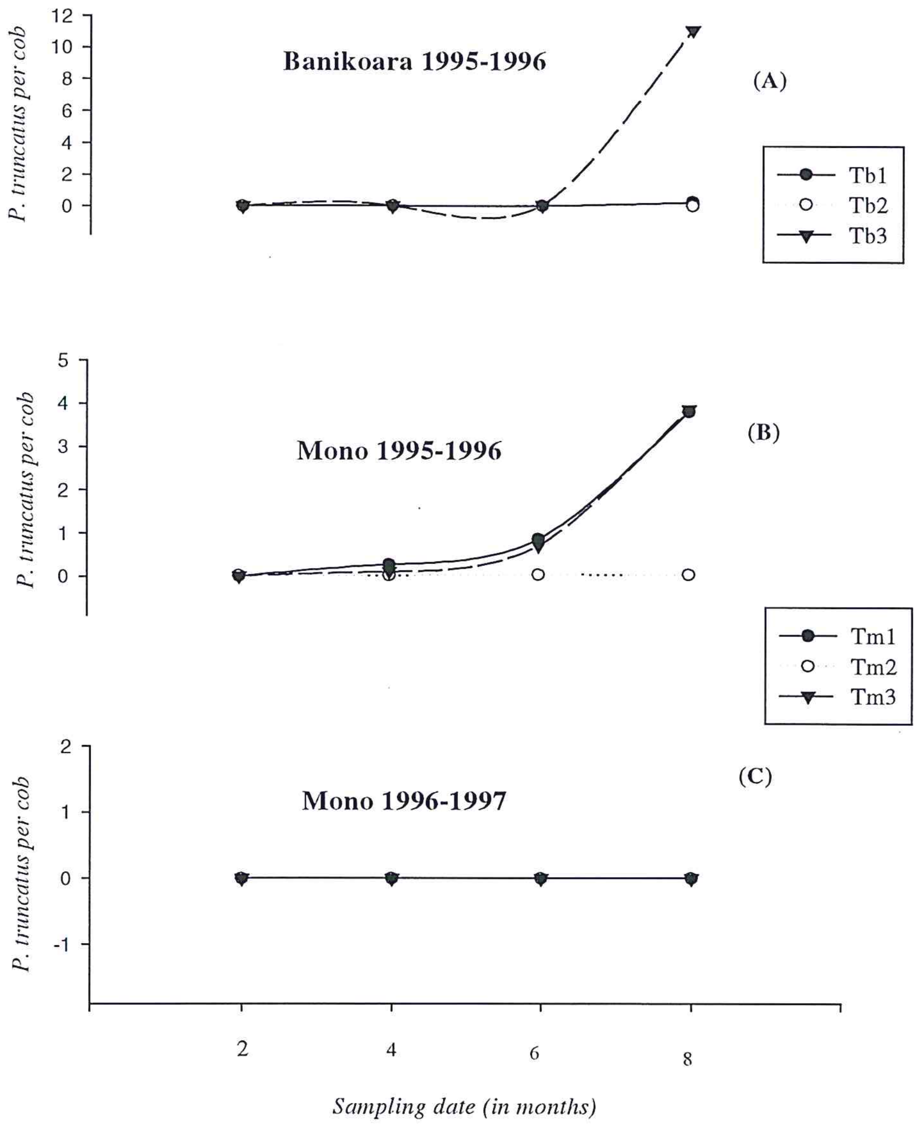


Figure 3.1 Population dynamic of *P. truncatus* in different storage systems according to locations and year.

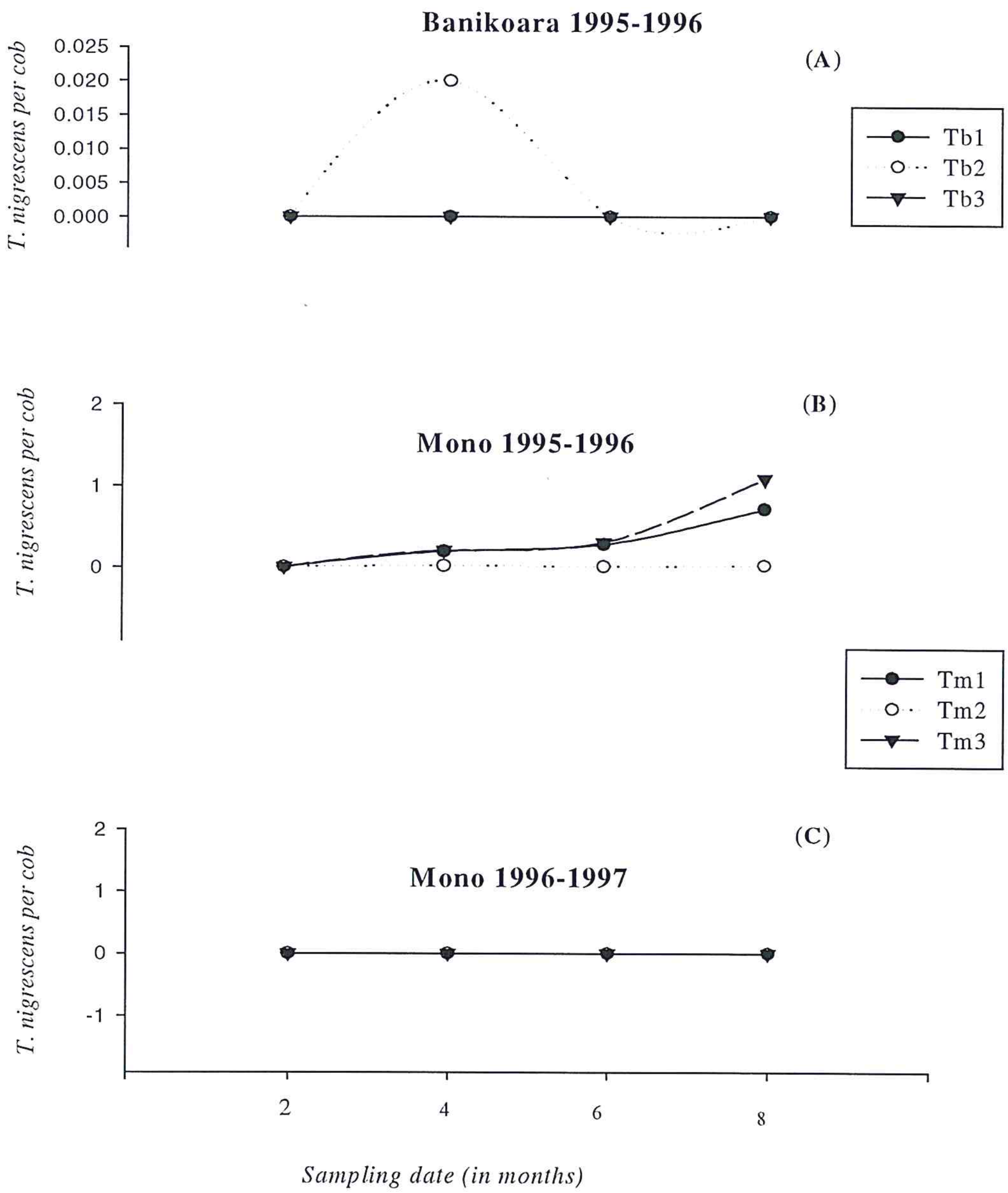


Figure 3.2 Population dynamic of *T. nigrescens* in different storage systems according to locations and year.

In Dogbo, the overall density of “other insects” was lower in 1996-1997 compared to the previous storage period (figure 3.4(B) and (C)). The relatively low level of losses (figure 3.5), particularly in Banikoara, reflected the low incidence of primary pests, especially of LGB.

In all treatments, grain weight losses in Banikoara were extremely low, not exceeding 3% after eight months of storage (figure 3.5 (A)). In Dogbo, in both years the level of grain weight losses was also comparatively low, with maximum grain losses around 14%. However, in both years the lowest grain weight losses were recorded in the insecticide-treated Tm2 treatment (figures 3.5 (B and C)). Independent of the maize variety used, the moisture content during the first six months of storage were always lower in the northern (Banikoara) compared to the southern (Dogbo) site (figures 3.6 and 3.7).

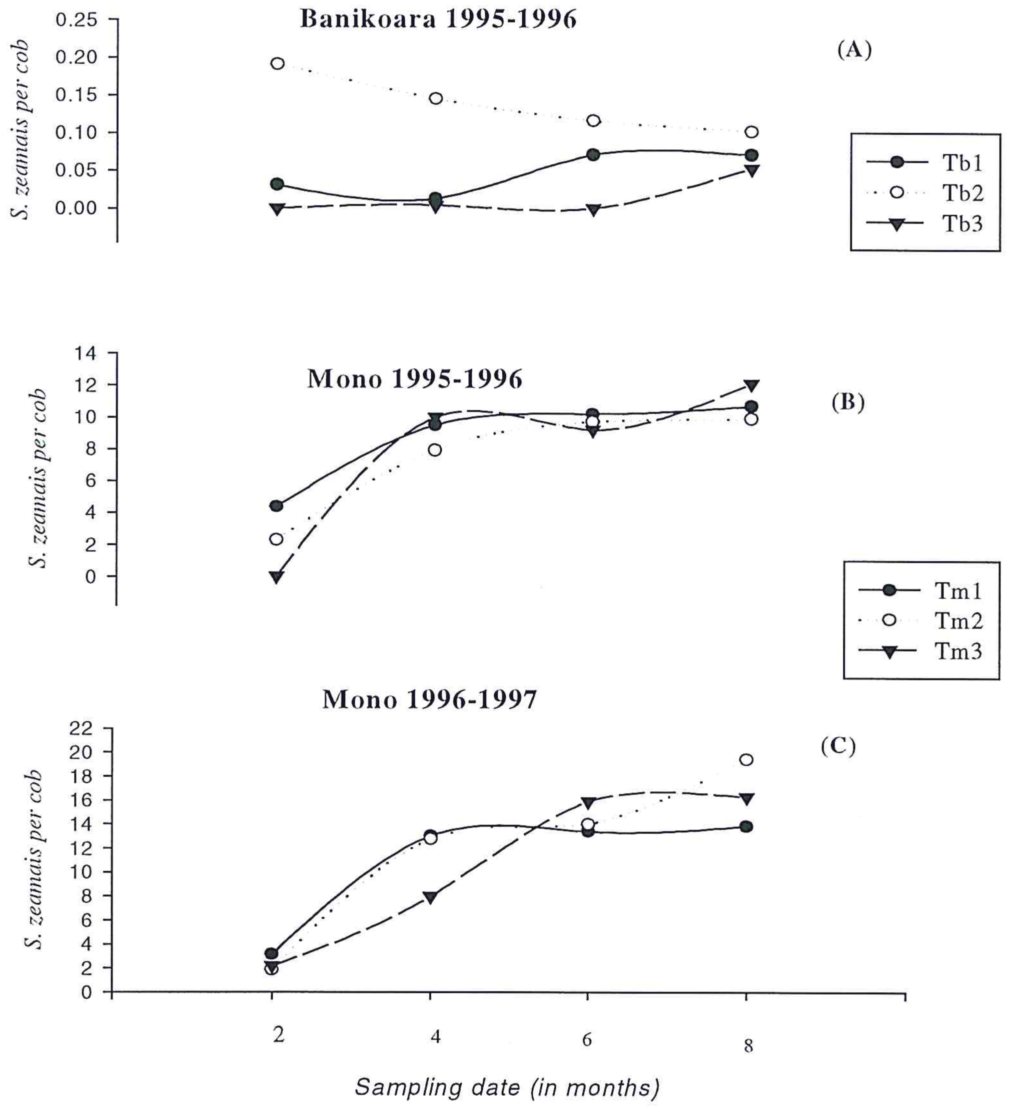


Figure 3.3 Population dynamic of *S. zeamais* in different storage systems according to locations and year.

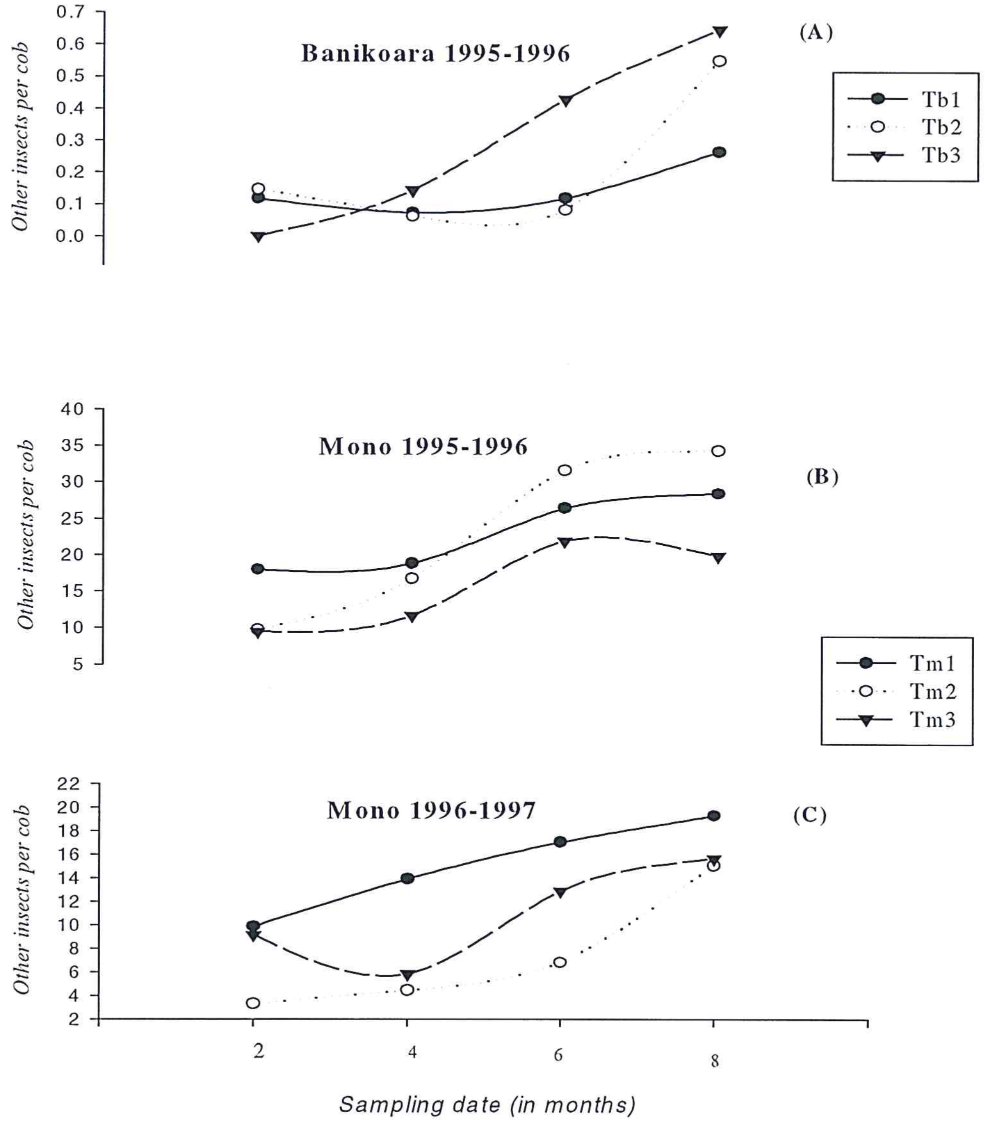


Figure 3.4 Population dynamic of "other insects" in different storage systems according to locations and year.

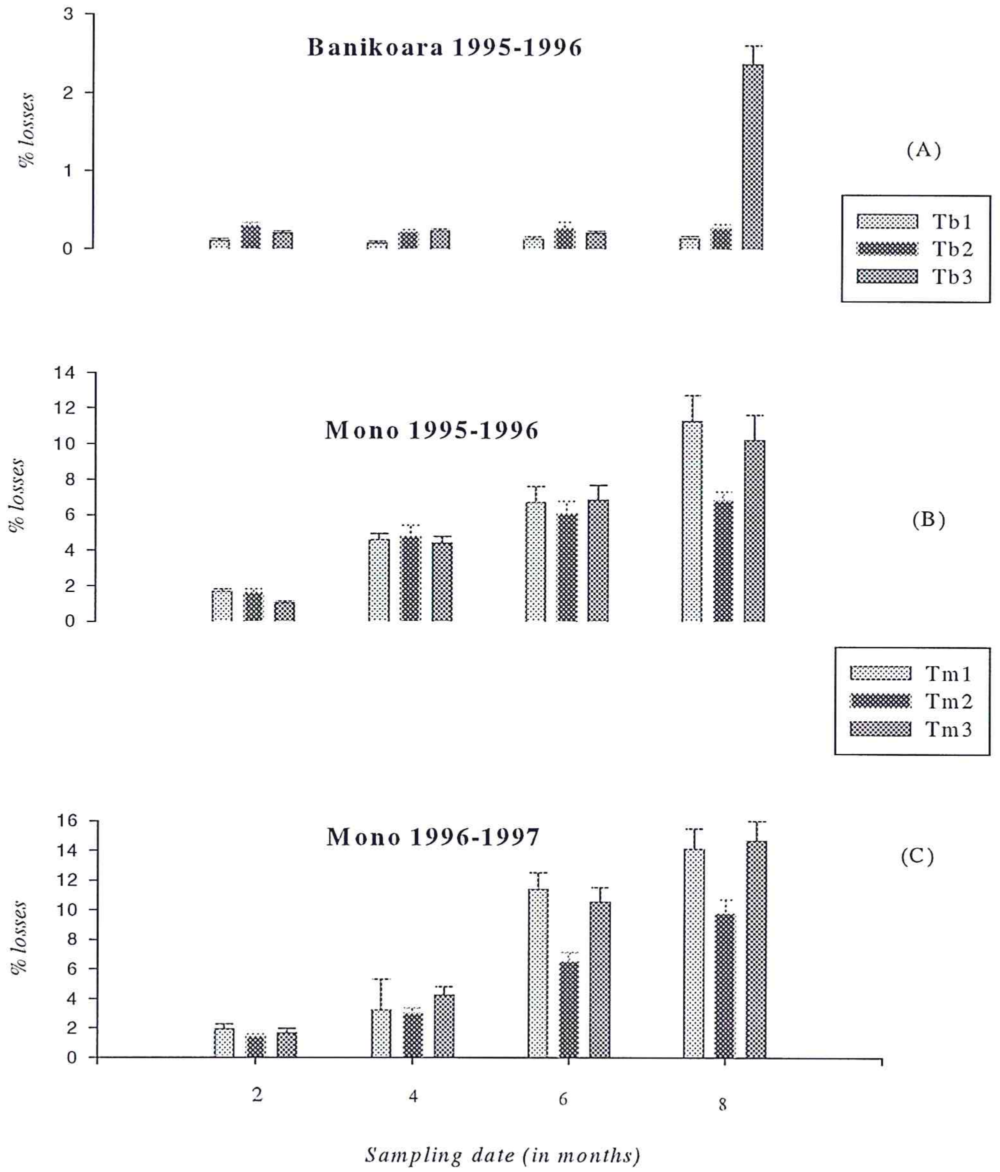


Figure 3.5 Evolution of losses affecting stored maize in different storage systems according to locations and year.

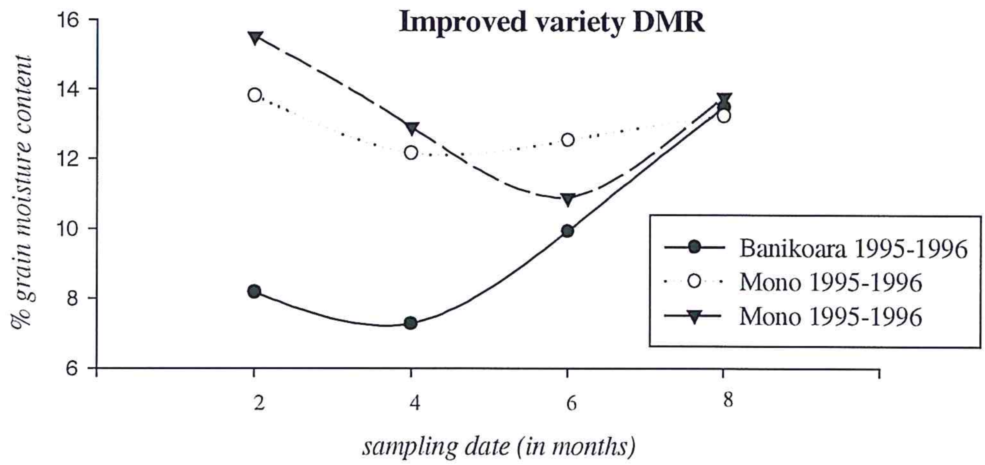


Figure 3.6 Evolution of the percentage grain moisture content in the stored improved variety DMR according to location and year.

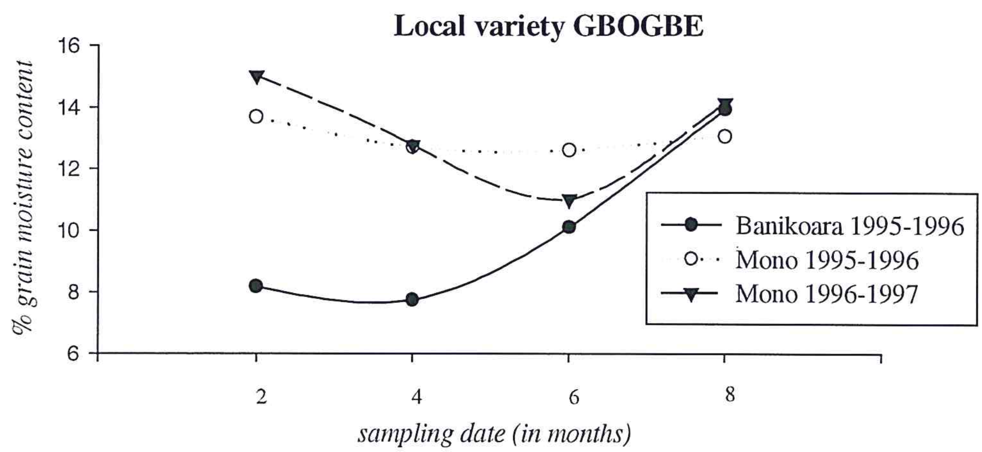


Figure 3.7 Evolution of the percentage grain moisture content in the stored local variety Gbogbe according to location and year.

3.5 Discussion

During the trials in Benin, pest densities were generally rather low. Despite the low incidence of *P. truncatus* in all treatments in Banikoara after eight months of storage, both the IPM (Tb1) and the insecticide treatment (Tb2) had a higher efficiency compared to the traditional storage method of the farmers (Tb3). However, even in the Tb3 treatment, maize losses were negligible. The northern part of Benin, with its hot and dry climate offers better conditions for maize storage, as shown by the considerably lower grain moisture content during the first six months of storage in Banikoara compared to Dogbo. Low moisture content has a negative impact on the survival of many stored-product pests (Fields and Korunic, 2000). Also, temperature, relative humidity and moisture content of stored produces are interrelated and constitute key factors influencing the population dynamics of pest organisms in storage (Gwinner *et al.,* 1996). Often, 13 % of grain moisture content in maize is considered safe for storage (Markham, 1981; Gwinner *et al.*, 1996). Such conditions, easily reached in the north of Benin (at least for the first six months of storage) can not be achieved in the south without extended field drying of the maize. However, in the south during field drying, maize is particularly vulnerable to an attack by various coleopteran and lepidopteran pests. The high densities of *S. zeamais* during the storage period 1996-1997 in Dogbo are probably related to the quasi absence of *P. truncatus* during this period. However, in the preceding year no such clear trend was observed.

The results obtained, particularly the ones from Dogbo did not meet our expectations. The pest incidence, especially that of *P. truncatus*, during the two years of the study in Dogbo, probably coupled with the use of a common local variety ('Gbogbe') in both the IPM approach (Tm1) and the farmers' storage systems (Tm3) did not permit to detect any differences between those two storage systems. The relative superiority of the insecticide use (Tm2) was only observed during the 1995-1996 trial. In previous experiments, considerably higher infestation levels, particularly by larger grain borer and maize weevils, were recorded in the Mono Department (Adda, 1991; Fandohan, *et al.,* 1992; Borgemeister *et al.,* 1994).

4 General discussion

Maize and wheat constitute the most important cereals in the world, and by the year 2020, almost 60% of the world's maize consumption will be in developing countries (Hoisington *et al.*, 1999). Therefore, there has been an ever-increasing need to ensure a more efficient protection of these crops. Since some decades, concepts for integrated pest management (IPM) have been developed and refined in response to widespread scientific and public concern about adverse effects, both on the environment and health, resulting from the overuse and misuse of chemical pesticides (Gotsch and Braunschweig, 1999).

Based on research findings at the International Institute of Tropical Agriculture (IITA), IPM packages intended to control the principal maize storage pests had been developed and were evaluated in Benin and Togo, two West African countries seriously threatened by outbreaks of the larger grain borer. The research was conducted in a collaborative manner to encourage the participation of the clients (the farmers) and to allow them to draw their own conclusions. Farmers usually show great interest in any propositions that involve no major changes to their usual methods and require little extra cost. The usefulness of such IPM packages have been presented and discussed separately in chapter 2 and 3. In this general discussion, the major findings from the 2-year research project are pinpointed.

The results confirmed that pest population dynamics and subsequent losses could vary significantly during one season and/or between two seasons as well as between two different regions. Both pre- and post-harvest pests determine the subsequent losses of maize during storage (Markham, 1981; Pantenius 1988; Borgemeister *et al.*, 1998; Sétamou *et al.*, 1999). In Togo and in Benin, the population dynamics of primary pests and subsequent losses were rather low compared to previous studies (Pantenius, 1988; Adda, 1991, Anonymous, 1992; Wright *et al.*, 1993; Borgemeister *et al.*, 1994; Helbig, 1995; Richter *et al.*, 1997).

During the experiment in Togo (chapter 2), T1 and T2, the two treatments intended to simulate farmers' storage systems in the Plateaux region, performed extremely poor, mainly because of the detrimental impact of *P. truncatus* on grain quality and grain losses. This can be explained first by the lack of appropriate storage management techniques in T2, and second by the choice of a highly susceptible maize variety, coupled with a severe pre-harvest pest infestation level of the maize in T1. Although the cob selection procedure failed to control maize weevil infestations throughout the entire storage season, in treatments T3 and T4 that followed our IPM approach, it proved to be efficient in keeping *P. truncatus* numbers very low. The only difference between T2 heavily attacked by *P. truncatus*, and T4, free of larger grain borer infestation, was the cob selection procedure prior to storage. The same intervention ensured in T3 a long-lasting protection against infestations by *P. truncatus*, while in T1 high numbers of larger grain borer towards the end of the storage season lead to serious grain losses, both in terms of quality and quantity. Most likely, the good husk characteristics of the local variety used in T3 prevented major losses due to *P. truncatus*, whereas the hybrids used in T1 were already heavily infested by coleopteran and lepidopteran pests in the field.

Having the highest *P. truncatus* densities, coupled with a considerably higher infestation level of *S. zeamais*, and consequently the greatest dry weight losses, particularly after eight months of storage, during the collaborative evaluations the treatments T1 and T2 were significantly less preferred than T3, T4 and T5 by farmers and representatives of SPV.

Many West African farmers intend to preserve a certain quantity of their maize harvest for long-term storage, mainly to sell it later at periods of higher maize prices. The contradictory results between the net return from storage (NRS) and the net return including the yield of the maize (NRY) analyses can be explained as follows: The NRS values are strongly determined by the performance of the maize in the store, ignoring the varying yields levels of the different varieties. The local variety Gbade in T3 was only moderately attacked by post-harvest pests. Thus, at the end of the storage season, the maize from this treatment was relatively free of signs of an insect attack. In a field study in Ghana, Compton *et al.* (1998) showed that the level of insect damage largely determines the price of the maize on rural markets. However, the higher yield potential of the improved varieties overcompensated the lower level of post-harvest losses in the local variety Gbade, despite the generally poorer performance of the improved varieties in the farmers' stores.

In Benin (Chapter 3), the low pest incidence during the 2-year experiments did not permit to discern any difference between the different storage systems, particularly in the southern part of the country. Nevertheless, the better storability of maize in the northern part of Benin, due to the prevailing unfavourable climatic conditions (hot and dry) for insect pests in this region, were well observed. Fields and Korunic (2000) clearly demonstrated that low moisture content has a negative impact on the survival of many stored-product pests. Also the importance of temperature, relative humidity, moisture content and their interrelations for the development of insects have been documented (Gwinner *et al.*, 1996).

The quasi absence of the larger grain borer in southern Benin, a region previously heavily infested by *P. truncatus,* during our research is a confirmation of the success of the on-going biological control. Borgemeister *et al.* (1997) previously demonstrated the success of the biological control of *P. truncatus* by its predator *T. nigrescens* in southern Benin. Moreover, Schneider (1999) revealed a gradual reduction of *P. truncatus* population coupled with rising numbers of *T. nigrescens* also in other parts of Benin.

The results of the study in Togo (Chapter 2), clearly demonstrated that an IPM approach in maize storage can be implemented as an alternative to the use of chemicals. The IPM approach performed better than the indigenous techniques of storage of farmers from the Plateaux region, and is also compatible with biological control of the larger grain borer. However, because of the high variations of insect population dynamics between different seasons, results of a single experiment should not be generalised. The IPM approach would merit further collaborative testing in other sites.

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