UNIVERSITY OF CAPE COAST

STUDIES OF STORAGE INSECT PESTS OF MAIZE (*ZEA MAYS* L.) IN SOUTHERN GHANA

BY

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DECLARATION

I hereby declare that this is the result of my own original research and has not been part or wholly presented for any degree in this University or elsewhere.

Candidate.............................. .... Date 16/6/2004

(Eric Anim Frimpong)

SUPERVISORS' DECLARATION

We hereby declare that the preparation of the thesis were srpervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

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ABSTRACT

A market survey was carried out between October 2001 and April 2002 to determine insect pests associated with maize sold in the market and the knowledge base of local maize traders on these pests. The persistence of the pests from the field through storage (in cribs) to the markets was also investigated. Two Quality Protein Maize (QPM) and two local maize varieties were used in a further study to determine varietal susceptibilities, under field and laboratory conditions, and moisture content preferences of various SIP. Effort was also made to identify common wild plant seeds that could serve as alternative hosts. Traders purchase and store small quantities for short periods due to lack of capital, fear of destruction by pests and mould growth. *Sitophilus* sp. was the commonest pest identified by traders and was ranked as the most destructive. The susceptibility of improved maize varieties, as claimed by traders was confirmed by results of common susceptibility parameters conducted with *Sitophilus* sp. as the test insect. The varieties were however similar in other susceptibility parameters. Most insect pests infested maize from the field but a few persisted through storage to the markets as moisture content fell to 12%. These pests included *Ahasverus* sp., *Cathartus* sp., *Sitophilus* sp., *Tribolium* sp., *Mussidia* sp. and *Cryptophlebia* sp. Seeds of five out of twenty wild plants were found to serve as alternative hosts to only one SIP, *Araecerus* sp.

DEDICATION

This work is dedicated to my mum, Mrs Mary Asiamah Anin.

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CHAPTER ONE

INTRODUCTION

Maize is believed to have originated from Central America and the Andes in South America, where it was also first used as food. Its introduction into West Africa in the 16th century is accredited to the Portuguese (Miracle, 1965; Paliwal, 2000a and Norman *et. al.*, 1996). In most parts of Africa, it has adapted very well to prevailing environmental conditions and has been accepted by many consumers. It has therefore replaced traditional cereals such as sorghum and millet (Bencini, 1991; Norman *et. al.*, 1999).

Maize has edible starchy seeds which are the most important sources of carbohydrate for mankind (McLean, 1989). It constitutes a staple for the populace of several countries in Africa, Latin America and Asia (Goodman, 1976; Norman *et. al.,* 1996). Over 90% of the crop cultivated in these areas is used for human consumption (Norman *et. al*, 1999). In Ghana, maize forms a major food component right from infant weaning food through breakfast and lunch to supper for all ages (Lartey and Asibey-Berko, 1989). About 24 different food items in Ghana have been identified to be prepared from maize (Food Research Institute, Ghana, 1986) besides being boiled or roasted and eaten fresh on the cobs.

Generally, maize is low in protein, particularly in two amino acids, Lysine and Tryptophan (Bencini, 1991; Smith, 1995). Despite this, it ranks only after fish and the legumes in terms of annual protein production in Ghana (Twumasi-Afriyie, 1992).

One recent discovery is the development of Quality Protein Maize (QPM) in which the Lysine and Tryptophan composition have been improved for human and animal consumption (CIMMYT, 1987a). It has been documented that children suffering from acute protein malnutrition recovered fully after being put on diets prepared from Lysine-rich maize (Bressani, 1975; Pradilla *et. al.*, 1975; Goodman, 1976). Thus the adoption of the QPM varieties will supplement the protein needs and may help reduce protein malnutrition, particularly among children, in Ghana.

Ghana, being one of the few tropical countries which has accepted and grows QPM varieties on commercial basis (Paliwal, 2000b; Sallah, *et. al.*, 2003), has developed several varieties including; *Obatanpa*, *Okomasa*, *Mamaba*, *Dadaba*, *Cidaba* among others (Twumasi-Afriyie *et. al.*, 1992 and 1997). Two of these QPM varieties (*Obatanpa* and *Mamaba*) are very rich in Lysine and are being promoted under the Food Crop Development Programme (FCDP) by the Ministry of Food and Agriculture (MOFA) (FCDP, 2001). The aim of the FCDP, increasing household food security and farm incomes (FCDP, 2001), may not be achieved if the storage performance of the varieties being promoted is not evaluated against stored product pests. This is because most of the improved maize varieties evaluated were found to be more susceptible to insect pests in storage (FAO, 1980; Bencini, 1991; Vowotor, 1993; Vowotor *et. al.*, 1995a and 1995b and Boateng and Ayertey, 1996). Evaluation of susceptibility of these QPM varieties will help get stakeholders such as local maize traders in maize storage well informed about better control and management practices to be adopted.

1.1 MAIZE PRODUCTION CONSTRAINTS

It has been estimated that maize production in the tropics has increased by 35 – 50% (FAO, 1992). In Ghana for instance, maize production rose from 0.09 to 0.34 million tons from 1980 to 2001 (Sallah, *et. al.*, 2003). A report from the International Institute of Tropical Agriculture (IITA, 1997) attributed increase in maize production to development of improved varieties. These varieties are known to be early maturing, disease and drought resistant, and resistant to field insect pests. This notwithstanding, no tropical African country is among the 15 highest maize producers in the world (FAO, 1992).

Among the serious problems constraining maize production in Africa are climatic factors such as the volume and distribution of rainfall and poor crop management practices. The rest are factors affecting soil fertility and planting of varieties susceptible to diseases and pests. The major bane has been the effect of storage insect pests (Fajemisin, 1990; Kaaya, 1994).

Maize is attacked and destroyed by many insect pests both in the field and in storage. The principal field pests are the lepidopterous stem borers (Botchey, 2002; Ndemah and Schulthess, 2002). For some years now, increased field production of maize has been achieved through the development of maize varieties resistant to field pests, which to a large extent has increased field production (Smith *et. al.*, 1989; Mugo *et. al.*, 2001). Little attention was given to maize storage in most maize improvement programmes (Golob and Tyler, 1994). However, self-sufficiency food cannot solely be achieved by increasing field production. Thus, although field production of maize is increasing, a greater proportion would be destroyed by pests during storage

Some common sources of pest infestation are in stores, trucks, used sacks and field (Cotton, 1974; Ayertey, 1981). Meanwhile, field infestation has been identified as one of the major entry points for pests such as *Sitophilus spp.*, *Prostephanus truncatus* (Horn) and *Sitotroga cerealella* (Olivier). For this reason, it is expected that the longer the crop stays in the field, the higher the build up of populations of these pests (de Pury, 1974; Appert, 1987; CIMMYT, 1987b; and Granados, 2000). What is scarcely available now is information on the moisture contents (maturity stages) at which the ears get infested with the various storage insect pests in the field and in storage.

Maize storage using cribs constructed from local materials is widely practiced in Ghana (Rawnsley, 1969; Nyanteng, 1972; FAO, 1980 and Orraca-Tetteh, 1989). It is yet to be investigated into detail the drying stages at which these pests infest maize during storage in such structures.

Farmers and local traders are the main stakeholders in maize storage in Ghana. Of these, the former is said to store the bulk of the produce. As a consequence, local maize traders have received little attention in most scientific researches involving maize storage and pest management practices (The Ghana Farmer, 1973 and 1978; Nyanteng, 1972; Lindbald and Druspen, 1980; FAO, 1980; Orraca-Tetteh, 1989; Nkunika, 2002). Meanwhile, these traders through activities such as the exchange of infested sacks at point of purchase, transportation of maize from one place to another and the continual use of infested stores have among others contributed immensely to the spread of stored product pests. Consequently, implementation of pest control schemes may be difficult or could fail if the contribution of the maize seller is neglected. It has therefore become necessary to ascertain the level of awareness of local maize traders' about effective maize storage practices as well as the role of insect pests in the maize industry. This will help to effectively incorporate these traders into formulation of any storage insect pests' control programme.

One important factor in studying the biology of a pest is its location at any given time. Knowledge of alternative host plant is therefore an important guide to dealing with pests. Even though maize is in storage year round, albeit scarce during the lean season, its cultivation in Ghana is seasonal. Storage insect pests are thus apparently absent in the field during the lean period, only to resurface during the growing season. There are therefore other probable sources of re-infestation beside that from storage. In justifying why *P. truncatus* is abundant in the forest regions than the savanna, Ayertey and Brempong-Yeboah (1991) suggested this pest is probably haboured by certain tree species. It would therefore be helpful to screen some common plants, which provide alternative sources of food for store products pests, for their role in the survival of these insects. Information generated will help in the implementation of integrated pest management programmes on stored product pests.

1.2 OBJECTIVES

1) To conduct a market survey in order to:

   a) Find out the local maize traders' knowledge about storage insect pests.

   b) Sample for storage insect pests present in selected markets.

2) To determine the time of infestation and susceptibility of two QPM and two local maize varieties to storage insect pests.

   a) To determine the storage insect pest species and their populations on maize ears at various moisture levels.

   b) To investigate the survival of collected storage field insect pests in stores.

3) To investigate the performance of one key pest on QPM and local normal maize varieties.

4) To ascertain the suitability of some common plant seeds as alternative hosts for storage pests of maize.

CHAPTER TWO

LITERATURE REVIEW

2.1 MAIZE STORAGE AND STORED PRODUCT PESTS

Among the major pests of stored maize (insects, rodents and mites), insect pests have been the major constraint (Nyanteng, 1972; ARDC, 2001 and Boumans, 1985). Beside the damage caused to grains and difficulty in controlling them, in most cases, they evade early detection.

2.1.1 EFFECTS OF INSECT PESTS ON STORED MAIZE

Storage insect pests' infestation often leads to grain weight loss, reduction in nutritional value and seed viability as they feed on the kernels. Other adverse effects include impacting odour and flavour as well as "hot spots" which may lead to premature germination of seeds. The rest are contamination with excrement, empty eggs shells, exuvae and cardavas (Cotton, 1974; Ayertey, 1986; Appert, 1987; Higgins, 1987; McLean, 1989; Hill and Waller, 1990; ARDC, 2001). Weight loss is undoubtedly the greatest threat to stored maize worldwide. Over 30% weight loss due to storage insect pests has been recorded in some African countries after only a few months of storage (Rawnsley, 1969; IITA, 1997 and Kossou and Bosque-Perez, 1998). In Ghana, an estimated 25 – 45% of maize is destroyed during storage (Kaaya, 1994).

2.1.2 MAIZE STORAGE

Four levels of maize storage have been identified by Gahukar, (1994) and they are domestic, farm, commercial and national. Maize may be stored as food guarantee, for stability of the economy, barter exchange or for household enterprise, such as brewing (FAO, 1980; de Lucia and Assennato, 1994 and FAO, 1994).

Since maize production is seasonal, market supply depends on the harvest, which is limited to a few months and can fluctuate from one season to another and from year to year, depending on the climatic conditions (FAO, 1994). However, consumption of staple foods such as maize does not vary from one season to another or from year to year hence there is a stable but regular demand throughout the year (Nyanteng, 1972). To satisfy market demands, there is the need to store surplus produce and release it back onto the market during the lean season. Maize storage however involves substantial costs and risks as well as potential benefits in that, during storage, wholesomeness of the grains must be maintained (Lippert and Higgins, 1989; Golob and Tyler, 1994).

Due to the importance of maize in the diet of many people, storage is a vital component of the local economy (Hill and Waller, 1990). In Ghana for instance, maize is so critical in the economy that, according to Dartey (1998), a ball of kenkey was once presented in parliament and its price used as a measure of the state of the economy. For most peasant farmers therefore, loss of their maize during storage means food shortage and subsequent famine, and to the commercial farmers and maize traders loss of revenue as well.

2.1.2.1 SCALES OF STORAGE

2.1.2.1.1 SMALL SCALE

Most small-scale farmers (domestic storage level) often sell a large proportion of their maize at harvest when prices are low (Nyanteng, 1972; Ole, 1985), although the desire is to store grain in order to cover food requirement and future cash needs (FAO 1980). This is frequent with deficit producers; who must satisfy cash needs immediately after harvest and sell their produce at a lower price, only to buy food later in the season (Kat and Diop, 1985). Thus for most smallholder farmers, storage is limited to seed material (de Lucia and Assennato, 1994).

2.1.2.1.2 MEDIUM SCALE

The medium to large-scale farmers mostly stores much of their maize in anticipation of higher prices in the lean season. These farmers are estimated to hold over 70% of their produce in the on-farm storage system (FAO, 1994).

Some suggested storage practices to reduce or eliminate storage insect pests include: storing only clean and dry grains (usually at 12% or less moisture content); maintaining hygienic stores and storing new and old grains separately. Storing well-dried grains may not only reduce or eliminate infestation by insects but also mites and microorganisms such as fungi (Ayertey, 1986; Lippert and Higgins, 1989; Asiedu and Van Gastel, 2001). As indicated by Asiedu *et. al.*, (2002). The rule of the thumb suggests that 1.0% decrease in seed moisture content in storage doubles the storage life of seeds.

The most appropriate time for harvesting maize is at physiological maturity stage (about 35% moisture content), if the facilities to reduce the moisture content to 12% or below are available. In humid tropical Africa however, reducing the moisture content of maize to acceptable level before storage is a major problem to contend with. This is because of unavailability or unaffordability of advanced artificial drying technology if harvest is done early (Granados, 2000). Furthermore, the high humidity slows down the drying process in the field hence prolonging the stay of the crop in the field after attaining physiological maturity. The consequence of delayed harvesting is enhanced mould growth, insect infestation, losses to birds and germination of grains on the cob (de Lucia and Assennato, 1994).

Traders in most developing countries are believed to carry out very little inter-seasonal or long-term storage of maize (FAO, 1980). Rather they buy and sell quickly, earning a moderate profit on each transaction. It is also believed that traders dispose of stocks as quickly as possible, in order to minimize losses associated with pest infestation and to avoid the extra expense of pest control (Kat and Diop, 1985; FAO, 1994). Other suggested reasons include lack of financial resources and physical facilities (Kat and Diop, 1985).

2.1.3 MAIZE STORAGE CONSTRAINTS

Dry maize can be stored husked, unhusked or shelled on the farm, in the residence, at a collection centre, or in silos by individuals or storage agencies (de Lucia and Assennato, 1994). Grains, like other raw foodstuffs, are stored as living kernels and therefore face possible deterioration. Grain quality may therefore be maintained by identifying the causes of deterioration and employing the right management practices. The factors of deterioration include high grain moisture content, insect pests, moulds and relative humidity of store (Appert, 1987).

The most difficult of these factors to manipulate during maize storage is storage insect pests. The presence of insect pests may greatly influence grain moisture content and growth of mould (Ayertey, 1986).

2.1.2.1.3 LARGE SCALE

Traders, food processors, and grain warehousing agencies (which may be governmental or private) are the main stakeholders in the commercial level of maize storage.

2.1.2.2 CURRENT TRENDS IN MAIZE STORAGE

In most developed countries and a few African countries, governmental marketing boards and consumers buy in anticipation of future household needs (FAO, 1980). However, in most developing countries where governmental storing agencies existed, they have collapsed. Ghana for instance used to have a centralized buying and storing agency, the Ghana Food Distribution Corporation (GFDC), but its operations have collapsed (Edwards, 1989; Tripp, 2001). Structural adjustment programmes and trade liberalization policies in a number of African countries is increasing the involvement of private buying agencies in maize storage (FAO, 1994).

2.1.2.3 TRADERS' AND MAIZE STORAGE

FAO (1994) however indicated that information on storage by traders is scanty and scattered, thereby making it difficult to make discussion on their role in grain storage.

Losses to storage insect pests have been found to increase steadily from moisture content of 26% downward, as the crops stays in the field. For instance, loss of 3.76%, 10.2% and 13.0% were recorded at moisture contents of 26%, 20% and 16% respectively in field drying (FAO, 1980). There are therefore heavy losses in most developing countries where pre-harvest drying is prolonged, usually until the grain moisture is about 20% (Granados, 2000). Some farmers however harvest their produce earlier or in some humid areas, maize is harvested wet and subsequently dried using rudimentary facilities or sun drying (FAO, 1980 and CIMMYT, 1987b and Granados, 2000).

2.1.4 STORAGE METHODS OF MAIZE

Several traditional methods that rely on the sun or natural air for drying, termed ventilated system, have also been developed to reduce grain moisture to 'safe' level before long-term storage. Most of these ventilated structures constructed from local materials such as woven straw, sticks, bamboo, sawn timber and metal roofing sheets double as drying and temporal storage for maize on cob (Ole, 1985, FAO, 1980 and de Lucia and Assennato, 1994). Some of the common ventilated systems employed in Ghana are shown in Fig. 1 and describe as follows:

1) Thatch covered platform (A): it is constructed from bush sticks laid horizontally on a series of upright posts raised off the ground.

This system provides little protection from weather and pests and requires periodic firing from below.

2) Ewe maize barn (B): It is similar in construction to the thatch covered platform but in this crib, the whole cobs are laid with their butts outwards to form a wall that tapers inward. Ears are then piled inside the outer wall. This arrangement, together with its overhanging thatch provides some protection from rain and insects. Natural ventilation is however poor.

3) Ashanti maize crib (C): It is constructed from sticks fastened to upright posts by nails or ropes. It comes in rectangular shape that is roofed with thatch. Its open slatted sides permit a high degree of internal ventilation.

4) An inverted cone (D): The base features a basket-type cone with the roof supported on wooden poles. The conical base may be supported by stones, in which case the stored maize is prone to rodent pests and ground moisture. Good ventilation is provided at ground level. This differs from the thatch-covered platform in that the base is conical. This system provides protection from ground moisture. Good ventilation is provided at ground level (FAO, 1980).

5) Round slatted wall (E): Palm leaves supported by slats and tied-vines are usually used to build walls on platforms raised 30 – 100cm above ground, for protection from rodents and ground

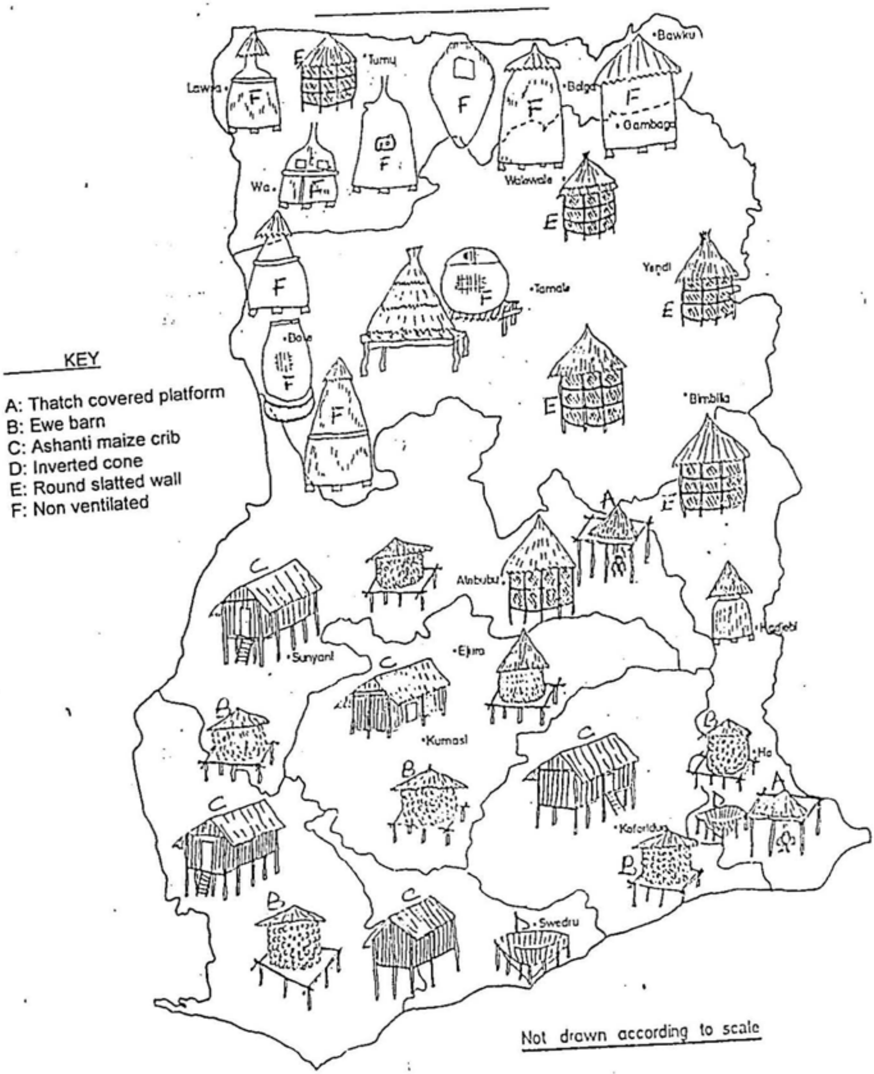

Fig. 1: Some traditional maize storage structures commonly used in Ghana (Adapted from Nyanteng, 1972).

moisture. This is commonly used in the dryer savanna regions of Ghana because thee walls limits the amount o natural ventilation (Nyanteng, 1972; FAO, 1980; FAO, 1987; FAO, 1994; Ofosu, *et. al*., 1998).

There has been some improvement in the traditional ventilated storage systems for storing cob maize. The Ashanti storage system, which is widely used in humid parts of Ghana, has been said to be the basis for the improved designs (Ofosu *et. al*., 1998). In these designs, cribs may be constructed from sticks, bamboo or sawn timber. The width of the crib is made narrow, with 60cm being the maximum. Cribs are also fitted with rat guards and galvanized-iron roofing which makes them durable and impervious to rain. Unlike the thatch roofing system, the galvanized roofing does not harbour pests. It employs natural airflow through a non-compacted bulk of dehusked cobs oriented at right angles to the prevailing wind (FAO, 1980, and 1994; Appert, 1987).

The ventilated storage systems are mainly for temporary storage. For prolonged storage, the dry maize is dehusked and shelled before it is transferred into non-ventilated structures. The non-ventilated structures (Fig. 1) have solid walls constructed from mud, concrete or metal. Containers such as gourd calabash and earthenware pots of varying sizes may also be used. This storage system offers better protection of the stored grains against infestations by insects and rodents as well as mould growth, once grains are well-dried (FAO, 1980 and Appert, 1987).

2.2 AGRONOMIC AND POST-HARVEST CHARACTERISTICS OF MAIZE

Maize is a warm-weather crop requiring warmth from planting until flowering. It thrives in a wide range of soils, from sand, loam to heavy clays and requires moderate rainfall (Norman *et. al*, 1996). Maize cultivation in Ghana is primarily rain dependent as a result there are two sowing periods in the southern sector (which is made up of forest and transition zones): major (April – May) season and minor (August – September) seasons. However in the Northern sector (Guinea Savanna), there is usually a single sowing periods, in April – May, to conform to the single rainy period in the area (Rouanet, 1987; Asiedu *et. al.*, 1989).

2.2.1 GROWTH STAGES OF MAIZE

The duration of the growth stages however depends on the maize variety. Growth stages of maize are divided into two broad categories when at least 50% of the plants show the corresponding features. They are the vegetative and reproductive stages (Granados, 2000, Sallah, *et. al.*, 2003):

I. Vegetative phase of maize: The coleoptile of the sown seed emerges from the soil surface after about 5 days after sowing (DAS). The collar of the first and second leaves becomes visible at the 9th and 12th DAS respectively. A single leaf grows at each node once every 3days until a total of about 16 – 23 leaves are attained.

II. Reproductive phase of maize: The maize plant is monoecious, bearing the male flowers in the tassel and the female on the lateral ear shoots. The emergence of tassels at 48 – 55 DAS marks the first reproductive phase of the plant. The lateral ear shoots starts forming 6 – 8 nodes below the tassel, after about 10days from tassel initiation. These shoots produces silk in about 51 – 57 DAS after which fertilization takes place.

Grain filling and maturity, which occur after the fertilization, is divided into 5 stages:

1) Blister stage: After fertilization, carbohydrates and nutrients rapidly accumulate in the developing kernel in the form of clear fluid. Kernels shaped like small blister appear on the rachis at about 61 – 71 DAS.
2) Milk stage: At this stage, kernels arte filled with white, milky fluid at about 71 – 80 DAS. The fluid has high sugar content and kernels

are suitable for consumption as fresh maize. Sugar and water content decreases as the starch content increases.

3) Dough stage: This stage is divided into two phases, the soft-dough and high-dough. At soft-dough, kernels are filled with white paste. The white paste in the kernel gradually solidifies to starch, starting from the crown of the kernels, at the hard-dough stage. A milk line, which separates the mature starchy area from the milky region near the base of the kernel, is formed. This line moves toward the base of the kernel as it continues to mature. The position of the milk line is a useful way of monitoring the maturity of the kernels. Moisture content reaches about 40% at the hard-dough stage.

4) Dent stage: If the genotype is a dent type, the kernels start to dent at the crown and the milk line moves close to the base of the kernels. Moisture content reaches about 40% at the hard-dough stage. This occurs at about 90 – 100DAS.

5) Physiological maturity: The kernel becomes fully matured and transport of assimilates to the kernel ceases. A black layer (abscission layer) forms at the base of the kernel. At this stage, the kernel's moisture content is about 30 – 35% and it takes about 90 – 112 DAS to reach this stage. Although the ears are harvestable at this stage, harvesting is usually delayed to allow the moisture content to drop to about 20 – 25%.

2.2.2 MAIZE VARIETIES

Maize is usually classified on the basis of maturation period, protein content and the hardness of the kernel. Based on the maturation period maize can be categorized as extra-early and early maturing, which takes 75 – 80 and 90 – 95 days respectively to mature. Examples are *Dodzi* for extra-early and *Mamaba* for the early maturing. The rest are the intermediate and late that also takes 90 – 100 and 115 – 120 days respectively to reach maturity (Asiedu *et. al.*, 2001a; Sallah *et. al.*, 2003). *Obatanpa* and a typical local variety *Fante* are examples for the intermediate and late maturing varieties respectively.

On the basis of protein content, maize is grouped into normal maize and Quality Protein Maize (QPM). In the QPM, the Tryptophan and Lysine (essential amino acids) constituents, which are low in normal maize, have been improved (Goodman, 1976; Twumasi-Afriyie, 1992; Paliwal, 2000b,).

Kernel hardness may be classified as soft or hard. The hard kernels include:

1) Pop; small smooth kernels with hard endosperm eg. *Owifompe* maize.
2) Flint; large smooth kernels, mainly hard endosperm but often

with a floury centre eg. *Fante, Mamaba* maize.

Among types with soft kernels are:

1) Floury; large smooth kernels with floury endosperm.
2) Dent; large kernels with a central core of floury endosperm, which on drying shrinks more than the surrounding hard tissue, denting the kernel eg. *Obatanpa.*
3) Sweet; kernels with carbohydrates stored largely as sugar. Kernels wrinkle and become translucent when dry (Norman *et. al.*, 1996; Norman *et. al.*, 1999).

2.2.2.1 VARIETAL RESISTANCE TO STORAGE INSECT PESTS

Resistance of plants to insect attack as defined by Granados and Paliwal (2000) is the relative amount of heritable qualities possessed by the plant that influence the ultimate degree of damage inflicted by the insects. According to Saxena (1985), resistance of a plant is expressed as the inhibition of certain activities of pests, such as orientation, feeding, metabolism of ingested food and oviposition. These resistance characteristics are expressed primarily by exhibiting one or combination of antixenosis, antibiosis and tolerance (Stiling, 1985; van Emden, 1989; Dent, 1991).

Stored seeds combine antixenosis and antibiosis modes of resistance against storage insect pests (Legg *et. al.*, 1987; Santos and Foster, 1983). In cereals these properties are expressed through hard grains, phenolic acid content, a flinty corneous endosperm, the presence of glumes, and the compact arrangement of pericarp layers (Dobie, 1974; Gahukar, 1989; Wargo, 1990, Arnason *et. al.*, 1997 and Serratos *et. al.*, 1997). Schoonhoven *et al.* (1976) on their part suggested smoothness of kernels as another factor conferring resistance against weevils. They argued that smooth kernel would prevent the weevils from gripping the pericarp with their mandibles to feed and oviposit. High susceptibility in the improved varieties is also thought to be due to high protein content since most insects thrive better on plants with high protein (Schoonhoven *et. al.*, 1998)

Although a number of varieties of maize resistant to field insect pests are widely distributed, resistant varieties against storage insect pests appear to be scarcely available (Granados and Paliwal, 2000; Stoll, 2000). The usual resistance exhibited by improved varieties in the field is usually referred to as apparent resistance. This is because some of these varieties are early maturing and thus are able to evade peak periods of pest population (Stiling, 1985).

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A number of improved varieties tested against storage insect pests have been found to be more susceptible than the traditional varieties (FAO, 1980; Golob, 1981; Badu-Apraku *et. al.*, 1992; Vowotor, 1993; Boateng and Ayertey, 1996; Vowotor *et. al.*, 1995a and 1995b). According to Hill and Waller (1990), typical local maize might record 5 – 10% infestation by pests within 30 days of on-farm storage while the improved varieties would have 60 – 80% infestation over the same period. Boateng and Ayertey (1996) on the other hand indicated that losses in local varieties stored in cribs soon after harvest are relatively low during the first month of storage but increase sharply thereafter.

Differences in susceptibility of different varieties to stored product pests have influenced the agronomic practices in some maize growing areas. Some farmers in Zimbabwe for instance have responded to this by growing high yielding but susceptible varieties for immediate sale and low yielding but resistant varieties for storage (Giga and Katarere, 1986 as cited in FAO, 1994).

2.2.2.2 MEASUREMENT OF SUSCEPTIBILITY

Several parameters have been used to measure varietal susceptibility of maize grains against storage insect pests. Among these are number of eggs laid, total number of progeny, percent of grain damage and grain weight loss (Obeng-Ofori *et. al.*, 2002). Although efficiency and adaptability of these parameters have been evaluated to be effective, some difficulties are encountered in relating singularly, any of the parameters to genetic differences. Grain weight loss for instance rated well in economic evaluation and resistance measurements (Widstrom *et. al.*, 1972). Dobie (1974) therefore suggested an index of susceptibility based on a method developed by Wheatley (1973). This method incorporates the total F1 progeny that develops during the test period and average development period from the midpoint of oviposition to the emergence of 50% of the progeny. Urrelo *et. al.* (1990) modified Dobie's index of susceptibility by replacing the total F1 progeny and 50% emergence with total number of eggs laid and days to first emergence respectively.

2.3 STORED INSECT PESTS OF MAIZE

Coleoptera and Lepidoptera form about 75% and 15% respectively, of stored products pests. The rest belong to Diptera, Hymenoptera, Blattodea, Psocoptera and Thysanura. (Benz, 1987; Lippert and Higgins, 1989). These insects may be classified as primary or secondary pests, scavengers, predators or parasites (Christensen and Kaufmann, 1969; Kossou and Bosque-Perez, 1998).

Insect pests have become formidable pests of stored maize and other grains due to the short time required for them to develop from egg to adult (about 30 days or less for most species under optimal conditions). Moreover they have high reproductive rate per individual (often 300 or more eggs per female) (Appert, 1987; Lippert and Higgins, 1989 and Haines, 1991). These attributes ensure that only few individuals are necessary for large number to develop in a relatively short time.

2.3.1 FACTORS AFFECTING INSECT PESTS IN STORED MAIZE

Species composition and abundance of insect pests in stored maize have been found to be influenced by maize variety and form of storage. Other factors of infestation of maize by storage insect pests include moisture content, temperature, relative humidity and the intactness of the grains (Vowotor 1993; Urrelo, 1991; Badu-Apraku *et. al.*, 1992; Vowotor *et. al.*, 1995a and 1995b and Boateng and Ayertey, 1996).

Maize stored as unhusked ears are less susceptible to *Sitophilus spp.* but suffer heavy damage by *Prostephanus truncatus* (Horns) and *Sitotroga cerealella* (Olivier). (Dick, 1988; Bosque-Perez, 1992; FAO 1994; Prah, 2000). Thus maize is better stored unhusked in areas where *Sitophilus sp.* is the major pest and as grains where *Prostephanus truncatus* (Horns) and *S. cerealella* are the common pests.

Drying the maize to moisture content of 12% or less before storage has been observed to reduce the spectrum of pest species to one or few of the major pests. None of the insect pests thrives below 8% grain moisture content.

Feeding and reproduction of most storage insect pests occur at a narrow temperature range of 5 – 10 degrees around the optimal 30°C and RH of over 40% (Kossou and Bosque-Perez, 1998). However, during storage, all the three physical factors are inter-related. For instance, 48 hours of exposure of stored maize at RH of 90% may increase its moisture content from 13% to 18% at a temperature of 23°C (FAO, 1982).

Intact grains are infested mainly by primary pests. Cracked or already damaged grains are invaded by a wide range of pests and are also prone to mould growth (Appert, 1987). Only a few species are thus important pests of maize at a particular locality (Kossou and Bosque-Perez, 1998).

2.3.2 STORAGE INSECT PESTS OF PRIMARY IMPORTANCE

2.3.2.1 COLEOPTERAN

Table 1: The most coleopteran insects of importance

Family	Species
Curculionidae	*Sitophilus zeamais*, *Sitophilus oryzae* and *Sitophilus granarium*.
Bosrtrichidae	*Prostephanus. Truncates* (Horn), *Rhizopertha dominica* (Fabricius) and *Dinoderus minutus* (Fabricius
Dermestidae	*Trogoderma granarium* (Dejean).
Nitidulidae	*Carpophilus* sp.
Tenebrionidae	*Tribolium* sp., *Cathartus quadricollis* (Guerin)
Silvanidae	*Ahasverus advena* (Waltl), *Cryptolestes* sp and *Oryzaephilus*
Anthribiidae	*Araecerus coffeae* (Degeer).
Anobiidae	*Lasioderma serricorne* (Fabricius).

Source: (Christensen and Kaufmann, 1969; Cotton, 1971; Haines, 1991 and, Kossou and Bosque-Perez, 1998, Van Tonder and Prinsloo, 2000).

2.3.2.1.1 *SITOPHILUS SPP.*

Sitophilus spp. is well known as the most important primary pest of stored cereal grains and the most widely distributed among the storage insect pests (Appert, 1987; Haines, 1990). With the exception of *S. granarium*, which is limited to the temperate regions, they are found in all warm tropical parts of the world. While *S. zeamais* is dominant on maize, *S. oryzae* prefers wheat (Kossou and Bosque-Perez, 1998) and rice (Ayertey and Akibu, 1982; Appert, 1987).

However neither species is a significant pest of smaller grains, such as millet, which is too small to permit full development of the larva within a single grain (Haines, 1991).

Sitophilus spp. colonize maize ears in the field and can survive on whole or undamaged grains of maize, sorghum, rice and wheat so long as the grains are not exceptionally dry (Appert, 1987; Hill, 1987). They are responsible for heavy losses of stored maize every year (The Ghana Farmer, 1973; Boumans, 1985; Hill, 1987). In Ghana for instance, Rawnsley (1969) reported 35% weight loss of stored maize to *Sitophilus spp.* after only eight weeks of storage

2.3.2.1.2 *PROSTEPHANUS* AND *RHIZOPERTHA*

P. truncatus and *R. dominica* are basically wood-borers and their wood boring activities may weaken crib structure and provide hiding places for residual pest populations. These pests are tolerant of low moisture, capable of thriving in grains with less than 8% moisture content, making them formidable pests (Appert 1987; Kossou and Bosque-Perez, 1998; Lippert and Higgins, 1989; Stoll, 2000).

P. truncatus is native to the Americas was recently introduced to Africa. It was first reported in Tanzania in the late 1970s where it spread to other East African countries. It was accidentally introduced to Togo in 1984 and was first found in Benin and Ghana in 1986 and 1989 respectively (Haines, 1991). It has been predicted that *P. truncatus* has the potential of spreading to all maize growing areas of Africa (Haines, 1991; Kossou and Bosque-Perez, 1998). Results from an investigation by Ayertey and Brempong-Yeboah (1991) shows that the population of *P. truncatus* is concentrated in the Volta Region and dwindles as one move across the country westwards. This pest was absent in Weija (Greater Accra Region) and Kasoa (Central Region) in April 1991. Another work by Prah (2002) however indicates the presence of *P. truncatus* in Cape Coast and Breman-Asikumah, both in the Central Region.

Both adults and larvae of *P. truncatus* feed on the grains on the cob (with or without the sheath) before and after harvest, causing extensive damage (Boateng and Ayertey, 1996). Adults also feed on dry cassava and wood. Losses of maize stored in cribs have been found to be as high as 34% after 3 – 6 months of storage, which according to Kossou and Bosque-Perez (1998) is 3 – 5 times higher than losses caused by other pests. In Nicaragua, unprecedented 40% weight loss has been recorded (Giles and Leon, 1975). A predatory beetle, *Teretriosoma nigrescens* (Lewis), however, has been found as a natural enemy of *P. truncatus* and is on trial in some African countries (Ayertey, 1986; Haines 1991; Kossou and Bosque-Perez, 1998).

Adults and larvae of *R. dominica* are voracious feeders (Pans, 1982) causing economic damage to stored maize. While the adults feed on the germ, the larvae empty the whole grain (Appert, 1987). Unlike *P. truncatus*, *R. dominica* does not attack crops in the field (Stoll, 2000).

Another bostrichid, *Diminutus minutus* (Fabricius), which is principally associated with dried cassava and bamboo beside wood has been found to occasionally infest certain varieties of maize (Haines, 1991).

2.3.2.1.3 *TRIBOLIUM* SP.

Tribolium spp. is one of the most important secondary pests infesting stored maize although *T. confusum* and *Gnathocerus* sp. may occasionally be of importance. They proliferate on broken grains or grains already damaged by other pests, causing musty smell as well as extensive damage to grains. Adult *Tribolium* spp. is known to actively fly in large numbers in the late afternoon (Hill, 1987; Haines 1991; van Tonder and Prinsloo, 2000).

Several species of the families Silvanidae and Nitidulidae infest maize prior to harvest. They thrive best in grains with high moisture content and in humid stores.

2.3.2.1.4 LEPIDOPTERANS

The lepidopteran pests of prime importance to stored maize are *Sitotroga cerealella* (Olivier), *Ephestia* spp. and *Plodia interpunctella* (Hubner). Although *Mussidia nigrivenella* (Ragonot) and *Cryptophlebia leucotreta* (Meyrick) are field pests, may survive during storage (Haines, 1991 and, Kossou and Bosque-Perez, 1998, Van Tonder and Prinsloo, 2000).

Damage caused by moths in stored maize is limited to the larvae, which feed on and web grains together with silk. Although larvae of *M. nigrivenella* and *C. leucotreta*, are field pests, they survive in storage when maize is not exceptionally dry (Prah, 2000). Larvae of these moths feed at the embryo area of the grains, making tunnels in the grains that may cause grains to get detached from the cob. Damage by these ear borers predisposes maize to attack by pre- and post-harvest insect pests and mould infestation (Mcmillian, 1987; IITA, 1997 and Setamou *et. al.*, 1998).

The larvae of *S. cerealella* can cause considerable damage and may be comparable to that of *Sitophilus spp.* and in more arid areas, may replace them (Appert, 1987). Larvae enter grains upon hatching to complete their life cycle to the adult after which they emerge, leaving a characteristic emergent hole with a flapped window on the grain.

Infestation can therefore be detected by the presence of these flapped windows. Infestation by *S. cerealella* typically starts before harvest (de Pury, 1974;Hill, 1987; Rouanet, 1987).

2.4 STORAGE INSECT PESTS CONTROL

The four main methods of maize used to control insect in stored maize are physical, chemical, biological and irradiation:

1) Physical: This method involves the manipulation of physical factors such as sieving, moisture content, temperature, relative humidity or exposure to the sun etc in order to create unfavourable conditions to prevent the pest from surviving. For example fecundity of the pest reduces as the temperature of the store decreases from 20^{0}C. At temperatures below 10^{0}C reproduction is inhibited and at about 0^{0}C all insects die (Appert, 1987, Asiedu, *et. al.*, 2001b).

2) Chemical: Both synthetic and botanical insecticides are applied to the grains to kill insect pests. This is the commonest and the most effective method of controlling insect pests, especially with the synthetic beings and other animals because of their high toxicity, residues in foodstuffs and prolonged persistence at the environment. Over reliance and improper usage have led to rapid build up of resistance of these pests to many insecticides (Benz, 1987; Tomlin, 2000).

3) Biological: Other living organisms that prey on the pests are employed to control pest populations. A typical example is the use of *T. nigrescence* to control *P. truncatus* (Aryetey, 1986; Van Emden, 1996).

4) Irradiation: Grains are exposed to ionizing radiation from either radioisotopes or devices that produce x-rays or electrons. Depending on the dose of the radiation, the insect is killed or rendered infertile (Appiah and Montsford, 1999).

2.5 OVERVIEW

The current trend in maize storage suggests, maize traders will form the pivot and thus must be well covered in current researches. To this far, it is clear that the maize trader as a stakeholder has received little attention and an effort must be made to develop adequate data on their activities. This will help make a well-coordinated discussion and incisive decisions on their role in storage pest management.

Introduction of new plant cultivars come with their characteristics usually different from indigenous cultivars, necessitating the adoption of different management practices. However, little or no changes have been made on the storage systems employed in Ghana, although several maize cultivars have been developed and are widely grown. There is the need to consider the storability of these cultivars under the traditional storage systems used for the indigenous cultivars. This will help stakeholders to determine whether the current systems must be changed or maintained.

CHAPTER THREE

METHODOLOGY

The research covered four main experimental areas:

1) Market survey
2) Time of onset of storage insect pests infestation of maize
3) Susceptibility of four maize varieties to storage insect pests
4) Alternative hosts of storage insect pests of maize.

3.1 MARKET SURVEY

Guided questionnaires were used to assess local maize traders' knowledge about stored product pests in some major markets in southern Ghana. This was followed up with sampling of maize being sold in the markets to determine whether storage insect pest species present agree with those identified by traders.

3.1.1 LOCATIONS

The study area covered four towns in four Regions in southern Ghana. The towns included Cape Coast (Central), Accra (Greater Accra), Sekondi/Takoradi (Western) and Kumasi (Ashanti) (Fig. 2). These towns were chosen because of their high population densities and their characteristic major markets. The specific markets were:

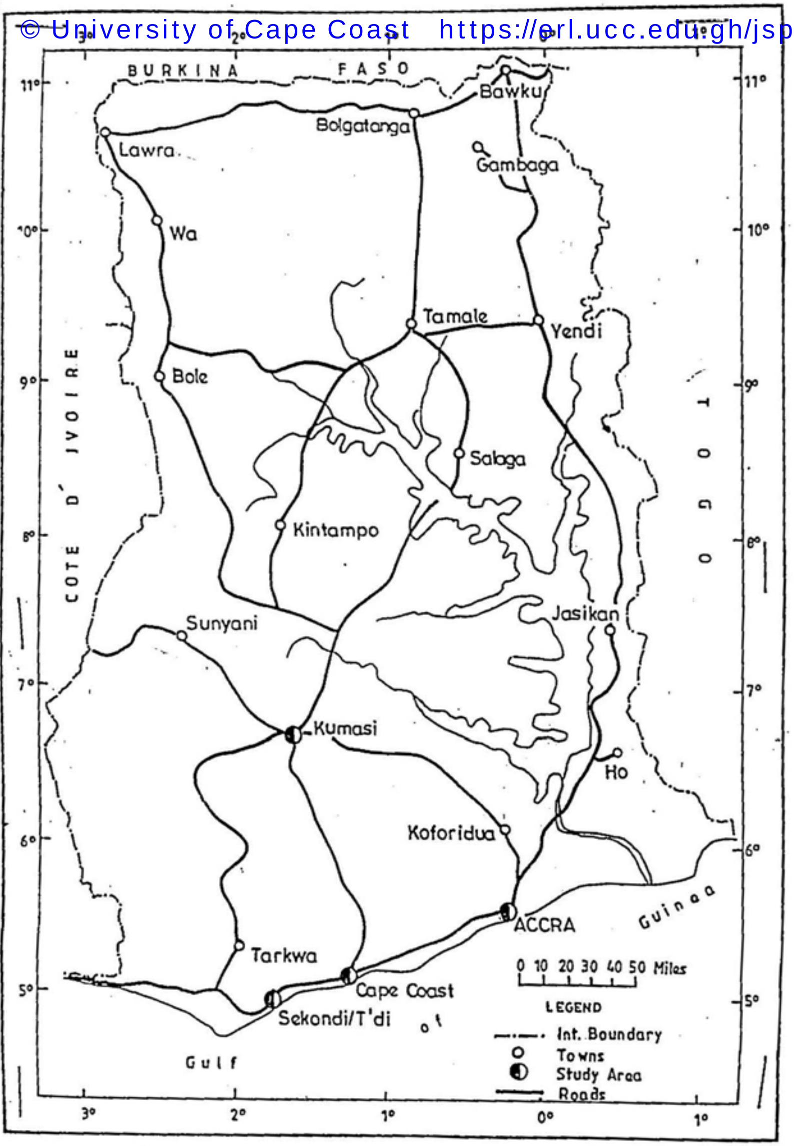

Fig. 2: Map of Ghana showing towns for the market survey.

1) Cape Coast – Abura and Kotokuraba
2) Accra - Agbogbloshie, Madina and Mallam Atta
3) Sekondi/Takoradi - Sekondi Central, Market Circle and Apremdo
4) Kumasi - Asafo and Central Market.

3.1.2 MAIZE TRADERS' PERCEPTION OF STORAGE INSECT PESTS

The study involved 94 out of 100 targeted maize traders from 10 major markets in southern Ghana. Based on sizes and population density of the various markets, 35% of the respondents were from Agbogboshie, Madina and Mallam Atta markets in Accra. At Kotokuraba and Abura markets in Cape Coast, 13% of the respondents were selected from the two markets. Twenty-seven percent of the traders were selected from Central and Asafo markets in Kumasi. The rest of the 25% were from Sekondi Central, Market Circle and Apremdo in Sekondi/Takoradi. Traders were preliminarily numbered to estimate their total number in each market. The required number was then selected at random.

The guided questionnaire (Appendix 1) used was designed to seek information mainly on source of maize, maize storage, storage insect pests and their control. Questionnaire was pre-tested in the Anafo and

Kotokuraba markets in Cape Coast in October 2001 while the main study was conducted in April 2002. Respondents who were involved in the pre-testing were excluded from the main study.

3.1.3 STORAGE INSECT PESTS IN MAIZE SOLD IN THE MARKETS

About 2kg of maize of mixed varieties was purchased from each of forty-two maize traders selected at random from the same 10 markets named above. Three to six maize traders were selected at random from each market, depending on the size of the market. The samples were taken to the laboratory where the moisture content was determined as described below (section 3.1.4). The rest were sealed in polythene bags and incubated for 40 days at 28.9°C and 71.0% R.H. This was to allow the eggs, larvae and the pupae to emerge. Coleopterans and insect larvae were collected and preserved in labeled vials containing 70% ethanol Adult lepidopterans were freeze-killed and then sun dried. There were two samplings for storage insect pests in the markets, one in October 2001 and the other in April 2002.

Insects collected were preliminarily identified using two dichotomous keys prepared by British Museum (Hinton and Corbert, 1975) and Natural Resources Institute (Haines, 1991). Samples of the identified pests were subsequently sent to specialists at the Zoology

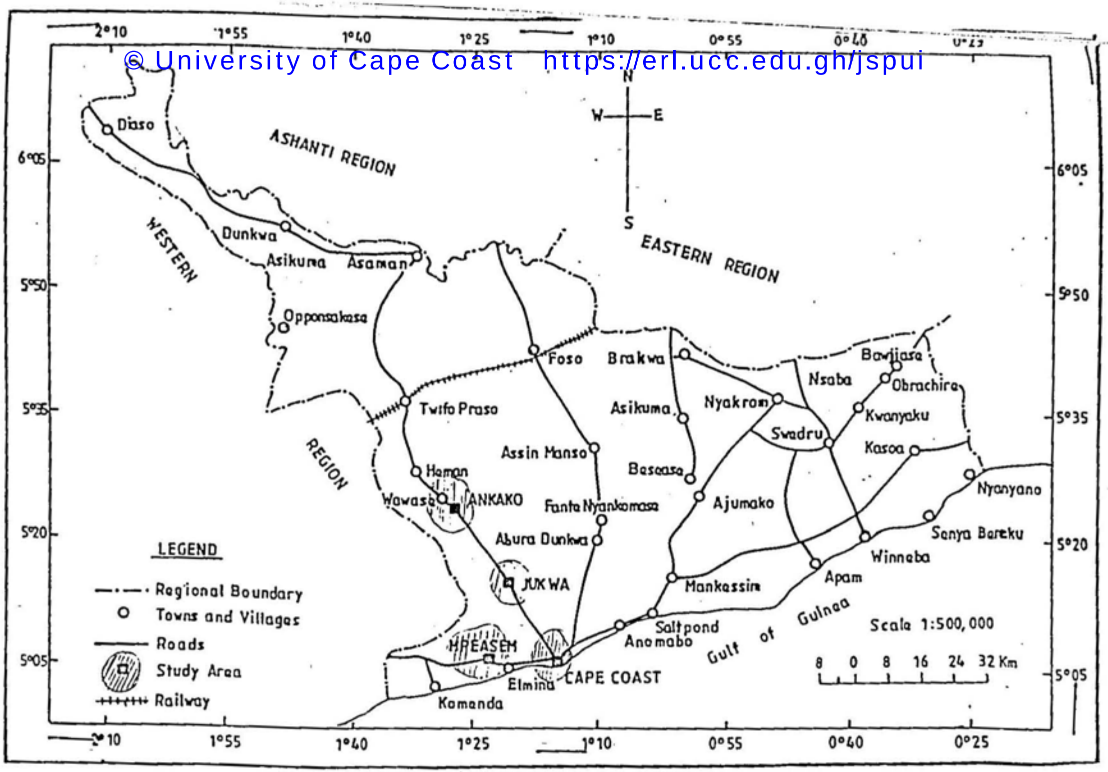

Fig . 3: Map of Central Region showing sampling sites in the minor season storage insect pests that survived from the field through storage, those that infest in the field but were absent in storage and those that came in only during storage.

3.2.1 FIELD PLOTS

Field observations were made over two cropping seasons, the major and the minor season. The major cropping season's experiment was carried out at the Technology Village of the School of Agriculture, University of Cape Coast, Cape Coast. Crops that were cultivated (by other researchers) at the time of the research included cabbage, sweet pepper, garden eggs, cassava, maize, carrot and plantain. The plot of land for the research which measured 20m x 30m was bounded by a thicket on the north and by cassava on the east. The southern portion was bounded by grass and maize at a distance of about 80m away.

The research during the minor season was carried out in four selected farms located in four towns. They were Ankako, Jukwa, Mpeasem and Cape Coast, all in the Central Region (Fig. 3). All the farms were bounded primarily by *Cassia* trees and *Chromolaena odorata*, except in Cape Coast, where the farm was located near a sugar cane plantation.

3.2.2 LAND PREPARATION, PLANTING AND CROP HUSBANDRY

3.2.2.1 MAJOR SEASON

The land used had already been ploughed so there was no further ploughing. The land was manually cleared with a cutlass and tufts of grass subsequently uprooted with hoe. The prepared land was divided into four plots, each measuring 6m x 18m. A distance of 1m separated the plots. Each of the two Quality Protein Maize (QPM) varieties (*Mamaba* and *Obatanpa*), and two local varieties, (*Fante* and *Owifompe*) were randomly assigned to plots.

Sowing was done in rows at a rate of two seeds per hill with a distance of 90cm between rows and 40cm within rows (CRI, 1999). There was about 90% germination for *Obatanpa* and *Fante*, and about 80% for *Mamaba* and *Owifompe* varieties: acceptable germination period in Ghana for certified seeds is 85% (Ocran *et. al.*, 1989). Refilling was carried out three days after germination. There were three weeding sessions with a cutlass on the 14th, 35th and 50th day after emergence.

3.2.2.2 MINOR SEASON

All the four farms selected during the minor season were manually cleared with a cutlass. The thrash were allowed to dry and then burnt before sowing. In this season, only *Obatanpa* variety was sown in all the four farms. This was because farmers' farms were used and the farmers had only the *Obatanpa* seeds for planting. Planting was randomly done and there were three seeds per hole. Weeding was done three times, also with a cutlass.

3.2.3 COLLECTION, PRESERVATION AND IDENTIFICATION OF INSECTS

In the major season, ten ears were harvested at random at weekly intervals from the milk stage [11th week after emergence (WAE), for *Obatanpa* and *Mamaba*, and 13th WAE for *Fante* and *Owifompe*] until completely dry (indicated by the distal end of the ears pointing downwards). This coincided with the peak time of harvest in the locality.

In the minor season however, ten maize ears were harvested randomly at weekly intervals from the milk stage (12^{th} WAE), from the selected farms. Harvesting continued until ears were completely dry; as in the major season.

All larvae and adult insect pests on the ear stalks and ears were collected with the aid of forceps and moistened fine brush. All Insects collected were immediately preserved as in section 3.1.3.

The harvested ears, with their husks on, were incubated in feed sacks for 10 days at ambient temperature of 28.6°C and 87.4% relative humidity (R.H), and 29.7°C and 77.8% during the major and minor seasons respectively. Both measurements were taken with Diplex electronic thermometer/hygrometer and wet and dry bulb whirling hygrometer. The ten-day incubation period was to allow the eggs to hatch as well as to minimize crushing of that might have been laid on the ear husk. After the ten-day period, the sacks were checked every 5 days for 40 days for any emerged adult storage insect pests. Husks of the ears were removed after the 40 days, in order to count all insects present. All insects collected were identified as in section 3.1.3.

3.2.4 DETERMINATION OF MOISTURE CONTENT

Five ears were harvested at random for each variety, during both the major and minor seasons, from each farm on each harvesting week. The grains were shelled and the moisture content determined as in section 3.1.4.

3.2.5 INSECT PESTS DURING STORAGE

Sixty uniformly sized ears of each maize variety, harvested on 18th WAE of the major season planting were stored in two cribs constructed from sawn timber, raffia fronds and leaves. Each crib measured 3m high, 1m and 2m in width and length respectively. They were raised 1m above ground level and the stands were fitted with rat guards. Each crib was partitioned into four chambers using raffia fronds (Plate 1). The cribs were erected against the prevailing wind and were located about 120m away from the farm.

Ten ears of each variety were randomly sampled from each crib fortnightly. These were dehusked and kernels shelled from the cobs onto a white tray. Storage insect pests present were collected, preserved and identified. Moisture content of the grains on each sampling day was also determined. This was repeated until the maize stored in each crib was sampled.

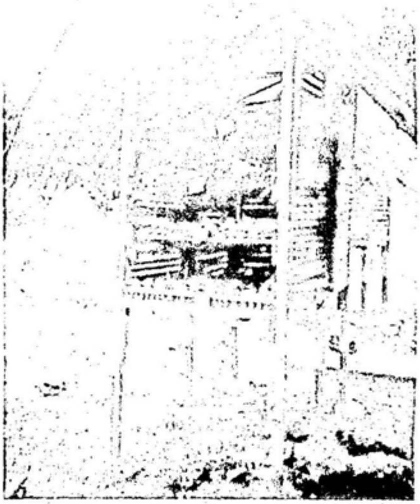

Plate1: Crib showing partitioning and maize

3.3. SUSCEPTIBILITY OF QPM AND LOCAL MAIZE VARIETIES STORAGE INSECT PESTS

This work compared the susceptibility of two QPM (*Obatanpa* and *Mamaba*) and two local (*Fante* and *Owifompe*) maize varieties in the field and in storage. Another laboratory experiment investigated the performance of *Sitophilus* sp. on the four varieties. The parameters investigated included: oviposition, adult emergence rate, susceptibility index (SI), population growth rate and grain weight loss (Obeng-Ofori *et. al*., 2002)

3.3.1 WEIGHT LOSS OF FOUR MAIZE VARIETIES TO STORAGE INSECT PESTS

At the tenth week of storage of maize in section 3.2.4, five ears per variety from each crib were selected at random, shelled and the total number of kernels counted. Both unbored and bored kernels were separated, counted and weighed (Plate 2). Percentage weight loss was calculated using the method of FAO (1985 as cited in Obeng-Ofori *et. al*., 2002) as:

$$\%\ \text{weight loss} = \frac{[UaN - (U+D)]}{UaN} \times 100$$

Where U = weight of undamaged fraction in the sample

N = total number of grains in the sample

Ua = weight of one undamaged grain

D = weight of damaged fraction in the sample.

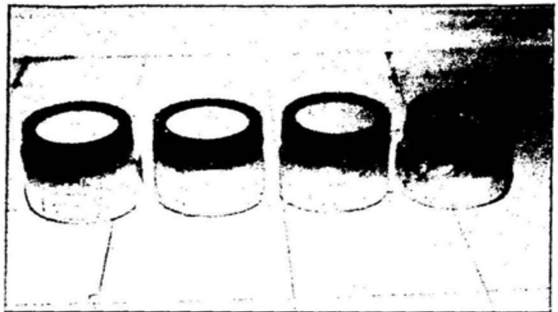

Plate 2: Kilner jars containing four maize varieties to test their susceptibility to *Sitophilus* sp.

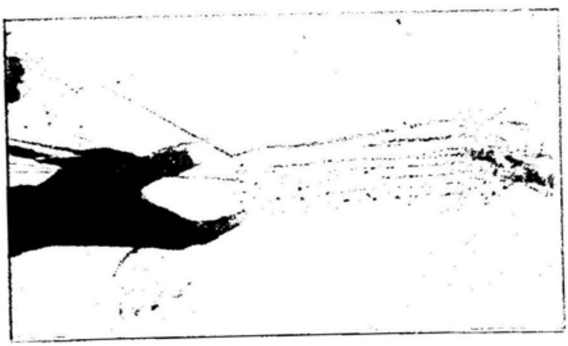

Plate 3: Maize on the cob infested with storage insect pests.

3.3.2 PERFORMANCE OF *SITOPHILUS* SP. ON FOUR MAIZE VARIETIES

3.3.2.1 PREPARATION OF GRAINS

Some of the grains of the four varieties harvested from the field were used. Seeds with signs of infestation and other debris were separated from those without any sigh of infestation. Wholesome seeds of each variety weighing about 3kg were transferred into glass jars, covered with muslin cloth held in place with rubber bands. These were incubated at ambient temperature of 28.8°C and 80% R.H. for 45 days. They were examined daily and any insect pests emerging from the grains were removed. Grains were then stored until needed.

3.3.2.2 CULTURE OF INSECTS

The stock insects for the experiment were collected from infested maize in the crib in the previous experiment and brought to the laboratory for culturing. Two kilogrammes of uninfested maize were placed into each of three 2 – liter capacity jars and 100 adult *Sitophilus* sp. added to it. To ensure ventilation the top of the jars were covered with muslin cloth. Regular inspection of the culture was done to ensure that it did not grow mouldy. Adult *Sitophilus* sp. were sieved out a week before any scheduled experiment and the adults that emerged afterwards used.

3.3.2.3 OVIPOSITION

Twenty unsexed adult *Sitophilus* sp. of about one week old from the culture were selected at random and added to 100 grains of maize placed in a 500ml kilner jar and sealed with muslin cloth (Plate 3). They were incubated at 29.1°C ambient temperature and 82.4% R.H. for 7 days. After this period, the parent insects were discarded and the grains with eggs deposited in them determined using the colorimetric method as described by Appert (1987). Grains were steeped in water for 15 minutes before soaking in 0.5% solution of acid fuchsin diluted in 50cm³ of ice – cold acetic acid and 950cm³ distilled water for another 15 minutes (female weevils plug holes bored at oviposition with a gelatinous secretion which turns cherry-red in this solution). Grains were examined under a stereomicroscope to determine kernels with eggs deposited in them. These were identified by the presence of cherry-red stained gelatin on the grains. It was assumed that all grains containing eggs were plugged with gelatin. There were four replicates for each of the four varieties.

3.3.2.4 DEVELOPMENT TIME AND SUSCEPTIBILITY INDEX

Grains of the four varieties were infested as in the oviposition experiment but after discarding the parents (after the 7 days oviposition period) the incubation period was extended for up to 55 days. Jars were examined daily and newly emerged adults were removed, counted and discarded. This was done in order to prevent oviposition from the F1 generation. The total number of adult *Sitophilus* sp. that emerged from each jar was recorded.

For each treatment, the middle development time was measured as the middle of oviposition period (3.5 days) to the emergence of 50% of adults (Dobie, 1974). The susceptibility index (SI) was then calculated as:

$$SI = \frac{(\log_e F) \times 100}{D}$$

Where F = Number of F1 progeny of *Sitophilus* sp.

D = Middle development period (in days)

There were four replicates for each of the varieties. The mean ambient temperature and R.H. in the laboratory were held at ambient 30.5°C and 84.2% respectively.

3.3.2.5 POPULATION GROWTH AND GRAIN WEIGHT LOSS

About a week old twenty unsexed adult *Sitophilus* sp. were introduced into 300g of each maize variety in a 500ml capacity kilner jar. Jars were sealed with muslin cloth and incubated in the laboratory at 30.3°C and 82.1% R.H. for 90 days (about two generations of insects). The jars were set at 4 rows and 4 columns, which were randomly changed every 10 days. Both parents and adults that emerged were maintained throughout the experiment. The total number of both live and dead weevils were counted and recorded at the end of the experiment. The population growth rates were calculated as Kaaya, 1994, using the equation:

$$MGR = \frac{(N_f - N_i)}{N_i}$$

Where MGR = Mean growth rate

N_i = Initial number of *Sitophilus* sp.

N_f = Final number of *Sitophilus* sp.

Debris produced from the grains, as a result of the feeding activities of the insects, was cleaned with tissue paper and the weight determined. The number of both bored and undamaged grains were separated, counted and recorded. Percentage weight loss for each variety was calculated using the method of FAO (1985), as in experiment 3.3.1. The layout was randomly set at 4 rows and 4 columns. The experiment was replicated four times.

3.3.3 DATA ANALYSIS

Data on number of pest species and population densities were transformed by log x+1 before being analyzed using Analysis of variance (ANOVA). Grain weight loss values during crib storage were transformed into Arcsine values and analyzed with ANOVA and means separated using Duncan's Multiple Range Test (DMRT). All transformed values were reconverted to their original values before being interpreted.

3.4. ALTERNATIVE HOST PLANTS OF STORAGE INSECT PESTS OF MAIZE

This study was designed to find out some wild plants that may serve as alternative hosts to storage insect pests of maize. The study was conducted Cape Coast. The plants sampled included seeds/fruits from various trees, shrubs and grasses in the wild. The main selection criterion was on the size of seeds/fruits produced. Sampling was carried out between January and April 2002, a time when maize was not likely to be available in the field.

Ripe seeds/fruits (Plate 4) were harvested into polythene bags and sent to the laboratory. Samples of the seeds/fruits together with leaves of the plants were sent to the University of Cape Coast's herbarium for identification. The rest of the harvested seeds/fruits were then incubated in the laboratory at 28.7°C and 74.2% R.H. for 40 days. Samples were inspected every 5 days and adult storage insect pests that emerged were collected, preserved and identified.

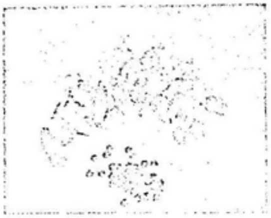

Plate 4a: *Adenthera pavonina*

Plate 4b: *Grenia carpinifolia*

Plate 1c: *Erythrophleum guineese*

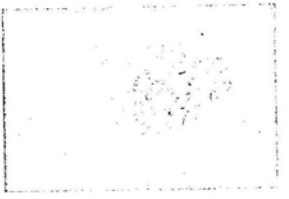

Plate 4d: *Crotalaria retusa*

Plate 4e: *Dalium guineense*

Plate 4f: *Centrosema pubescence*

Plate 4g: *Cassia* sp.

Plate 4h: *Bauhania purpurea*

CHAPTER FOUR

RESULTS

4.1 MARKET SURVEY

4.1.1. LOCAL MAIZE TRADERS PERCEPTION OF STORAGE INSECT PESTS

4.1.1.1. PERSONAL DETAILS OF RESPONDENTS

Out of the 94 respondents, only 7, representing 7.5% of the population were males; indicating that maize retailing is a female-dominated enterprise (Table 2).

Table 2. Gender composition of respondents

Sex	Frequency	Percent
Male	7	7.5
Female	87	92.5
Total	94	100

Forty-five percent of the respondents fall within 31 - 40 years age group (Table 3). The general age distribution of the sample population showed that a greater percentage, 62.8% fell within the range of 20 - 40 years. This indicated the high involvement of the active working age group in the retailing of maize.

Table 3: Age distribution of respondents

Age	Frequency	Percent	Cum. Percent
20-30	18	18.1	18.1
31-40	45	44.7	62.8
41-50	27	26.6	89.4
>50	10	10.6	100
Total	94	100	

A good number (36.2%) of the respondents were illiterate (Table 4). The proportion decreased from 28.7% for Primary school graduates with heightens of the academic ladder to 11.7% in Senior Secondary/Technical/Commercial school graduates. More than half of the traders, (64.9%), had up to primary education. There were no graduates from tertiary institutions such as Teacher Training and Polytechnic or Universities. These results showed that marketing of maize is predominantly for the lowly educated strata of society in the study areas.

Table 5 shows that majority of the traders (40%) had been involved in the maize business for many years. While 26.5% had been in the business for 6 – 10 years, over 40% had spent ten or more years in selling maize. Only 33% had less than six years working experience in maize retailing.

Table 4: Level of education of respondents

Educational level	Frequency	Percent	Cum. Percent
Illiterate	34	36.2	36.2
Primary School	27	28.7	64.9
Junior Sec./Middle School	22	23.4	88.3
Senior Sec./Technical/Commercial/	11	11.7	100
Teacher Training	0	0	100
Polytechnic/University	0	0	100
Total	94	100	

Table 5: Number of years of experience in maize trade

Number of years	Frequency	Percentage	Cum. Percent
< 1	12	12.8	12.8
1-5	19	20.2	33.0
6-10	25	26.6	59.6
>10	38	40.4	100
Total	94	100	

Most of the maize traders also traded in other commodities during the lean season when maize is not available to supplement their earning when maize is in season. These commodities included charcoal, groundnut, beans, rice, *konkonte* (dry cassava chips) and onions.

4.1.1.2 SOURCE AND CONDITION OF MAIZE

Table 6: Sources from where traders acquire their maize

Source	Frequency	Percentage
Farmers	12	12.8
Middlemen	70	74.4
Both farmers & middlemen	12	12.8
Total	94	100

Middlemen (those who buy from farmers and wholesale to traders) were the major source of maize supply to the maize vendors in the markets. Traders who bought maize either from farmers alone or from both farmers and middlemen form 12.8%. The traders who bought maize from both the farmers and middlemen further indicated that they purchased from farmers (usually peasant farmers) immediately after harvest (August – October). On the other hand they purchased from the middlemen primarily during the lean season. None of them sell self-cultivated maize.

Majority of the traders from all the four towns, namely, Accra, Takoradi/Sekondi, Kumasi and Cape Coast got their maize supplies from Techiman in the Brong Ahafo Region (BA). The other sources of supply were Sunyani and Nkoranza (BA), Tamale (Northern Region), and Kumasi, Sekyidumasi, Ejisu and Ejura (Ashanti Region).

All respondents answered in the affirmative that they determined whether the prospective maize to be purchased was dry enough. According to them, dryness (moisture content) was evaluated because wet grains are more prone to fungal growth and insect infestation and damage. Several methods were employed by respondents to determine the dryness of maize grains. Some of them were:

1) Shaking a handful of grains in the hand. Grains that rattle are considered well dried.
2) Scratching the grains with the fingernails. Well-dried grains are difficult to bruise.
3) Cracking grains with the teeth. Well-dried grains are hard to crack and are deemed to contain "little water".
4) Dipping the hand into bulk or sack-full of grains for warmth (least dry maize is warmer).

4.1.1.3 STORAGE

As illustrated in Fig. 4, there appears to be three main groups of traders with respect to the quantity of maize purchased. The first group constituted retailers who purchase up to 10 bags (100 kg/bag), equivalent to one ton of maize grains. The second group was those who double as both retailers and wholesalers, buying and stocking between 6 – 20 bags.

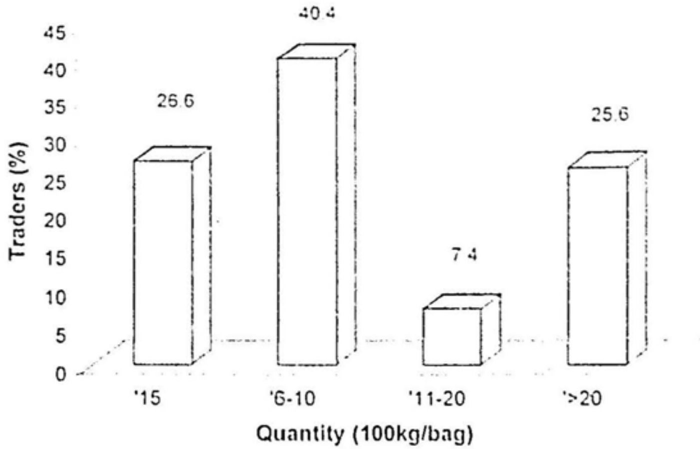

Fig. 4: Mean quantity of maize purchased by traders at a time.

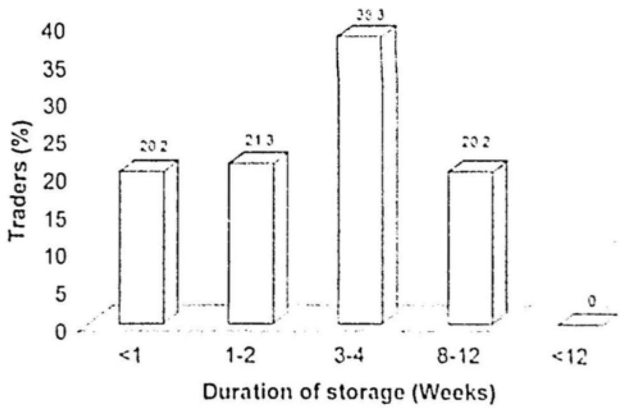

Fig. 5: Percentages of traders that stock maize for different durations between purchase and retail.

These first two groups form the majority in the maize business. The third group was made up of wholesalers who buy over 20 bags (ie 2 tons) at a time.

The maximum storage period for purchased maize was 12 weeks with a high percentage (79.8%) of the traders storing maize up to 4 weeks (Fig. 5). None of them stored maize for more than 12 weeks (3 months). This shows that traders store their maize but only for short periods. Reasons assigned to the quantity purchased and storage duration included:

1) Lack of capital to buy in large quantities;
2) Fear of destruction by pests (insects and mice);
3) Fear of the maize growing mouldy, particularly between August and October when the maize has been freshly harvested and the moisture content is high.

Table 7: Number of traders who conduct periodic checks on their maize for storage insect pest infestation

Response	Frequency	Percentage
Yes	75	80
No	19	20
Total	94	100

The survey revealed that market stalls (open or close) and the open air (but protected from rain using tarpaulin) are the main storage facilities used by traders. Few keep their stock in storerooms at home.

Eighty percent of the traders routinely check their wares for possible insect infestation during storage (Table 7). This, according to them, is done to avert losses due to destruction by pests and growth of mould. The 20%, (mainly retailers) who do not check for pest infestation justified the practice by saying that they do not store it enough for pests to cause any appreciable damage. This notwithstanding, the retailers claimed they sieve off the pests when they buy from the wholesalers.

4.1.1.4 PEST INFESTATION

All the 94 respondents of the survey said they were capable of detecting maize infested with storage insect pests. Three main methods were used by respondents to detect infested maize (Table 8). All the traders interviewed said they identified infested maize by the physical presence of insects among grains or on sacks containing maize. The other two modes of detection were by auditory (clicking sound made by adult weevils) and the presence of powder.

Table 8: Modes of detecting the presence of storage insect pests in maize

Mode of detection	Frequency*	Percent*
Physical presence of pest	94	100.0
Clicking sound	20	21.3
Presence of powder	15	16.0

*Total exceed sample size due to multiple responses.

A high percentage (87%) of the traders reject maize infested with storage insect pests, some accepting it if level of infestation is light or moderate (Fig. 6). Thirteen percent however accepts all maize irrespective of the level of infestation. Those who accepted infested maize irrespective of the level of infestation did so because the maize was sold to them at a lower price and they in turn sold to poultry farmers.

All the respondents identified *Sitophilus* spp. as the key pest of stored maize while 37.2% further identified *Tribolium* spp. (Fig. 8). Respondents were however not able to differentiate between some members of the families Nitidulidae (*Carpophilus* sp), Silvanidae (*A. advena*, *C. quadricollis*, and *Oryzaephilus* sp.) and Cucujidae (*Cryptolestes* sp.). This is because of their similar size and appearance. For this reason, the results of the four species were

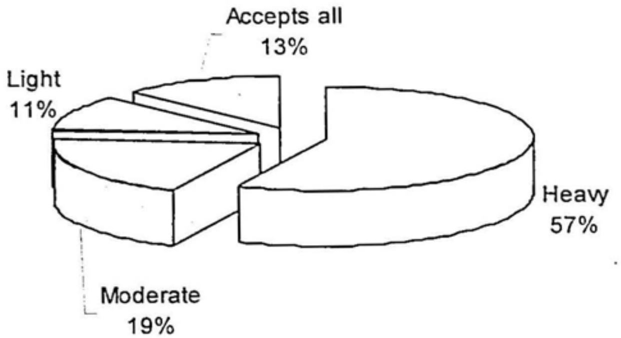

Fig. 6: Level of infestation at which traders reject maize.

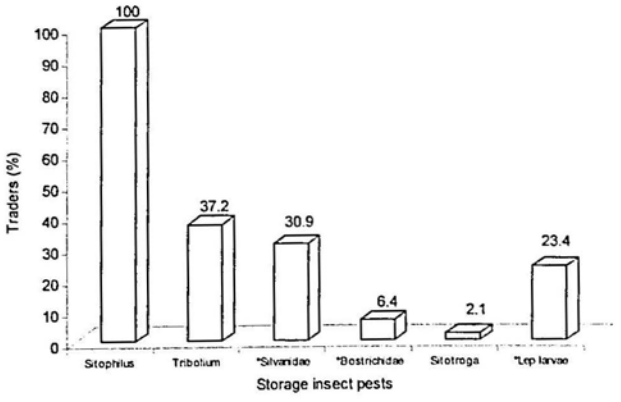

Fig. 7: Storage insects identified by traders as pests of maize.

*Silvanidae = *Cathartus, Ahasverus, Oryzaephilus* and *Cryptolestes* (Cucujidae)
*Bostrichidae = *Rhyzopertha* and *Prostephanus*
*Lep larvae = Lepidopterous larvae

pooled together as Silvanidae and 29 respondents, representing 30.9%, identified them as pests of stored maize.

Two other species of the family Bostrichidae, *R. dominica* and *P. truncatus* could also not be differentiated and were pooled together. When the two were pooled together, 6.4% of the respondents identified them as pests of stored maize. Only 2 out of the 94 respondents identified *S. cerealella* as a pest of stored maize. Twenty-two respondents identified the lepidopterous larvae and intimated that they were present only in maize bought between August and October.

Table 9: Common and most destructive storage insect pests

	Common		Most destructive	
Pest	Frequency	Percentage	Frequency	Percentage
Sitophilus spp.	94	100	94	100
Tribolium spp.	6	6.4	-	-

*There were multiple responses by some traders.

All respondents identified *Sitophilus* sp. as the commonest and the most destructive (Table 9). *Tribolium* pp. was identified by 6.4% of the traders, in addition to *Sitophilus* sp., as common pest in stored maize. The rest of the pests identified were seen as relatively unimportant pests of stored maize since none of them was included in the list of the commonest and most destructive pests.

The mode of spread of insect pests, as known by respondents was by flight since the pests have got wings that enable them to fly. Sources of infestation as perceived by respondents include:

1) Farm (Natural infestation in the field)
2) Farmers' barn (in storage)
3) Infested empty sacks
4) Mixing infested and uninfested grains.

4.1.1.5 PEST CONTROL

Table 10: Control pests with insecticides (surveyed traders, percentage responses)

Responses	Frequency	Percentage
Powder repellent[a]	11	12
Synthetic insecticide	0	0
No insecticide	83	88
Total	94	100

[a] Made up of only respondents who said they sprinkle powdered insecticide around their stock in order to repel pests.

None of the respondents claimed to treat maize with pesticide. The 12% shown in Table 10 represent those who, though said they do not treat grains with pesticide, rather sprinkle dust insecticide formulations around or on sacks to repel the insect pests. The non-chemical treatment of maize by traders, according to them, was due to the fear of food poisoning. Two non-chemical control methods employed by traders were identified. These include sieving pests off the grains and sun drying in order to allow the pests to fly away.

4.1.1.6 KNOWLEDGE OF MAIZE VARIETIES

As shown in Table 11, 87% of the respondents were capable of differentiating between local and improved maize varieties. However, 13% of the traders could not. Traders used several features (Table 12) to differentiate between the local and improved varieties.

Table 11: Number of traders able to differentiate local from improved varieties of maize

Response	Frequency	Percentage
Yes	82	87
No	12	13
Total	94	100

Table 12: Characteristics used to differentiate local from improved maize varieties

Varietal characteristics	
Local	**Improved**
1) Small kernels	1) Large kernels
2) Kernels are relatively heavy	2) Kernels are relatively light
3) Hard (when cracked with the teeth)	3) Soft (when cracked with the teeth)
4) May be coloured or white (white grains are bright)	4) Always all white (white colour is dull)

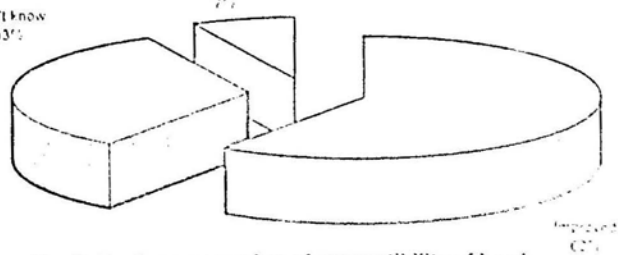

Fig. 8: Traders perception of susceptibility of local and improved maize to storage insect pests.

Most traders (60%) perceived the improved varieties as more susceptible to storage insect pests than the local varieties. However, about one-third could not tell which of the two varieties is more susceptible, while only 7% thought the local varieties were more susceptible (Fig. 8). Respondents perceived the *ewe* (another local maize variety) maize as the most resistant to pest attack, even among the local varieties that they know.

4.1.2 STORAGE INSECT PESTS IN MARKETS

The storage insect pests found among maize samples from markets in Kumasi, Accra, Cape Coast and Sekondi/Takoradi are shown in Tables 13 and 14. As expected, the pest complex at the end of crib storage and that of the market sampling in October 2002 did not differ except in the absence of *R. dominica, D. minutus* and an unidentified Curculionid from the latter. The pest spectrum and frequency at the various markets differed between samples taken in April and October (Tables 13 and 14).

Sitophilus spp. and *Tribolium* spp. were the predominant species found in all the market samplings. *C. quadricollis* and *Carpophilus* spp. were also common as they were found in 9 and 8 respectively, out of the 10 markets.

M. nigrivenella and *C. leucotreta* were present in maize bought in October but were absent during April. While *Cryptolestes* spp. was present in samples from only two markets in October, it was encountered in six out of the ten markets in April. *P. truncatus* was recorded from samples taken in April in three markets, namely Madina and Agbogbloshie in Accra and market circle in Takoradi (Tables 13 and 14).

The mean moisture content (mc) of maize available in the markets in October (11.01 ± 0.01%) was slightly lower than those obtained at the end of storage in cribs (12.1%; section 4.2). However maize sampled in April had moisture content (12.88 ± 0.08%) higher than those in October (Tables 13 and 14).

Table 10a: Insects associated ...

Weeks	Mean grain moisture content (%)	Insect pests present													
Field (Weeks after emergence)		Ah	Ar	Br	My	Ha	Ms	Cb	Cf	Ct	St	Di	Tr	Rh	Un
11	45.0	■	■	■	■	■	■	■	-	-	-	-	-	-	-
12	41.4	+	-	+	+	+	+	+	■	-	-	-	-	-	-
13	38.3	-	-	+	-	+	+	+	+	-	-	-	-	-	-
14	32.9	+	+	+	+	+	+	-	+	■	-	-	-	-	-
15	28.0	-	-	+	-	+	+	-	+	+	■	-	-	-	-
16	23.1	+	-	+	+	+	-	-	-	+	+	-	-	-	-
17	21.7	+	+	+	+	-	+	+	+	+	+	■	-	-	-
18	20.3	-	+	+	-	-	-	+	-	+	+	-	-	-	-
Storage															
2	17.1	+	+	+	+	-	+	-	+	+	+	+	■	-	-
4	14.1	+	-	-	+	-	+	-	+	+	+	-	+	-	■
6	13.9	+	+	-	-	-	-	-	-	+	+	+	-	-	-
8	13.8	+	-	-	-	-	-	+	-	+	+	+	-	-	+
10	13.1	+	-	-	-	-	-	+	+	+	+	+	-	-	+
12	12.3	+	-	-	-	-	+	+	-	+	+	+	+	-	+

Legend

■ = First appearance of pest + = Pest present − = Pest absent

Ah = *Ahasverus advena* Ar = *Araecerus coffeae* Ms = *Mussidia nigrivenella* Di = *Dinoderus minutus* Br = *Brachypeplus* sp
My = *Mycetaea subterrannea* Ha = *Haptoncus luteolus* Cb = *Cryptophlebia leucotreta* Ct = *Cathartus quadricollis* Tr = *Tribolium* spp
Cf = *Carpohilus spp.* Rh = *Rhyzopertha dominica* St = *Sitophilus* sp Un = Unidentified Curculionidae

Town	Market	Moisture content (%)	Pest species									
			Ahasverus advena	*Carpohilus spp.*	*Cryptolestes sp*	*Cathartus quadricollis*	*Gnathocerus cf. maxillosus*	*Sitophilus sp.*	*Tribolium spp.*	*Mussidia lenigrinevella*	*Cryptophlebia leucotreta*	*Sitotroga cerealella*
Cape Coast	Kotokuraba	11.6	-	+	-	+	+	+	+	+	-	-
	Abura	10.5	+	+	-	+	-	+	+	+	+	-
Sekondi/ Takoradi	Sekondi Central	11.9	-	+	-	+	-	+	+	+	-	-
	Market Circle	10.2	+	+	-	+	+	+	+	+	-	+
	Apramdo	1.8	-	+	+	+	-	+	+	-	-	-
Accra	Mallam Atta	11.0	-	-	+	+	+	+	+	-	-	-
	Madina	10.9	-	+	-	+	-	+	+	+	-	-
	Agbobloshie	11.4	+	+	-	+	+	+	+	+	+	-
Kumasi	Central	10.5	+	+	-	-	+	+	+	+	-	+
	Asafo	10.3	-	+	-	-	-	+	+	-	-	-

Mean moisture content = 11.01 ± 0.10

Legend

+ = Pest present   - = Pest absent

Town	Market	Moisture content (%)	Pest species							
			Carpophilus. fumatus	*Cryptolestes sp*	*Cathartus. quadricollis*	*Gnathocerus cf. maiollosus*	*Sitophilus sp.*	*Tribolium spp*	*Sitotorga Cerealella*	*Prostephanus truncatus*
Cape Coast	Kotokuraba	12.8	+	+	-	+	+	+	-	-
	Abura	13.5	-	-	-	+	+	+	-	-
Sekondi/ Takoradi	Sekondi Central	13.0	-	-	-	+	+	+	+	-
	Market Circle	12.9	+	+	+	+	+	+	-	+
	Apramdo	12.4	-	+	+	-	+	+	-	-
Accra	Mallam Atta	12.1	-	+	+	-	+	+	-	-
	Madina	12.4	-	-	-	+	+	+	-	+
	Agbobloshie	13.2	+	+	-	+	+	+	+	+
Kumasi	Central	14.0	-	+	+	+	+	+	-	-
	Asafo	12.5	+	-	-	-	+	+	-	-

Mean moisture content = 12.88 ± 0.08%

Legend: + = Pest present - = Pest absent

4.2 STORAGE INSECT PESTS INFESTING MAIZE IN THE FIELD

4.2.1 MAJOR SEASON PLANTING

A total of 24 species belonging to 13 families of storage insect pests were found infesting the maize ears in the field during major season planting in Cape Coast (Appendix 2). The 10 most frequently encountered species were *A. advena, Brachypeplus* spp., *Carpohilus spp., C. quadricollis, Mycetaea. subterranea, Sitophilus* spp., *H. luteolus* and two corn ear borers, *M. nigrivenella* and *C. leucotreta* (Tables 15a-15d). Parasitoids, parasites and predators recorded included *Anisopteromalus* sp. *Diapersticus erythrocephalus* Olivier (Earwig), respectively. Unidentified insects belonging to Staphylinidae, Psocoptera and Scaphidiinae were also recorded.

At the beginning of harvesting, when the mc was in excess of 40% (milk stage), the storage insect pests present were *Brachypeplus* spp., *H. luteolus, M. subterranea, A. advena, Carpohilus spp.., A. coffeae and M. nigrevenella and C. leucotreta* (Table 15a - 15d and 16). *C. quadricollis* first appeared at mc of 33.0% while *Sitophilus* sp. first appeared when moisture content had dropped to 30.2%. *D. minutus* was the only Bostrichid found infesting maize prior to harvest. It was first encountered when the maize was due for harvesting at about 20.0% mc (Tables 15a – 15d). *Tribolium* spp. was encountered only in *Mamaba* in the field, at mc of 28.5%. The rest of the varieties, *Obatanpa*, *Fante* and *Owifompe* recorded their first occurrence of *Tribolium* spp. in storage at moisture contents as low as 17.1%, 16.1% and 16.45% respectively.

The QPM varieties which mature early reached the milk stage in the 11th WAE while the locals, *Fante* and *Owifompe* attained the same stage in the 13th WAE (Tables 15a – 15d; Plate 5a and 5b). However at the time of harvest (18th WAE), all the four varieties had attained almost the same mc (*Obatanpa*, 20.3%; *Mamaba*, 20.3%; *Fante*, 20.0% and *Owifompe*, 20.3%) (Fig. 9).

Table 15b: Insects associated with ears of Mamaba in the field from [illegible]

Weeks	Mean grain moisture content (%)	Insect pests present													
Field (Weeks after emergence)		Ah	Ar	Br	My	Ha	Ms	Cb	Ca	Ct	St	Di	Tr	Rh	Un
11	45.0	■	-	■	■		■	-	-	-	-	-	-	-	-
12	41.4	-	■	+	-	+	+	■	■	-	-	-	-	-	-
13	38.3	-	+	+	+	+	+	+	+	■	-	-	-	-	-
14	32.9	+	-	+	+	+	+	+	+	-	-	-	-	-	-
15	28.0	-	-	+	-	+	+	-	+	+	■	-	-	-	-
16	23.1	-	+	+	+	-	-	+	-	+	+	-	■	-	-
17	21.7	+	+	+	+	+	+	-	+	+	+	-	-	-	-
18	20.3	+	-	+	+	-	-	+	+	+	+	-	+	-	-
Storage															
2	17.1	+	+	+	+	-	-	+	+	+	+	■	+	-	-
4	14.1	+	-	-	+	-	+	-	+	+	+	+	-	-	-
6	13.9	+	-	-	-	-	+	-	+	+	+	-	-	■	-
8	13.8	+	-	-	+	-	-	-	-	+	+	+	+	+	-
10	13.1	+	-	-	-	-	+	+	-	+	+	-	+	+	■
12	12.3	+	-	-	-	-	+	+	-	+	+	+	+	-	+

Lege Legend

■ = First appearance of pest + = Pest present – = Pest absent

Ah = *Ahasverus advena* Ar = *Araecerus coffeae* Ms = *Mussidia nigrivenella* Di = *Dinoderus minutus* Br = *Brachypeplus* sp
My = *Mycetaea subterrannea* Ha = *Haptoncus luteolus* Cb = *Cryptophlebia leucotreta* Ct = *Cathartus quadricollis* Tr = *Tribolium* spp
Cf = *Carpophilus spp.* Rh = *Rhyzopertha dominica* St = *Sitophilus* sp Un = Unidentified Curculionidae

Table 15c: Insects associated with ears of *Fante* in the field from soft dough stage through to harvest

Weeks	Mean grain moisture content (%)	Insect pests present													
Field (Weeks after emergence)		Ah	Ar	Br	My	Ha	Ms	Cb	Cf	Ct	St	Di	Tr	Rh	Un
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	44.5	■	-	■	■	■	■	■	■	-	-	-	-	-	-
14	39.4	-	-	+	+	+	+	-	-	-	-	-	-	-	-
15	30.1	-	-	+	+	+	+	+	+	■	■	-	-	-	-
16	27.1	+	-	+	+	+	-	+	+	+	-	-	-	-	-
17	23.8	+	-	+	+	-	+	+	+	+	+	-	-	-	-
18	20.0	+	-	+	-	-	+	-	-	+	+	■	-	-	-
Storage															
2	16.1	+	-	+	+	-	+	+	-	+	+	+	■	-	-
4	15.3	+	-	-	+	-	-	+	-	+	+	+	+	■	-
6	14.4	+	-	-	-	-	-	+	-	+	+	+	-	-	-
8	13.1	+	-	-	-	-	+	-	-	+	+	-	+	-	■
10	12.7	+	-	-	-	-	+	-	+	+	+	-	+	+	-
12	11.7	+	-	-	-	-	-	+	-	+	+	+	+	-	-

Legend

■ = First appearance of pest + = Pest present − = Pest absent

Ah = *Ahasverus advena* Ar = *Araecerus coffeae* Ms = *Mussidia nigrivenella* Di = *Dinoderus minutus* Br = *Brachypeplus* sp
My = *Mycetaea subterrannea* Ha = *Haptoncus luteolus* Cb = *Cryptophlebia leucotreta* Ct = *Cathartus quadricollis* Tr = *Tribolium* spp
Cf = *Carpohilus spp.* Rh = *Rhyzopertha dominica* St = *Sitophilus* sp Un = Unidentified Curculionidae

Table 15d: Insects associated with ears of *Owifompe* in the field from soft dough stage through to harvest

Weeks	Mean grain moisture content (%)	Insect pests present													
Field (Weeks after emergence)		Ah	Ar	Br	My	Ha	Ms	Cb	Cf	Ct	St	Di	Tr	Rh	Un
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	44.6	-	-	■	■	■	■	■	■	-	-	-	-	-	-
14	38.6	■	■	+	+	+	+	+	+	-	-	-	-	-	-
15	32.1	+	-	+	-	+	+	+	+	■	■	-	-	-	-
16	28.4	+	+	+	-	+	-	-	+	+	+	-	-	-	-
17	24.8	+	-	+	+	+	-	+	+	+	+	-	-	-	-
18	20.3	+	+	-	-	+	-	+	-	+	+	■	-	-	-
Storage															
2	16.4	+	+	+	+	-	-	-	+	+	+	+	■	-	-
4	14.4	+	-	-	-	-	-	-	+	+	+	-	-	-	■
6	13.9	-	-	-	-	-	+	-	+	+	+	+	+	■	-
8	13.1	+	+	-	+	-	-	+	+	+	+	-	-	-	-
10	12.3	+	-	-	-	-	+	+	-	+	+	+	+	-	-
12	12.0	+	-	-	-	-	+	-	-	+	+	-	+	-	+

Legend ■ = First appearance of pest   + = Pest present   - = Pest absent

Ah = *Ahasverus advena*   Ar = *Araecerus coffeae*   Ms = *Mussidia nigrivenella*   Di = *Dinoderus minutus*   Br = *Brachypeplus* sp
My = *Mycetaea subterrannea*   Ha = *Haptoncus luteolus*   Cb = *Cryptophlebia leucotreta*   Ct = *Cathartus quadricollis*   Tr = *Tribolium* spp
Cf = *Carpohilus spp.*   Rh = *Rhyzopertha dominica*   St = *Sitophilus* sp   Un = Unidentified Curculionidae

Table 15d: Insects associated with ears of *Owifompe* in the field from soft dough stage through to harvest

Weeks	Mean grain moisture content (%)	Insect pests present													
Field (Weeks after emergence)		Ah	Ar	Br	My	Ha	Ms	Cb	Cf	Ct	St	Di	Tr	Rh	Un
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	44.6	-	-	■	■	■	■	■	■	-	-	-	-	-	-
14	38.6	■	■	+	+	+	+	+	+	-	-	-	-	-	-
15	32.1	+	-	+	-	+	+	+	+	■	■	-	-	-	-
16	28.4	+	+	+	-	+	-	-	+	+	+	-	-	-	-
17	24.8	+	-	+	+	+	-	+	+	+	+	-	-	-	-
18	20.3	+	+	-	-	+	-	+	-	+	+	■	-	-	-
Storage															
2	16.4	+	+	+	+	-	-	-	+	+	+	+	■	-	-
4	14.4	+	-	-	-	-	-	-	+	+	+	-	-	-	■
6	13.9	-	-	-	-	-	+	-	+	+	+	+	+	■	-
8	13.1	+	+	-	+	-	-	+	+	+	+	-	-	-	-
10	12.3	+	-	-	-	-	+	+	-	+	+	+	+	-	-
12	12.0	+	-	-	-	-	+	-	-	+	+	-	+	-	+

Legend ■ = First appearance of pest + = Pest present – = Pest absent

Ah = *Ahasverus advena* Ar = *Araecerus coffeae* Ms = *Mussidia nigrivenella* Di = *Dinoderus minutus* Br = *Brachypeplus* sp

My = *Mycetaea subterrannea* Ha = *Haptoncus luteolus* Cb = *Cryptophlebia leucotreta* Ct = *Cathartus quadricollis* Tr = *Tribolium* spp

Cf = *Carpohilus spp.* Rh = *Rhyzopertha dominica* St = *Sitophilus* sp Un = Unidentified Curculionidae

Table 16: Summary of mean moisture content at which pests were first and lastly recorded

Pest	Mean moisture content (mc) %	
	First recorded	Last recorded
H. luteolus(+)	44.7	25.1
Brachypeplus sp.(++)	44.7	16.9
A. coffeae (++)	41.9	16.1
M. subterranea(++)	44.7	13.9
Carpophilus sp (++)	43.2	13.4
M.negrivinella (++)	44.7	12.1*
C. leucotreta (++)	44.7	12.1*
A. advena (+++)	43.2	12.1*
C. quadricollis (+++)	33.0	12.1*
Sitophilus sp.(+++)	30.2	12.1*
D. minutus (+++)	20.0	12.1*
Tribolium spp.(+++)	-	12.1*
R. dominica (t)	14.2	12.1*

*Mean moisture content at the end of storage.

Legend
+ = Field infested but phased out before harvest
++ = Field infested but phased out after harvest
+++ = Field infested and persisted through storage
t = Infested in storage and persisted

Plate 5a: Maturity stage of ears of *Owifompe* (Local variety) at 11th week after emergence

Plate 5b: Maturity stage of ears of *Obatanpa* (QPM variety) at 11th week after emergence

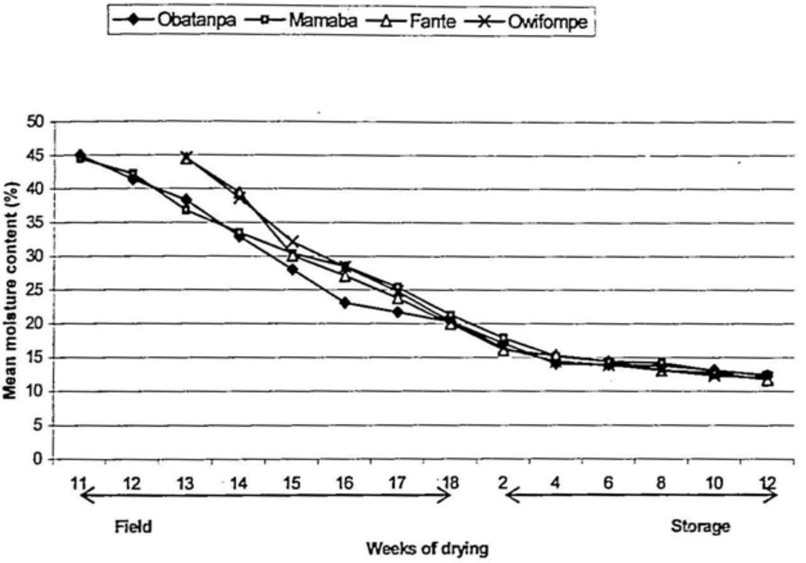

Fig. 9: Rate of drying of four maize varieties in the field and storage

4.2.2 MINOR SEASON PLANTING

In all, 12 stored grain insect species comprising 9 Coleopterans and 3 Lepidopterans were collected. The coleopterans were *A. advena, A. coffaea, Brachypeplus* sp., *C. quadricollis, Carpohilus spp.. Sitophilus* sp., *Tribolium spp.*, unidentified Scolytinae and *M. subterranea*. The lepidopterans included *M. nigrivenella*, *C. leucotreta* and *S. cerealella* (Table 17). The mc at which the various pests first appeared are shown in Table 18. Unlike the major season where the Scolytinae was found only on the nodes where ears were attached, it infested the maize ears in the minor season. One parasitoid, *Anisopteromalus* sp., and two predators, *Diapersticus erythrocephalus* (Olivier) and an unidentified Scaphidiinae, were also recorded.

As recorded in the major season, the pest population increased with the maturation of maize in the field. Pest populations among the four farms were not significantly different (P>0.05) (Appendix 5). The pest infestation did not differ from one farm to the other (Appendix 6).

Generally, the number of species of storage insect pests encountered in the major season exceeded those in the minor season although some appeared once and others only on a few occasions. For example, *H. luteolus*, which dominated the pre-harvest pests in the

Table 17: Storage insect pests of maize (*Obatanpa*) at successive drying stages during the minor season planting

Location of farm	Week after emergence (WAE)	mc %	Storage insect pests present											
			Ah	Ar	Br	Cf	My	Mu	Cb	Ct	Us	St	Tr	Sg
Ankako	12	46.7	■	-	■	-	-	■	■	-	-	-	-	-
	13	41.3	+	■	+	-	■	+	+	-	-	-	-	-
	14	32.5	-	-	+	-	+	+	-	■	-	-	-	-
	15	31.8	-	+	-	-	-	-	-	-	-	■	-	-
	16	27.5	-	+	+	-	+	+	+	+	-	+	■	-
	17	24.1	+	-	-	-	-	+	+	+	-	+	-	-
	18	20.6	-	-	+	-	-	+	+	+	-	+	+	-
	19	19.9	-	+	-	-	+	-	-	+	-	+	-	-
Jukwa	12	47.7	-	■	-	-	-	■	■	-	-	-	-	-
	13	35.8	■	-	■	■	-	+	-	-	-	-	-	-
	14	42.1	+	+	-	+	■	+	+	-	-	-	-	-
	15	36.5	+	-	+	-	-	+	+	■	-	-	-	-
	16	29.0	+	+	+	-	+	+	+	+	-	■	-	-
	17	26.3	+	+	+	+	+	+	+	+	-	+	-	-
	18	22.1	-	-	+	-	+	-	-	+	-	+	-	■
	19	20.4	+	-	+	+	-	+	+	+		+	-	-
Cape Coast	12	45.3	■	■	-	-	■	■	■	-	-	-	-	-
	13	39.6	-	+	+	+	+	+	+	■	-	-	-	-
	14	34.9	+	-	-	+	-	+	-	+	-	-	-	-
	15	33.1	+	-	+	-	+	+	-	+	-	-	-	-
	16	27.1	+	+	+	-	-	+	+	+	■	■	-	-
	17	22.8	-	-	-	-	+	+	-	+	+	+	+	-
	18	18.91	+	-	+	+	-	+	+	+	-	+	-	■
	19	18.3	-	+	-	+	+	-	+	+	-	+	■	+
Mpeasem	12	45.9	■	■	■	-	■	■	-	-	-	-	-	-
	13	40.4	+	-	+	-	+	+	■	-	■	-	-	-
	14	35.4	-	+	+	-	+	+	+	-	-	-	-	-
	15	29.7	+	-	+	-	+	+	+	■	+	■	-	-
	16	26.6	-	+	-	-	-	+	+	+	+	+	-	-
	17	23.4	+	-	-	-	+	+	+	+	+	+	-	-
	18	20.1	-	-	-	-	-	-	-	+	-	+	-	-
	19	19.8	-	-	+	-	-	+	+	+	-	+	-	■

Legend

■ = First appearance of pest   + = Pest present   - = Pest absent

Ah=*A. advena*   Ar=*A. coffeae*   Br=*Brachypeplus* sp.   Ca=*Carpophilus sp*

My=*M. subterranea*   Mu=*M. nigrivenella*   Ct=*C. quadricollis*   Cb=*C. leucotreta*

St =*Sitophilus* sp   Tr =*Tribolium* spp.   Sg = *S. cerealella*

Us=Unidentified *scolytinae*

Table 18: Summary of mean moisture contents at which pests were first recorded in the minor season.

Pest	Moisture content (%)				
	Ankako	Jukwa	Cape Coast	Mpeasem	Mean
A.advena	46.7	47.7	45.3	45.9	46.4
M. nigrivenella	46.7	47.7	45.3	45.9	46.4
C. leucotreta	46.7	47.7	45.3	40.0	44.9
A. coffeae	41.3	42.1	45.3	45.9	43.1
Brachypeplus sp.	41.3	42.1	39.6	45.9	43.6
M. subterranea	41.3	42.1	45.3	45.9	43.7
C. fumatus	41.3	42.1	39.6	45.9	42.2
C. quadricollis	36.5	36.5	39.6	35.4	37.0
Sitophilus sp.	31.8	29	27.1	29.7	29.4
Tribolium spp.	27.5	-	22.8	29.7	-

4.2.3 FIELD INSECT PESTS THAT PERSISTED UNTIL STORAGE

Out of the 10 major storage insect pest species that infested maize in the field during the major season, only *H. luteolus was* absent by mc of 25.1% before the ears were harvested (Tables 15a – 15d and i6). *A. advena*, *A. coffeae*, *C. fumatus* , *C. quadricollis*, *M. subterranea* and *Sitophilus* sp. survived the lower also present at the time of harvesting and thus followed the maize into moisture contents (about 20%) at harvest and thus accompanied the harvested ears into storage. In addition, two other pests, *D. minutus* and *Tribolium spp.* were storage (Tables 17a – 17d).

4.2.4 FIELD INFESTED INSECT PESTS THAT PERSISTED THROUGHOUT THE STORAGE PERIOD

While some of the pests that accompanied the harvested ears from the field into storage phased out in the course of storage, others persisted throughout the entire storage period as shown in Tables 14a – 14d and 15. Some pests phased out as the moisture content of the stored maize dropped. These included *A. coffeae*, *M. subterranea*, and *Carpophilus spp.* at 16.1%, 13.9% and 13.4% mcs respectively. *A. advena*, *C. quadricollis*, *D. minutus*, *Sitophilus* sp. and *Tribolium spp.* and the ear borers, *M. nigrivenella* and *C. leucotreta* survived throughout storage at the least attained mc of 12.1%, at the end of the crib storage (Table 15).

4.2.5. INFESTATION IN STORAGE

Tables 14a – 14d show that only two insect pest species began infestation of the maize in storage. *R. dominica* infested the maize when the mc was 14.2% while the other pest, an unidentified curculionid, recorded for the first time at 13.7%. Both pests persisted to the end of the storage period. High numbers of *Anisopteromalus* sp. and an arachnid of the order Pseudoscorpiones were the parasitoid and predator respectively identified in maize stored in cribs.

4.3 SUSCEPTIBILITY OF FOUR MAIZE VARIETIES TO STORAGE INSECT PESTS IN THE FIELD

4.3.1 SPECIES COMPOSITION OF STORAGE INSECT PESTS RECORDED ON FOUR MAIZE VARIETIES IN THE MAJOR SEASON

The mean number of species of storage insect pests recorded per ear per week in the field were 0.7, 0.8, 0.8 and 0.8 for *Obatanpa, Mamaba, Fante* and *Owifompe* respectively. During storage, *Obatanpa, Mamaba, Fante* and *Owifompe* recorded means of 0.9, 0.8, 0.8 and 0.6 respectively. The number of species was not statistically different (P>0.05) among the four varieties, both in the field and in storage (Appendix 7).

Generally, storage insect pest densities on all the four varieties increased in subsequent weeks from the field through storage. The increment was not as sharp in the field as in storage (Fig. 11). The numbers dropped during the second week of storage but rose again from the 4^{th} week in storage. There were sharp increases in the populations from 24.4 and 16.2 pests per ear in the 6^{th} week of storage, to 165.9 and 137.6 per ear in the 12^{th} week of storage for *Obatanpa* and *Mamaba* respectively. Over the same period, the pest populations on *Fante* rose from 25.2 to 52.4 and *Owifompe* from 16.7 to 46.1 per ear respectively. Thus the pest populations on the QPM

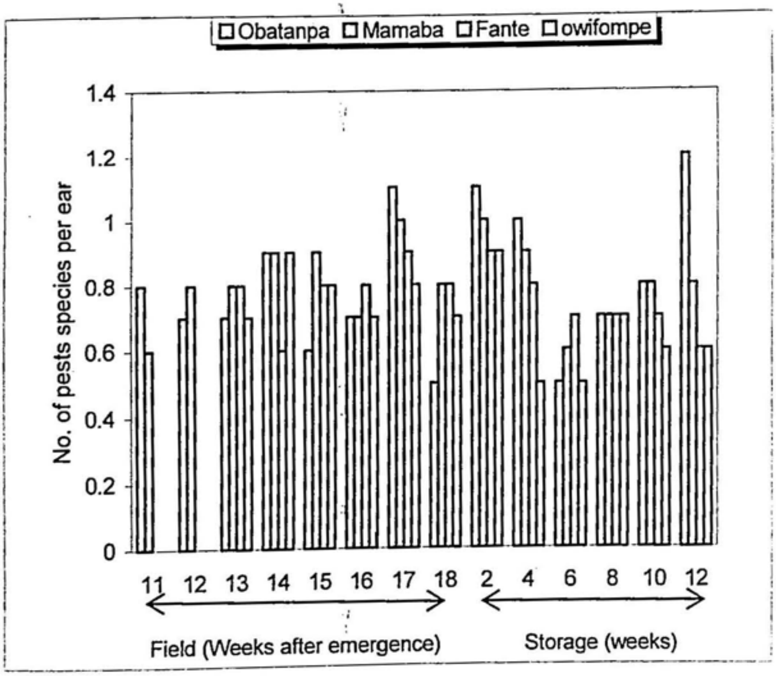

Fig. 10: Number of storage insect pest species on four maize varieties in the field and in storage in the major season in 2002.

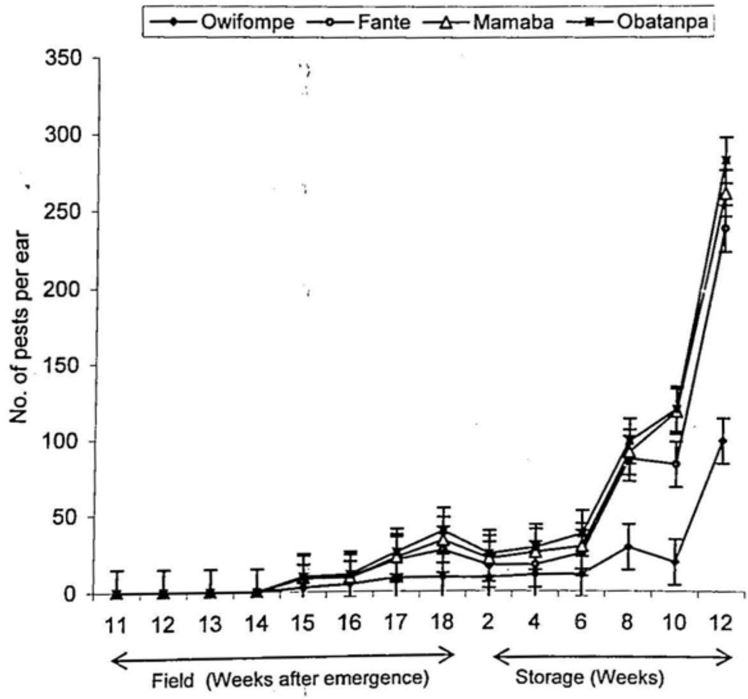

Fig. 11: Storage insect pest populations on four maize varieties in the field and in storage in the major season. (Vertical bars represent $LSD_{0.05}$).

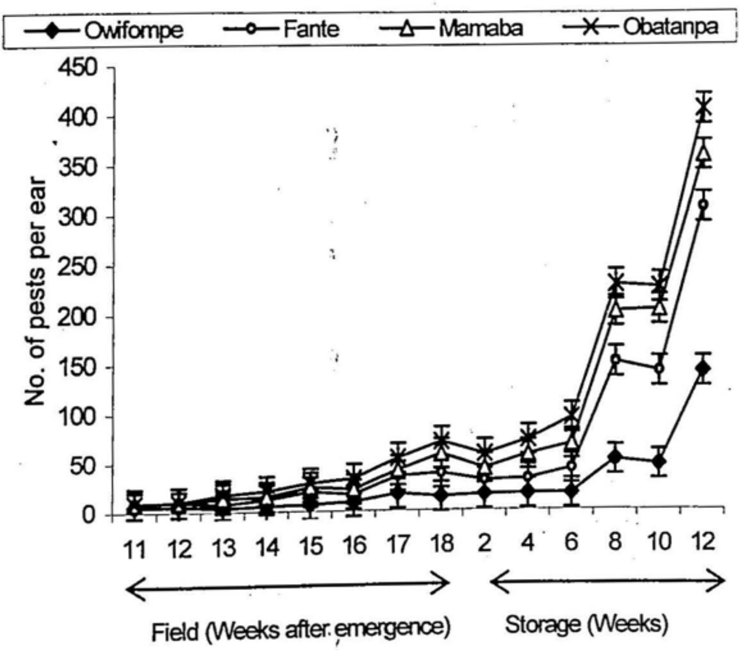

Fig. 12: Number of *Sitophilus* sp. on four maize varieties in the field and in storage in the major season. (Vertical bars represent $LSD_{0.05}$).

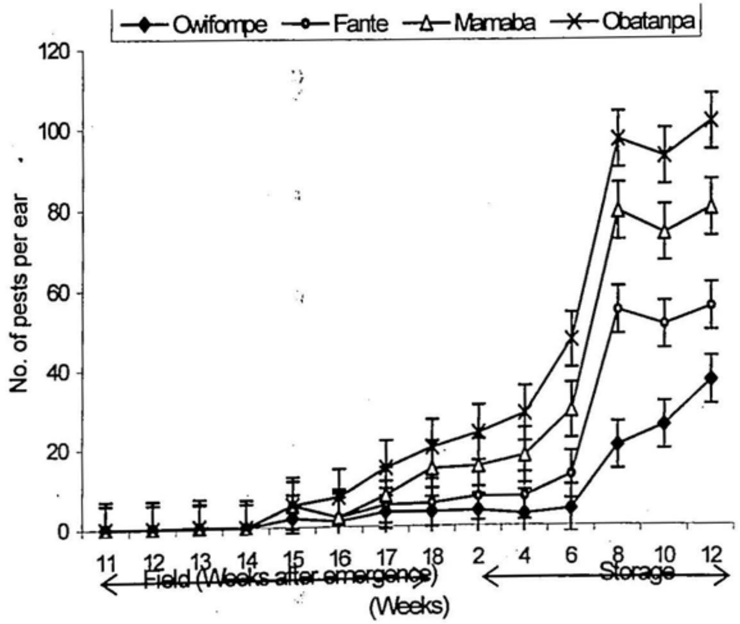

Fig. 13: Number of *C. quadricollis* on four maize varieties in the field and in storage in the major season. (Vertical bars represent $LSD_{0.05}$).

varieties were over three times higher than that on the local varieties at the end of the 10-week storage period. Apart from *Fante* maize, the pest population dropped on the 10th week of storage on all the varieties (Fig 11).

The differences among the four varieties were however not statistically significant (P>0.05)(Appendix 7).

As shown in Fig. 12, the population of *Sitophilus* sp. was higher on *Obatanpa* and *Mamaba* (QPM varieties) than on *Fante* and *Owifompe* (local varieties) both in the field and in storage. On the other hand, the population of *C. quadricollis* on *Fante* and *Owifompe* exceeded that on *Obatanpa* and *Mamaba* varieties. The differences observed were however not significant (P>0.05) (Appendices 9 and 10).

Significantly higher grain weight losses were recorded for the QPM varieties, as compared to the local varieties, after 10 weeks of storage in cribs (Table 18). The damage levels of the QPM varieties were 4 – 8 times higher than the local varieties.

Table 18: Mean weight loss of four varieties maize to storage insect pests after 10 weeks of crib storage

Variety	
Obatanpa	72.37 ± 1.71a
Mamaba	44.68 ± 2.99b
Fante	10.51 ± 1.49c
Owifompe	8.64 ± 0.96c

Means followed by the same letter in a row are not significant using Duncan Multiple Range Test at 0.05%.

4.3.2 PERFORMANCE OF *SITOPHILUS* SP. ON FOUR MAIZE VARIETIES

4.3.2.1 OVIPOSITION

The mean number of eggs per 100 grains by *Sitophilus* sp. after seven days oviposition period were 65.3, 56.8, 41.8 and 30.3 for *Obatanpa*, *Mamaba*, *Fante* and *Owifompe* maize varieties respectively (Table 20). There was no significant difference between the two QPM, *Obatanpa* and *Mamaba*. The two local varieties *Fante* and *Owifompe* also showed no significant difference. The differences between the QPM and the local varieties were however significant (P< 0.05) (Table 20).

4.3.2.2 DEVELOPMENT TIME

The mean times taken by adult *Sitophilus* sp. to emerge, from first day of infestation, for *Obatanpa, Mamaba, Fante, Owifompe* were 37.1, 38.8, 38.4 and 39.1 days respectively (Table 19). The observed differences were not significantly different at P>0.05. The median development periods for the 4 varieties are also presented in Table 19.

4.3.2.3 NUMBER OF EMERGED ADULTS

As shown in Table 19, the highest mean number of adults to emerge (32.75) was recorded on *Obatanpa* while the least, 16.25, was recorded on *Owifompe*. The difference between them was significant (P<0.05). The number of adults that emerged from *Mamaba* (28.50) and *Fante* (26.75) were significantly different. Both *Mamaba* and *Fante* had significantly higher number of adults emerging than *Owifompe* but lower than *Obatanpa*.

4.3.2.4 POPULATION GROWTH RATE

The highest population growth rate of 15.01 was obtained on *Obatanpa* while the least, 9.99, was obtained on *Owifompe*. *Mamaba* and *Fante* had 12.86 and 11.90 respectively. The differences observed were significantly different from each other at P<0.05 (Table 19).

4.3.2.5 GRAIN WEIGHT LOSS

After 90 days of storage, the highest weight loss of 23.91g was observed in *Obatanpa* followed by *Mamaba* (16.40g), with *Fante* variety recording the least. The weight loss of the local varieties *Fante* and *Owifompe*, were significantly lower (P<0.05) than that of the QPM, *Obatanpa* and *Mamaba* maize varieties (Table 19).

4.3.2.6 SUSCEPTIBILITY INDEX

There was no significant difference between, *Mamaba* (QPM) and *Fante* (local) varieties. However the differences between *Obatanpa* (QPM) and *Owifompe* (local), and the other two (*Mamaba* and *Fante*) varieties were significant at P<0.05 (Table 19).

Table 20: Performance of *Sitophilus* sp. on farmer maize varieties.

Variety	Mean ± Standard error of performance measures					
	Oviposition (Eggs/100 grains)	Development period (days)*	Number of emerged adults	Population growth rate	Weight loss (%)	Susceptibility Index (SI)
Obatanpa	65.25 ± 5.20a	37.11± 0.69a (35.00)	32.75± 2.40a	15.01± 0.37a	23.91± 0.12a	9.85a
Mamaba	56.75 ± 4.39a	38.77± 0.79a (34.88)	28.50 ± 1.20b	12.86± 0.59 b	16.40 ± 0.14b	8.60b
Fante	41.75 ± 3.33b	38.35 ± 0.74a (35.00)	26.75 ± 1.32b	11.90 ± 0.40c	13.69 ± 0.12bc	8.39b
Owifompe	30.25 ± 3.23b	39.12 ± 0.67a (35.38)	16.25 ± 1.50c	9.99 ± 0.31d	9.61 ± 0.03c	7.88c

Means followed by a common letter in a column are not significant at 5% level usning Duncan Multiple Range Test.

*Median development periods are shown in parentheses.

4.4. ALTERNATIVE HOST PLANTS OF STORAGE INSECT PESTS OF MAIZE

A total of 20 plant species were sampled for storage insect pests (Table 20). Out of these plants, 12 of them were found to be infested by one or more insect pests. None of the grasses sampled was found to be infested with storage insect pests. All pests encountered were found on seeds/fruits/nuts of trees and shrubs. Among the pest identified, only *A. coffeae* is known to be a pest of stored maize. *Acanthoscelides* sp., *Careydon* sp. and *Callosobruchus* sp. (also infesting groundnut) are important pests of beans and pulses.

Table: 21 Some alternative host plants of some storage Insect pests

Host Plant	Storage Insect pests				
	A. coffeae	*Careydon sp.*	Unidentified Scolytinae	*Acanthoscelides sp.*	*Callosobruchus sp.*
Grenia carpinifolia	+	-	-	-	-
Cassia sp	-	+	-	-	-
Bauhinia purpurea	+	-	+	-	-
Adanthera pavonina	+	-	+	-	+
Erythrophleum guineense	+	+	-	-	-
Centrosema pubesscence	-	+	+	-	-
Dialium guineense	-	+	-	-	-
Crotalaria retusa	-	-	+	-	-
Byrosocarpos coccineus	-	-	-	-	-
Caesalpinia pulcheerrima	-	-	-	-	-
Gliricidia sepium	-	-	-	-	-
Adenia lobata	-	-	+	-	-
Albizzia lebbeck	-	-	-	+	-
Grifonnia simplicifolia	-	-	+	-	-
Schrantia leptocarpus	-	+	-	-	+
Panicum maximum	-	-	-	-	-
Setaria pallide fusca	-	-	-	-	-
Setaria barbata	-	-	-	-	-
Brachiaria alata	-	-	-	-	-
Eichinocloa arundinaceum	-	-	-	-	-

Legend

+ = Pest present   - = Pest absent

CHAPTER FIVE

DISCUSSION

5.1 MARKET SURVEY

The storage insect pests problem is multifaceted and the employment of Integrated Pest Management (IPM) has now been accepted as the best approach to dealing with it (Benz, 1987). The local maize seller as a stakeholder has been neglected in most pest management programmes. Arguably, the accidental introduction and spread of *P. truncatus* in Africa was through trade (Haines, 1991). Although local maize traders are not involved in International trade, their role is significant in the spread of storage insect pests locally. The perception of the local maize seller, which forms one of the aspects of this study, is therefore very important in recognizing their role in pest outbreak and management. This will help integrate them in framing policies partaining to pest management.

Higher education is probably not a pre-requisite for maize selling as indicated by the study, as most of the respondents not educated beyond primary school. However, with two-thirds of the traders having been involved in the maize enterprise for over six years, most of them are expected to possess adequate knowledge and experience in handling maize and its associated pests (Tables 4 and 5). This was however not entirely the case probably because they are usually excluded from benefiting from the technical advice from extension services. This is underlined by the revelation that none of the traders even produced part of the maize they sell by themselves This suggests that the traders do not benefit from the pest management education programmes given to farmers by extension officers, since farmers are their main focus (Giga and Biscoe, (1990): Nkunika, 2002). As a consequence, any knowledge on pests acquired by traders is probably by experience through prolonged trading in maize and information passed on from farmers. This shows how important it is to get maize traders involved in scientific understanding of any IPM programme towards the management of storage insect pests. Furthermore, the large involvement of the active age group (20 – 40 years) in the sector indicates that they can be depended upon in any pest control scheme.

Traders' consciousness of the importance of moisture content and storage insect pests in maize storage is highly commendable as these factors are very critical in maize storage. Their view that under-dried maize easily deteriorates due to increase in mould growth and storage insect pests infestation conforms to observations made by FAO, (1981) and Higgins, (1987).

With the exception of the determination of warmth emanating from stored seeds, all the other methods mentioned (rattling sound on shaking grains, bruising with fingernail, and cracking grains with teeth) have been documented as effective in estimating grain moisture. Moreover, all the main methods used to detect infestation - physical presence of pests, clicking sound and the presence of frass/powder - have also been documented as effective (Higgins 1987; FAO, 1994).

Maize traders rejected infested maize due to the threat of further loss to storage insect pests and low market value of damaged grains. The rejection of heavily infested maize and acceptance of light to moderate infested ones were based on two premises. Firstly, light to moderate infested maize attracted lower prices, which they in turn sell to poultry farmers at good prices. Secondly, they do not store maize long enough for appreciable loss to be incurred (Fig. 6).

Meanwhile both the infested and uninfested maize purchased by the traders (Fig 7) are transported and stored in the same vehicle as well as stores. There is therefore some risk of cross infestation of the uninfested from the infested maize but this appears to be unimportant to traders, probably due to ignorance.

The fact that majority of the respondents trade in other commodities such as grains, (groundnut, beans, rice), and dried cassava chips (*konkonte*) could help promote pest outbreak. This is because some storage insect pests such as *R. dominica*, *Sitophilus spp.*, *P. truncatus*, *Cryptolestes* sp., *A. advena* and *S. cerealella* infest maize, rice and dried cassava chips (Hill, 1987; Rajamma and Premakumar, 1994; van Tonder and Prinsloo, 2000) and therefore cross infestation among these commodities is imminent. Although the traders made mention of *Sitophilus* spp. and *Tribolium spp.* (the commonest pests) as infesting rice as well as maize, they never expressed any concern about a possible cross infestation among the two commodities.

In each of the markets, the storage places were market stalls (open or closed) and in the open-air, in which case stocks were protected from rain using tarpaulins. Only few relied on storerooms in their homes. These storage practices suggest the possibility of cross infestation between trader's stocks in the market.

These shortcomings were not evident to the traders who knew and mentioned only field, barn, empty infested sacks, and mixing infested and uninfested grains as sources of infestation.

Storage insect pests and mould growth associated with them, and mice are the major threats to stored maize (Nyanteng, 1972; Appert, 1987; Orraca-Tetteh, 1989: Benz, 1990: FAO, 1994). Traders therefore attributing the quantity of maize bought and short storage duration to effects of mould, insects and mice indicates their in-depth knowledge in this aspect of grain storage (section 4.1.1.2, Figs. 4 and 5). This is reinforced by their assertion that mould growth is at its peak around August-October. The other limiting factor, lack of capital, suggests that with adequate capital, more maize may be purchased and stored for relatively long periods. Prolonged storage periods will imply that they would be more involved in pest management thus requiring their upgrading their pest control practices from the current sieving and sun-drying.

Traders appear to be more familiar with *Sitophilus spp*. and *Tribolium* spp. as insect pests of stored maize (Fig. 7 and Table 9). These two pests were also the commonest pests in the market thereby confirming the assertion by the traders that they were the commonest storage insect pests of maize. Furthermore, the traders' opinion that *Sitophilus spp.* was the most destructive corroborates observations by Chritensen and Kaufmann (1969), Haines, (1991) and Kossou and Bosque-Perez, (1998).

The inability of the traders to differentiate between *Oryzaephilus* sp., *Carpophilus* sp., *A. advena*, *C. quadricollis* and *Cryptolestes* sp. on one hand, and *P. truncatus* and *R. dominica* on the other hand is justifiable. This is because at least a hand lens is required to correctly distinguish one of these pests from the others due to their identical appearance and small size (Lippert and Higgins, 1987). Further assertion by respondents that lepidopterous larvae are present in maize available in August – October shows they have some knowledge about storage insect pests. These are indications that maize traders can easily be integrated into maize pest management programmes.

Maize traders have employed more or less cultural control methods of storage insect pests (section 4.1.1.5). These methods, which include sun-dryng and sieving, have been reported (FAO, 1994; Granados, 2000) as effective methods employed by small-scale maize dealers, even though practicability of the latter is doubted (FAO, 1994). The widespread use of sieving among the traders shows its practicability for these small-scale handlers. Meanwhile, the sieving method may be to the disadvantage of consumers who tend to store the purchased maize for a long time. Visible stages of the pest may suggest their absence while in fact infestation may be manifest in the form of hidden stages. This was evident, in that, some of the maize bought from the markets were free from visible storage insect pests but had some adults emerging after storing for sometime. Consumers may thus be advised to regularly check for probable emergence of these pests from their stock if they intend to store the maize that they buy for relatively long periods.

5.1.1 PEST CONTROL METHODS ADOPTED BY MAIZE TRADERS

Although none of the traders claimed to apply insecticide, 11 out of the 94 hinted that locally made repellent insecticide powder peddled in the markets were sprinkled on the maize storage sacks or near bagged maize (Table 10). This is done to repel pests. Though they gave a very good reason as the fear of food poisoning as their basis for not using synthetic insecticides, the powders similar potential problems. This is because they have been made to believe, by the peddlers, that these powders are not toxic to humans. Furthermore, respondents believed the powder does not get into the maize itself since it is just sprinkled on or around the sacks.

Labels on samples of the insecticide powder indicate pyrethrin as the active ingredient. Although pyrethrin is known to be a non-persistent insecticide (Benz, 1987), it may pose health hazard considering the short storage duration of maize by traders. Further analysis of the content of the powders and their application by the traders needs to be carried out in order to determine their toxicity. Beside the health hazard, Hodges *et al.* (1992) pointed out the inefficacy of fabric or surface treatments, which rather accelerate the development of resistance to the insecticides. There is therefore the need to probe more into the usage of these powders.

5.2 INFESTATION OF MAIZE BY STORAGE INECT PEST AND THEIR PRESISTENCE IN STORAGE AND MARKET

The high number of storage insect pests recorded in the major season may be attributed to the high rainfall and humidity experienced during this period of the year. This is due to the fact that most of the pests which were absent in the minor season but present in the major season, especially members of the family Nitidulidae and Silvanidae, thrive best in damp grains and humid environment (Hill, 1987; Haines, 1991).

The phasing out of *H. luteolus* before harvest indicates their high moisture requirements. This makes them the least important among the post-harvest pests.

With the exception of *Sitophilus spp.* and *C. quadricollis*, all the major field-store pests were first recorded at the milk stage (grain moisture exceeding 40%) (Tables 15a – 15d). This means most of the field infestations occurred even before the maize became physiologically mature stage (30 – 35% moisture content). The most predominant storage insect pests recorded, *Sitophilus spp.* and *C. quadricollis* infested the maize in both seasons around the physiological maturity stage. Since maize cannot be harvested before this stage, total exclusion of *Sitophilus spp.* from maize in the field appears not to be feasible.

The absence of the field-to-store pests, *Brachypeplus* sp., *A. coffeae, M. subterranea* and *C. fumatus sp.* in storage (at 16.9%, 16.1%, 13.9% and 13.4% respectively) suggests that they can be eliminated (Table 15). This may be achieved if harvested ears are dried to the recommended 12% mc (can be attained in cribs) before prolonged storage. The persistence of *Sitophilus spp., C quadricollis* and *Tribolium* spp. at this moisture content and their wide distribution in maize demand the application of protectants before storage.

The moisture content at which *Tribolium* spp. infested maize was not very precise but the results showed that it attacked maize in the field. This is in contrast with assertion by de Pury (1974) that *Tribolium* spp. does not attack maize in the field.

Tribolium spp. was one of the pests that persisted throughout storage with the population increasing as storage duration was prolonged, making it a formidable pest. *Tribolium* spp. is a secondary pest but high damage is expected from this pest if a number of the grains are cracked or already damaged by other primary pests such as *Sitophilus spp.* (van Tonder and Prinsloo, 2000). The prevalence of *Sitophilus spp.* therefore indicates that damage by *Tribolium* spp. to traders' maize is imminent.

Among all the pests identified in this study, *M. nigrivenella, C. leucotreta* and *A. advena* thrived within the widest range of grain moisture. *M nigrivinella*, and *C. leucotreta* are known to infest only the standing maize crop in the field and may be present only at the initial storage period after harvest (Setamou, *et. al.*, 1998). The results in this study indicate these ear borers can persist even to the recommended 12% moisture content (Tables 13 and 15). The ability of these moths to survive a wide range of grain moisture in addition to the damage caused through the feeding activities of the larvae makes them serious storage pests to contend with. Early harvesting of maize in attempt to avoid them may not be helpful and therefore the control methods for stem borers may have to be adopted in order to reduce their infestation of maize (Botchey, 2002).

Meanwhile no adult *M. nigrivenella* and *C. leucotreta* were encountered at the time the maize was bought from the markets. Only the larvae were present, probably because the adults do not feed on the grains but rather lays eggs among them. Adults only emerged later during the incubation period. It can therefore be inferred that the maize sampled in October were infested prior to harvesting hence their absence in the April sampling.

The absence of *P. truncatus* from sampling areas (except in 3 markets in the second sampling in April) suggests this pest has probably not yet well established in areas where the traders purchase their wares. It is therefore possible the pest is colonizing new areas, marking the beginning of its spread to these areas, probably through trade. It is therefore worthwhile carrying further survey to find out the status of this pest in Techiman, Ejura, Sekyidumase etc, where traders acquire their maize.

Even though Ayertey (1979) reported *S. cerealella* as one of the important pests infesting stored maize in Ghana, there was low incidence of *S. cerealella* throughout this study. The low incidence may be related to the form of storage of the maize worked with. *S. cerealella* infestation is known to be rare in maize stored unhusked or as bagged grains, which were the storage forms held in cribs and by traders respectively.

R. dominica and *D. minutus*, which are able to thrive in low grain moisture were present at the end of crib storage but were absent in samples from the markets (Tables 13, 14 and 16). These pests were however expected to be present; hence their absence may probably be due to their low population levels during crib storage. It could also be that *R. dominica*, being a wood borer, was already present in the wood used to construct the cribs before the maize was stored in them.

5.3 DRYING RATE OF MAIZE IN THE FIELD

The difference in the drying rates of the four maize varieties in the field (Fig. 9), could have been attributed to the fact that seeds and cobs of the QPM were bulkier than the local varieties (Plate 6a) and therefore took a longer time to dry. This not withstanding, the drying rates of all the four varieties during crib storage were similar. It is therefore probable that an inherent characteristic of the standing crop is responsible for the difference in drying rates in the field.

5.4 MOISTURE CONTENT OF MAIZE IN THE MARKET

The rise in mean moisture content from 11.01 ± 0.01% to 12.88 ± 0.08% in the market surveys of October and April respectively may be due to absorption of atmospheric moisture. Maize grains are hygrocospic and therefore absorb moisture when ambient humidity is high; this is the case in surveyed areas around April (Asiedu and Ohemeng-Dapaah, 1991). A typical increase in grain moisture due to absorption from the atmosphere was demonstrated by FAO (1982): Exposure of maize for 48 hours at 90% R.H. increased the moisture content from 13% to 18% at a temperature of 23^0C. The consequence of grain moisture increment is an increase in mould growth and the proliferation of pest especially *C. fumatus, A. advena, C. quadricollis* and *Cryptolestes* sp. which prefer damp grains (Higgins, 1987; Appert, 1987). All these four pests are known to thrive in maize with high moisture content but sometimes survive in storage at low grain moisture (van Tonder and Prinsloo, 2000). This probably explains why *C. fumatus* disappeared at the end of crib storage, but was present in samples from the markets. The persistence of these pests and their presence in the market survey in April can therefore be attributed to the rise in grain moisture, which favours their survival.

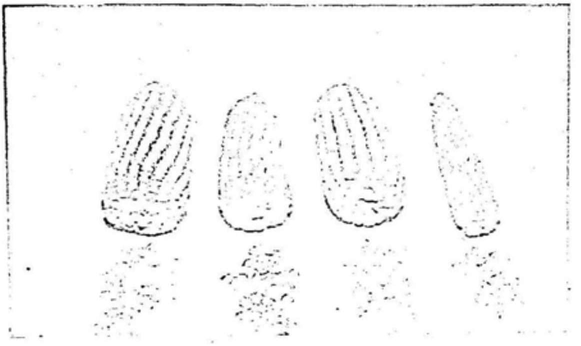

Plate 6a: Dehusked ears showing cob and grain sizes of four maize varieties. From left – right: *Mamaba*, *Fante*, *Obatanpa* and *Owifompe*.

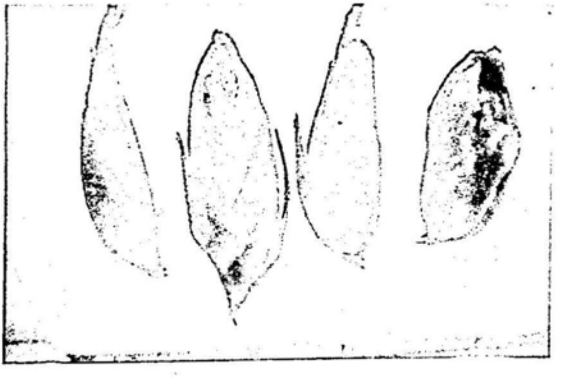

Plate 6b: Husked ears showing cob and grain sizes of four maize varieties. From left – right: *Owifompe*, *Mamaba*, *Fante* and *Obatanpa*.

5.4 SUSCEPTIBILITY OF QPM AND LOCAL MAIZE VARIETIES TO STORAGE INSECT PESTS

Several works have shown that long husk, which completely encloses cobs, offers some protection against storage insect pests, particularly *Sitophilus spp.* (Dick, 1988; McFarlane, 1988; Bosque-Perez and Mareck, 1990; Kossou *et. al.*, 1993 and Prah, 2000). Majority of the ears of *Fante* and *Owifompe* (local) were observed to have long intact husk (Plate 6b) and therefore might account for the lower incidence of *Sitophilus spp.* on these varieties than *Obatanpa* and *Mamaba* (QPM). On the same basis of husk cover, explanation may be given to the high incidence of *A. coffeae* on the QPM varieties, which had most cobs, exposed. No *A. coffeae* was recorded on *Fante* maize, which had almost all cobs, covered in long intact husk.

Protection offered by husk cover appears not to be apparent in the observation that *C. quadricollis* was higher on the local varieties than the QPM varieties both in the field and in storage. This might be due to the small flat stature of *C. quadricollis,* which enable them to enter through the distal end of the ears with relative ease. They therefore proliferated due to lesser competition from *Sitophilus* spp. This disparity observed in the populations of *Sitophilus spp.* and *C. quadricollis* on the QPM and local varieties needs further investigation.

The differences between the damage levels of the QPM and local varieties during storage may be related to the population and feeding habits of the two key pests, *Sitophilus spp.* and *C. quadricollis*, whose population dominated, both in the field and in storage (Figs. 11 – 13 and Table 19). Unlike *C. quadricollis* which is a secondary pest or fungus feeder (Merchant, 2000), *Sitophilus spp.* is a primary pest which feeds voraciously thereby causing greater damage to infested grains in storage (Haines, 1991 and Stoll, 2000). The higher *Sitophilus spp.* population density on the QPM varieties might therefore have contributed to the higher grain damage in these varieties. This not withstanding, kernel characteristics such as hardness of endosperm and seed coat (Dobie, 1974) as well as other storage insect pests that were present may as well be important in accounting for the high grain damage among the QPM. The kernel characteristics were evident in the laboratory evaluation of susceptibility of the four varieties (Table 20).

5.5.1 SUSCEPTIBILITY OF FOUR MAIZE VARIETIES TO SITOPHILUS SP.

The significantly higher oviposition and number of emerged *Sitophilus spp.* on the QPM than local varieties and the insignificant difference in development time may be attributed to the difference in the hardness of the endosperm and thickness and toughness of the seed coat.

Schulten (1976) and Arnason *et. al.* (1997) indicated that these characteristics are very important factors contributing to resistance to storage insect pests. The QPM varieties tend to have soft endosperm and seed coat (section 2.2.2) as compared to the local varieties. These characters renders the locals less desirable (CIMMYT, 1997). The insignificant difference in development time of *Sitophilus spp.* also implies the difference in protein content of the QPM and local varieties have no significant effect on the developmental time of *Sitophilus spp.* This observation agrees with the work of Arnason *et. al.* (1994 and 1997), which showed that higher protein content does not play significant role in the development of *Sitophilus spp.* and *P. truncatus.*

The results obtained from the oviposition and the number of adults that emerged indicated that the most probable resistance characteristic was the physical barrier offered by the seed coat against oviposition and emergence. Once eggs were laid, there was a high chance of survival irrespective of the nutritional status of the grains.

In using the susceptibility index (SI) to compare susceptibility, the variety with the highest SI is the most susceptible and vice versa. The susceptibility indices of the four varieties therefore show *Obatanpa* (QPM) as the most susceptible, with one QPM and one local; *Mamaba* and *Fante* respectively, recording the same susceptibility levels (Table

Inferring from the absence of *Cryptolestes* sp. in maize in the field maize might not be a favourite host in the field. Their absence in maize in the field and low numbers in the market sampling in October, also indicate that this pest is not probably carried from field to the markets. Rather, they are already present in the markets from where they infest newly arriving maize.

The unidentified Scolytinae, which was abundant on a number of the wild plants sampled (Table 21) and was occasionally found on maize in this study, raises questions about its status as a pest of maize. Members of this subfamily are mainly wood borers and are not known to infest maize hence their presence in maize gives some indication that this insect may probably switch to infest maize grains in future, as in the case of *P. truncatus* and *R. dominica*.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

Maize is a very important crop that is consumed worldwide yet solution to one of its major production constraints, insect pests, is still widely open. The focus on the local maize trader in this study, who hitherto has been neglected, highlighted their basic knowledge and understanding of how they can be incorporated into managing storage insect pests.

It was observed that local maize traders have adequate traditional knowledge of the presence of storage insect pests and their pest status. On this basis, they adopt their own control methods, some of which are undermined by their handling and storage practices. There is therefore the need to fill the gaps in their knowledge. Researchers and extension workers also need to involve maize traders in finding and adopting suitable pest control methods since some of their activities can either promote pest outbreaks or reduce their infestation. This calls for a collaboration of all stakeholders especially the researcher, the farmer, and the local maize trader.

Majority of the field-to-store insect pests of maize infest maize at high moisture content, even before it becomes physiologically mature but few persist through storage to the market. The most important field-to-store pest, *Sitophilus spp.*, infested maize at about the physiological maturity phase (about 30% moisture content) and their complete exclusion in the field appears not to be practicable. However ears could be harvested at physiological maturity because the population density increased as drying in the field is prolonged. Harvested ears can subsequently be treated and stored in narrow cribs which have proven to dry maize of high moisture content to acceptable levels (FAO, 1980 and 1982). This may also help control *R. dominica* and the unidentified Curculionidae which infested the maize during crib storage. The rapid pre-harvest drying rate of the local varieties can be investigated, and if found to be inherent characteristic, breeds that have shorter pre-harvest drying can be produced in order to reduce pre-harvest pest load.

The study also shows that *Sitophilus spp.* is still the most important storage insect pest of maize in Ghana. A further market survey in the Volta Region may help identify the status of *P. truncatus* in that area where field experiments suggest high prevalence.

The two QPM varieties, *Obatanpa* and *Mamaba* were more susceptible to storage insect pests, particularly *Sitophilus spp.*, than the local varieties, *Fante* and *Owifompe*. The higher susceptibility of QPM varieties call for improvement in current traditional crib storage

Associated with insecticide usage, cheaper artificial drying devices must be developed and promoted in the long term, in order to reduce pre-harvest pest load. The efficiency of biological control agents such as the parasitoids found can also be evaluated and applied if necessary.

6.1 LIMITATIONS OF THE RESEARCH

Lack of time did not permit large number of alternative hos plants over a wider area to be surveyed for storage insect pests of maize.

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Appendix 4: Storage insect pests of maize (*Obatanpa*) at successive drying stages during the minor season planting

Location of farm	Week after emergence (WAE)	mmc %	Storage insect pests per 10 ears											
			Ah	Ar	Br	Cf	My	Mu	Cb	Ct	Us	St	Tr	Sg
Ankako	12	46.7	4	0	3	0	0	1	2	0	0	0	0	0
	13	41.3	6	2	18	0	6	4	3	0	0	0	0	0
	14	32.5	0	0	32	0	6	6	0	9	0	0	0	0
	15	31.8	0	1	0	0	0	0	0	0	0	18	0	0
	16	27.5	0	2	12	0	8	2	1	44	0	32	1	0
	17	24.1	9	0	0	0	0	2	3	142	0	83	0	0
	18	20.6	0	0	4	0	0	3	2	151	0	159	2	0
	19	19.9	0	5	0	0	2	0	0	201	0	189	0	0
Jukwa	12	47.7	0	2	0	0	0	1	3	0	0	0	0	0
	13	35.8	3	0	4	2	0	5	0	0	0	0	0	0
	14	42.1	9	3	0	5	3	4	5	0	0	0	0	0
	15	36.5	7	0	10	0	0	3	1	10		0	0	0
	16	29.0	4	4	8	0	4	2	2	57	0	44	0	0
	17	26.3	5	1	6	1	1	6	2	84	0	98	0	0
	18	22.1	0	0	4	0	5	0	0	166	0	173	0	2
	19	20.4	6	0	2	1	0	5	2	232	0	261	0	0
Cape Coast	12	45.3	3	2	0	0	3	1	1	0	0	0	0	0
	13	39.6	0	6	4	2	1	6	1	12	0	0	0	0
	14	34.9	4	0	0	6	0	2	0	20	0	0	0	0
	15	33.1	12	0	12	0	4	4	0	66	0	0	0	0
	16	27.1	8	9	10	0	0	3	2	131	4	38	0	0
	17	22.8	0	0	0	0	2	2	0	138	6	99	2	0
	18	18.91	3	0	8	3	0	3	4	112	0	106	0	1
	19	18.3	0	2	0	1	1	0	3	231	0	221	1	4
Mpeasem	12	45.9	2	6	11	0	3	4	0	0	0	0	0	0
	13	40.4	7	0	10	0	2	4	3	0	3	0	0	0
	14	35.4	0	8	12	0	4	4	2	0	0	0	0	0
	15	29.7	2	0	6	0	1	6	5	38	7	6	0	0
	16	26.6	0	3	0	0	0	2	3	76	4	19	0	0
	17	23.4	8	0	0	0	3	1	1	73	2	56	0	0
	18	20.1	0	0	0	0	0	0	0	65	0	103	0	0
	19	19.8	0	0	4	0	0	2	1	111	0	189	0	3

Legend:

Ah = *A. advena*
Ar = *A. coffeae*
Br = *Brachypeplus* sp.
Cf = *Carpophilus sp*
My = *M. subterranea*
Ct = *C. quadricollis*
Mu = *M. nigrivenella*
Cb = *C. leucotreta*
Us = Unidentified *scolytinae*
St = *Sitophilus spp.*
Tr = *Tribolium spp.*
Sg = *S. cerealella*

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APPENDICES

APPENDIX 1

UNIVERSITY OF CAPE COAST

DEPARTMENT OF ZOOLOGY

INTERVIEW SCHEDULE TO FIND OUT THE LEVEL OF KNOWLEDGE OF STORED PRODUCT PESTS AMONG MAIZE TRADERS

Please answer the following questions by ticking or by providing appropriate answer.

A. **Personal details of respondents**

1) Sex (M) or (F)

2) Age...

3) Level of education:

( ) Primary school ( ) University/ Polytechnic

( ) Secondary School ( ) Adult Education

( ) Teacher Training ( ) No Schooling

4) What else do you trade in apart from maize?...

5) How long have you been in this business?

( ) < 1year ( ) 1-5 years

( ) 6-10 years ( ) >10 years

B. Source/condition of maize

6) Where do you buy your maize?

( ) Farmers ( ) Middle-men

( ) Self ( ) Any other (specify)........................

(i) If from farmers, where do they reside...............................

(ii) If from middle-men, from where do they bring their goods.........

(iii) If self where is your farm located.......................................

7) How do you determine if the maize you bought is dried?

....

8) When do you further dry your maize? ....

Why...

C. Knowledge of maize variety

9) Can you tell the difference between local and improved maize varieties?

( ) Yes ( ) No

If yes describe the difference:

Local..

....

Improved...

....

10) Which of these are more susceptible to pest destruction...........

D. Storage and pest infestation

11) Are you able to detect maize infested with pests? ( ) Yes ( ) No

If yes how?..

12) Do you reject maize infested with pests? ( ) Yes ( ) No

If yes when? ( ) Heavy infestation ( ) Moderate infestation

( ) Light infestation

Give reasons..

....

13) How many bags of maize do you usually buy?

( ) 1-5 bags ( ) 6-10 bags ( )11-20 bags ( ) >20 bags

Why?..

14) Where do you store your maize?..

15) How long and why do you usually store your maize?................

16) Do you periodically check for pest infestation? ( ) Yes ( ) No

Why?..

....

17) Which of the insect pests in the photograph have you seen in your maize

Before?

i)..

ii)..

iii)..

iv)..

18) i) Which of the list above is more common..........................

ii) Which of the list above is most destructive........................

19)How and when do you think the maize gets infested with these pests?

....

....

E. Pest control

20) Do you treat your maize with pesticides? ( ) Yes ( ) No

21) (i) If yes which brand...

(ii) If no how do you control pests in your maize?................

....

22) After treatment with pesticide, how long does it take before you sell

( ) 1 week ( ) 2 weeks ( ) 3weeks( ) 1 month

( ) 2months ( ) 3 months ( ) more than 3 months

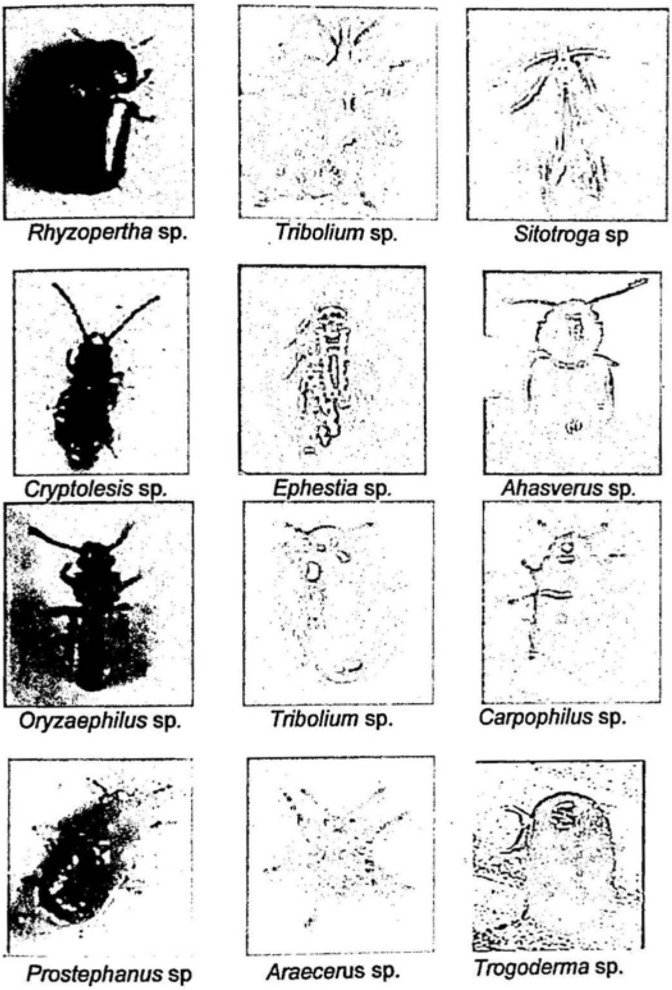

Plate 8: Some common stored product pests.

Appendix 2: Storage insect pests recorded

FAMILY	Species
ANOBIIDAE ANOBIINAE	*Lasioderma serricorne* (Fabricius)
ANTHRIBIDAE CHORAGINAE	*Araecerus* cf. *coffeae*
BOSTRICHIDAE DINODERINAE	*Dinoderus minutus* (Fabricius)
BOSTRICHIDAE	*Prostephanus truncatus* (Horn)
CUCUJIDAE	*Cryptolestes sp.*
CURCULIONIDAE SCOLYTINAE	Species indeterminate
CURCULIONIDAE	*Sitophilus spp.*
CURCULIONIDAE	Species indeterminate
ENDOMYCHIDAE	cf. *Mycetaea subterranea* (Fabricius)
GELICHIDAE	*Mussidia nigrivenella* (Ragonot)
GELICHIDAE	*Cryptophlebia leucotreta* (Meyrick)
NITIDULIDAE	Species indeterminate
NITIDULIDAE	*Carpophilus fumatus* (Boheman)
NITIDULIDAE	*Carpophilus sp.*
NITIDULIDAE	cf. *Soronia* sp
NITIDULIDAE	*Haptoncus luteolus* (Erichson)
NITIDULIDAE	*Brachypeplus* sp.
PYRALIDAE	*Sitotroga cerealella*
SILVANIDAE	*Ahasverus advena* (Waltl)
SILVANIDAE	*Cathartus quadricollis* (Guerin-Meneville)
SILVANIDAE	*Silvanus sp.*
TENEBRIONIDAE TENEBRIONINAE	*Tribolium castneum* (Herbst)
TENEBRIONIDAE TENEBRIONINAE	*Gnathocerus* cf. *Maxillosus* (Fabricius)
TROGOSSITIDAE	*Tenebroides mauritanicus* (Linnaeus)
PARASITES/PARASITOIDS/ PREDATORS	
PTEROMALINAE	? *Anisopteromalus*
STAPHYLINIDAE SCAPHIDIINAE	Species indeterminate
BETHYLIDAE	Species indeterminate
PSOCOPTERA	Species indeterminate
CLASS: ARACHNIDA ORDER: PSEUDOSCORPIONES	Species indeterminate
	Diapersticus erythrocephalus (Olivier)

Appendix 6a: Storage insect pests present in *Obatanpa* maize variety at successive drying stages both in the field and in storage

Weeks After Emergence (WAE)	Mean moisture content %	Storage insect pest per 10 ears																					
		Ah	Ar	Br	My	La	Ha	Ms	Cb	Cf	Ct	Sv	St	So	Ca	Sp B	Sc	Sg	Di	Tr	Rh	Te	Un
11	45.0	3	5	4	5	3	29	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	41.4	3	0	16	4	0	18	10	2	6	0	0	0	0	0	0	0	0	0	0	0	0	0
13	38.3	0	0	15	0	0	10	4	2	8	0	0	0	0	2	0	0	0	0	0	0	0	0
14	32.9	5	8	15	4	0	9	6	0	4	6	3	0	0	0	0	0	0	0	0	0	0	0
15	28.0	0	0	3	0	1	9	1	0	5	22	0	28	0	0	0	0	0	0	0	0	0	0
16	23.1	8	0	8	3	0	9	0	0	0	14	0	48	0	4	0	0	0	0	0	0	0	0
17	21.7	10	13	10	6	0	0	1	1	6	36	0	89	0	0	0	0	2	2	0	0	0	0
18	20.3	0	7	8	0	0	0	0	1	0	36	0	92	0	0	0	0	0	0	0	0	0	0
Storage																							
20	17.1	17	5	2	6	0	0	3	0	3	30	0	88	0	0	0	0	1	2	4	2	0	0
22	14.1	10	0	0	4	0	0	2	0	2	30	0	107	0	0	0	0	0	2	12	0	2	2
24	13.9	14	3	0	0	0	0	0	0	0	42	0	110	0	0	0	0	3	0	0	0	0	0
26	13.8	11	0	0	0	0	0	0	1	0	202	0	289	0	0	0	0	6	0	0	0	2	6
28	13.1	9	0	0	0	0	0	0	2	2	253	0	191	0	0	0	0	2	0	0	0	4	4
30	12.3	13	0	0	0	2	0	2	1	0	366	0	987	0	0	0	1	9	18	16	0	3	2

Legend

Ah = *Ahasverus advena*
My = *Mycetaea subterrannea*
Di = *Dinoderus minutus*
Ca = *Carpophilus fumatus sp.*
Tr = *Tribolium castaneum*

Ar = *Araecerus coffeae*
Ha = *Haptoncus luteolus*
Br = *Brachypeplus* sp.
Rh = *Rhyzopertha dominica*
Un = Unidentified Curculionidae

Mu = *Mussidia nigrivenella*
Cb = *Cryptophlebia leucotreta*
Ct = *Cathartus quadricollis*
St = *Sitophilus* sp
So = *Soronia* sp

Sy = *Sylvanus* sp.
Sg = *S. cerealella*
Sc = Unidentified scolytinae
Te = *T. mauriticanus*
La =

Appendix 3b: Storage insect pests present in *Mamaba* maize variety at successive drying stages both in the field and in storage

Weeks After Emergence (WAE)	Mean moisture content %	Storage insect pest species per 10 ears																					
Field		Ah	Ar	Br	My	La	Ha	Ms	Crb	Cf	Ct	Sv	St	So	Ca	Sp B	Sc	Sg	Di	Tr	Rh	Te	Un
11	44.5	1	0	12	5	0	16	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
12	42.2	0	4	8	0	3	12	6	1	7	0	0	0	2	0	0	0	0	0	0	0	0	0
13	36.8	0	2	3	6	0	11	4	2	6	3	0	0	0	0	0	0	0	0	0	0	0	0
14	33.5	6	0	16	8	2	18	4	2	7	0	2	0	0	0	0	0	0	0	0	0	0	0
15	30.4	0	0	13	0	2	9	5	0	4	33	3	59	0	4	0	0	0	0	0	0	0	0
16	28.5	0	6	5	6	0	0	0	3	0	10	1	44	0	0	0	0	0	0	2	0	0	0
17	25.4	10	10	4	9	0	1	2	0	6	18	0	118	0	1	0	0	0	0	0	0	0	0
18	21.3	6	0	8	6	0	0	0	2	6	22	0	178	0	0	0	0	0	0	12	0	0	0
Storage																							
20	17.9	7	5	2	6	0	0	0	1	3	35	0	83	0	0	0	0	0	1	2	0	0	0
22	15.2	19	0	0	5	0	0	4	0	1	45	0	67	0	1	0	0	1	5	0	0	0	0
24	14.4	28	0	0	0	0	0	1	0	1	86	0	139	0	0	0	0	0	0	0	2	0	0
26	14.2	43	0	0	5	0	0	0	0	0	342	0	580	0	0	0	0	0	7	16	3	0	0
28	13.0	21	0	0	0	0	0	3	2	0	254	0	641	0	0	0	0	0	0	23	6	0	3
30	12.4	32	0	0	0	0	0	1	2	0	186	0	1399	0	0	0	0	0	7	22	0	0	2

Legend

Ah = *Ahasverus advena*
My = *Mycetaea subterrannea*
Di = *Dinoderus minutus*
Ca = *Carpophilus fumatus sp.*
Tr = *Tribolium castaneum*
Ar = *Araecerus coffeae*
Ha = *Haptoncus luteolus*
Br = *Brachypeplus* sp.
Rh = *Rhyzopertha dominica*
Un = Unidentified Curculionidae
Mu = *Mussidia nigrivenella*
Cb = *Cryptophlebia leucotreta*
Ct = *Cathartus quadricollis*
St = *Sitophilus* sp
So = *Soronia* sp
Sy = *Sylvanus* sp.
Sg = *S. cerealella*
Sc = Unidentified scolytinae
Te = *T. mauriticanus*
La =

Appendix 9c: Storage insect pests present in *Fante* maize variety at successive drying stages both in the field and in storage

Weeks After Emergence (WAE)	Mean moisture content %	Storage insect pests per 10 ears																					
Field		Ah	Ar	Br	My	La	Ha	Ms	Crb	Cf	Ct	Sv	St	So	Ca	Sp B	Sc	Sg	Di	Tr	Rh	Te	Un
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	44.5	1	0	14	3	0	23	2	4	11	0	0	0	0	0	2	0	0	0	0	0	0	0
14	39.4	0	0	8	3	0	7	7	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0
15	30.1	0	0	8	4	0	10	3	6	2	10	0	6	0	0	0	0	0	0	0	0	0	0
16	27.1	5	0	8	4	0	4	0	8	11	8	0	0	3	2	0	0	0	0	0	0	0	0
17	23.8	3	0	3	6	0	0	1	4	2	24	0	16	0	1	0	0	0	0	0	0	0	0
18	20.0	30	0	5	0	0	0	2	0	0	86	0	64	0	0	0	2	0	10	0	0	0	0
Storage																							
20	16.1	27	0	1	1	0	0	2	2	0	76	0	4	0	0	0	0	0	10	2	0	0	0
22	15.3	49	0	0	2	0	0	0	1	0	103	0	82	0	0	0	0	0	6	7	4	0	0
24	14.4	37	0	0	0	0	0	0	1	0	163	0	44	0	1	0	0	1	5	0	0	0	0
26	13.1	10	0	0	0	0	0	1	0	0	248	0	243	0	0	0	0	0	0	2	0	1	4
28	12.7	14	0	0	0	0	0	2	0	3	231	0	351	0	0	0	0	0	0	18	2	0	0
30	11.7	32	0	0	0	0	0	0	1	0	247	0	228	0	0	0	0	0	2	14	0	0	0

Legend

Ah = *Ahasverus advena*
My = *Mycetaea subterrannea*
Di = *Dinoderus minutus*
Ca = *Carpophilus fumatus sp.*
Tr = *Tribolium castaneum*
Ar = *Araecerus coffeae*
Ha = *Haptoncus luteolus*
Br = *Brachypeplus* sp.
Rh = *Rhyzopertha dominica*
Un = Unidentified Curculionidae
Mu = *Mussidia nigrivenella*
Cb = *Cryptophlebia leucotreta*
Ct = *Cathartus quadricollis*
St = *Sitophilus* sp
So = *Soronia* sp
Sy = *Sylvanus* sp.
Sg = *S. cerealella*
Sc = Unidentified scolytinae
Te = *T. mauriticanus*
La =

Appendix 3d: Storage insect pests present in *Owifompo* maize variety at successive drying stages both in the field and in storage

Weeks After emergence (WAE)	Mean moisture content %	Storage insect pest species per 10 ears																					
Field		Ah	Ar	Br	My	La	Ha	Ms	Cb	Cf	Ct	Sv	St	So	Ca	Sp B	Sc	Sg	Di	Tr	Rh	Te	Un
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	44.6	0	0	3	2	0	6	9	4	10	0	2	0	0	0	0	0	0	0	0	0	0	0
14	38.6	8	6	9	4	0	4	12	2	10	0	0	0	0	0	4	0	0	0	0	0	0	0
15	32.1	8	0	5	0	8	3	6	1	3	0	0	5	0	0	0	0	0	0	0	0	0	0
16	28.4	9	8	8	0	0	7	0	0	6	51	0	19	0	0	0	0	0	0	0	0	0	0
17	24.8	8	0	2	5	0	2	0	2	2	69	0	35	0	0	0	0	0	0	0	0	0	0
18	20.3	0	0	0	0	0	2	0	1	0	55	0	60	0	3	0	0	0	3	0	0	0	0
Storage	-																						
20	16.4	7	2	2	1	0	1	0	0	8	85	0	33	0	0	0	0	0	3	1	0	0	0
232	14.4	5	0	0	0	0	0	0	0	0	106	0	31	0	1	0	0	0	0	0	0	0	5
24	13.9	0	0	0	0	0	0	3	0	0	178	0	83	0	0	0	0	0	0	2	1	0	0
26	13.1	7	1	0	0	0	2	0	3	2	178	0	74	0	0	0	0	0	0	0	0	0	0
28	12.3	5	0	0	2	0	0	4	2	0	189	0	15	0	0	0	0	0	0	4	0	0	0
30	12.0	6	0	0	0	0	0	2	0	0	214	0	214	0	0	0	0	0	0	22	0	0	3

<u>Legend</u>

Ah = *Ahasverus advena*
My = *Mycetaea subterrannea*
Di = *Dinoderus minutus*
Ca = *Carpophilus fumatus sp.*
Tr = *Tribolium castaneum*
Ar = *Araecerus coffeae*
Ha = *Haptoncus luteolus*
Br = *Brachypeplus* sp.
Rh = *Rhyzopertha dominica*
Un = Unidentified Curculionidae
Mu = *Mussidia nigrivenella*
Cb = *Cryptophlebia leucotreta*
Ct = *Cathartus quadricollis*
St = *Sitophilus* sp
So = *Soronia* sp
Sy = *Sylvanus* sp.
Sg = *S. cerealella*
Sc = Unidentified scolytinae
Te = *T. mauriticanus*
La =

Appendix 5: ANOVA for number of storage insect pests on four maize varieties in the major season (log x+1)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between treatment	0.10484	3	0.0349	0.1535	0.9269	2.79806
Within treatments	10.9253	48	0.2276			
Total	11.0301	51				

Appendix 6: ANOVA for number storage insect pest species on four maize varieties in the major season (Log x+1)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between treatments	0.0409	3	0.0136	2.7261	0.0534	2.7825
Within treatments	0.2583	52	0.0045			
Total	0.2988	55				

Appendix 7: ANOVA for number of storage insect pest species in four farms in the minor season (log x+1)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between treatments	0.0085	3	0.0028	1.0260	0.396	2.9466
Within treatments	0.0780	28	0.0027			
Total	0.0866	31				

Appendix 8: ANOVA for number of storage insect pests in four farms in the minor season (log x+1).

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between treatments	0.0935	3	0.0311	0.0939	0.9627	2.9466
Within treatments	9.2877	28	0.3317			
Total	9.3813	31				

Appendix 9: ANOVA for number of *Sitophilus spp.* on four maize varieties in the major season (log x+1)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between treatments	2.5660	3	0.8553	0.8671	0.4640	2.7825
Within treatments	51.291	52	0.9863			
Total	53.857	55				

Appendix 10: ANOVA for number of *Cathartus quadricollis* (Guerin) of four maize varieties in the major season (log x+1)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between treatments	0.13514	3	0.04506	0.0464	0.9865	2.7825
Within treatments	50.4583	52	0.97035			
Total	50.5939	55				

Appendix 11: ANOVA for number of kernels of four maize bored during crib storage in the major season (Arc sine)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between treatments	10435.82	3	3478.6	47.8238	3.82E	2.9466
Within treatments	2036.694	28	72.7398			
Total	12472.51	31				

Appendix 12: ANOVA for number of eggs oviposited by *Sitophilus spp.* in four maize varieties

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between treatments	2909	3	969.66	14.312	0.002	3.4903
Within treatments	813	12	67.75			
Total	3722	15				

Appendix 13: ANOVA for time of emergence of *Sitophilus spp.* in four maize varieties

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between treatments	9.0647	3	3.0215	1.4837	0.2686	3.4903
Within treatments	24.436	12	2.0363			
Total	33.501	15				

Appendix 14: ANOVA of number of adult *Sitophilus spp.* emerged from four maize varieties

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between treatments	589.65	3	196.56	14.811	0,0002	3.490
Within treatments	159.25	12	13.270			
Total	748.93	15				

Appendix 15: ANOVA for population growth rate of *Sitophilus spp.*on four maize varieties

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between treatments	52.410	3	17.4701	23.94	2.36o0	3.4903
Within treatments	8.7556	12	0:72963			
Total	61.166	15				

Appendix 16: ANOVA of grain weight loss to *Sitophilus spp.* on four maize varieties

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between treatments	6.6375	3	2.2125	11.024	0.009	3.490
Between treatments	2.4082	12	0.2006			
Total	9.0457	15				

Appendix 17: ANOVA for susceptibility index of four maize varieties

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between treatments	1.139	3	0.3797	18.457	8.62E	3.49
Within treatments	0.246	12	0.0205			
Total	1.385	15				