ON- FARM EVALUATION OF CANDLEWOOD ZANTHOXYLUM XANTHOXYLOIDES (LAM.) ON TWO STORED PRODUCT PESTS.

BY
CHARLES KWESI KOOMSON (B.Sc. HONS., ZOOLOGY)

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DEDICATION

To my siblings: Payin and Kakra Manful

DECLARATION

I do hereby declare that, except for references to works of other researchers which have fully been duly cited, this work is the result of my own original research, carried out at the Food Security Laboratory, Zoology Department, University of Ghana, Legon and the University of Ghana Farms, Legon, under the supervision of Dr. Ebenezer Oduro Owusu and Prof. J. N. Ayertey that this research neither in whole nor in part has been presented for another degree elsewhere.

.....
CHARLES KWESI KOOMSON
(STUDENT)

.....
DR. EBENEZER ODURO OWUSU
(SUPERVISOR)

.....
PROF. J.N. AYERTEY
(SUPERVISOR)

ABSTRACT

The biological activity of dry, ground plant parts (dust) and tablets of *Zanthoxylum xanthoxyloides* (Lam.) was assessed in both the laboratory and on the field against the maize weevil, *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) and the cowpea weevil, *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae).

Dry ground leaves, bark and roots were prepared in various proportions of 60% leaves and 40% roots; 70% leaves and 30% roots; 80% leaves and 20% roots; 90% leaves and 10% roots; 60% leaves and 40% bark; 70% leaves and 30% bark; 80% leaves and 20% bark; 90% leaves and 10% bark, as well as 100% leaves, 100% bark and 100% roots. These proportions were mixed with 5 kg of grains at 5% (wt/wt) concentration to assess contact toxicity, grain protection, effect on eggs and immature stages and persistency.

The biological activity of *Z. xanthoxyloides* was also accessed using tablets made from different concentrations of 2.2ml leaves and 1.8ml roots; 2.4ml leaves and 1.6ml roots; 2.6ml leaves and 1.4ml roots; 2.8ml leaves and 1.2ml roots; 2.2ml leaves and 1.8ml bark; 2.4ml leaves and 1.6ml bark; 2.6ml leaves and 1.4ml bark and 2.8ml leaves and 1.2ml bark. Five tablets of each of the different concentrations were mixed with 5 kg of grains to assess toxicity or grain protection by fumigation, effect on eggs and immature stages persistency and repellency.

The effective combinations of dry ground dusts were 60% leaves and 40% roots; 70% leaves and 30% roots; 60% leaves and 40% bark and 70% leaves and 30% bark. These significantly ($P<0.001$) induced over 68 % mortality of both species of insects, provided about 96% protection to the grains, inhibited the development of eggs and immature stages and were persistent for 2 months.

The effective tablet formulations were from concentrations of 2.2 ml: 1.8ml (v/v) leaves: roots; 2.4 ml: 1.6 ml (v/v) leaves: roots; 2.2 ml: 1.8ml (v/v) leaves: bark and 2.4 ml: 1.6ml (v/v) leaves: bark. These induced about 50% mortality, offered about 95% protection to the grains and evoked repellent actions against both insects. There was however, a rapid loss of activity after 7 days following treatment, irrespective of the dosage applied.

Z. xanthoxyloides, which is relatively safe to mammals because it is used for the treatment of ailments like tooth aches, stomach aches, leprous ulceration, and ulcers, syphilitic sores, fever, post-delivery pains while the leaves are fed to ruminants could be prepared into effective dry ground dust proportions as well as tablets for resource-poor farmers to protect their grains against some stored product pests.

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CHAPTER ONE

1.0 GENERAL INTRODUCTION

Post-harvest food loss is one of the major problems contributing to world food insecurity. Prior to the early 1970's, efforts to increase world food supplies largely concentrated on increasing production but after the early 1970's there was developing awareness that total food availability could be improved through the reduction of post-harvest losses (Boxall, 1986). FAO production figures in 1980 shows that 1,627.125 million metric tones of major grains were produced worldwide. Using the often-quoted conservative minimum overall food grain loss figures of 10% the total loss to mankind of cereal grains was estimated to be 162.7125 million tones (Ayertey, 1986).

Grains form the most important staple for the growing population in the tropics; with cereals and legumes providing important sources of carbohydrate and protein respectively (Niber, 1994). Grains are durable products, usually stored to provide a food reserve and seed for planting. However, grains in storage are damaged by several species of insect pests (Anon, 1958) leading to loss in weight and seed quality, especially germination ability (Richter, 1993). In West Africa, *Sitophilus zeamais* Mots. (Coleoptera:Curculionidae) has been reported to be the major pest of maize *Zea mays* and *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae), the major pest of cowpea, *Vigna unguiculata* (L.) Walp. (Dick, 1998) causing between 20-30% of stored grains (Hill, 1998).

Attempts at reducing infestation have concentrated on the use of synthetic insecticides. About 90% of those insecticides are imported with a high debt burden, due to high unfavourable exchange rates. Medium to large-scale farmers continue to depend greatly on pesticides. Thus, their usage has increased over the past 10-15 years due to the frequent association of insects, micro-organisms and weeds with crops (Poswal and Akpa, 1991).

However, the poor storage facilities of traditional farmers in developing countries are unsuitable for conventional chemical control, because most storage facilities are not air tight enough for fumigation and some are open to reinfestation by insects and this calls for repeated applications, leading to over use of insecticides. The widespread use and overuse of synthetic chemicals have led to serious problems, including the development of insect resistant strains to insecticides, toxic residues on stored grains, health hazards to grain handlers, food poisoning and environmental pollution among others (Champ and Dyte, 1976; Zettler and Coperus, 1980; White, 1985). Consequently, the need to find alternative candidate materials that are readily available, effective, affordable, less poisonous and less detrimental to the environment, has turned the attention of Entomologists and Toxicologists, to research into medicinal plants grown locally (Tierto, 1994).

Plants are rich sources of compounds that have insecticidal properties (Schmutterer, 1995; Bekele *et al.* 1997 Olaifa et al. 1987; Obeng-Ofori *et al.* 1998; Owusu, 2000). Seeds of *Melia volkensii* M. Guerke (Rombold, 1994), *Ocimum* species Willd. (Kumar, 1987), *Adzadirachta indica* A. Juss (Addae-Mensah, 1998), *Cassia sophera*

Oliv. (Koomson, 2000) as well as many others have been successfully used to control insect pests.

Candlewood, *Zanthoxylum xanthoxyloides* (Lam.) (Rutacesae) is effective against several stored product pests. Dry plant materials of the roots, stems, leaves and seeds have been shown to be effective against *S. zeamais, C. maculatus* and *Tribolium castaneum* Herbst, under laboratory conditions (Osafo, 1998; Udo, 2000). Extracts of the roots and stem proved most effective, giving 100% protection to maize and cowpea and completely inhibited progeny production and development of eggs and immature stages of *S. zemias* and *C. maculatus* within grains. The extracts also evoked a strong repellent action against *T. castaneum* but were moderately repellent against *C. maculatus* and *S. zeamais* (Udo, 2000).

According to Udo (2000), the bark and roots were most effective giving 100% mortality after 72 hours, with the leaves giving only about 64% mortality after 72 hours. But if the root and bark were to be used solely, it would mean destroying the plants. This is because the root is responsible for the absorption of water and mineral salts for photosynthesis and the bark protects the plant against mechanical injury as well as insect, fungal and bacterial attacks. The current aspect of the research was thus aimed at combining the leaves with the roots and bark in different proportions to determine how best to maximize the use of the leaves and minimize the use of the roots and bark of candlewood to control *S. zeamais* and *C. maculatus*.

But the questions that remain to be answered are:

1. Candlewood is effective in the laboratory, but will it work in the field?
2. What proportions of leaves, stem and roots would be effective in the field?
3. What is the effect of the effective proportions on the various life stages of *S. zeamais* and *C. maculatus*
4. How persistent are the active components?
5. Which formulation of Candlewood is most effective?

This research therefore sought to answer these questions and fill some of the gaps in our knowledge on the use of candlewood products to control insect pests. The main objective of this research was therefore to find out ways in which parts of Candlewood can be used to achieve maximum control of insects in the field.

Specific objectives were:

1. To determine how best the leaves, bark and roots of candlewood can be put into various proportions to improve efficacy.
2. To determine efficacy in an on-farm storage facility
3. To determine effect on the various life stages of *S. zeamais* and *C. maculatus*.
4. To determine persistency in an on-farm storage facility.
5. To determine the effective formulations of candlewood that can be used against *S. zeamais* and *C. maculatus*.

CHAPTER TWO

2.0 REVIEW OF LITERATURE

2.1 Overview

The battle against pests has been an age-long one, to improve man's welfare and ensure food security. Various practices aimed at managing pest situations through an integrated approach, which advocates for a combination of methods such as cultural, biological, genetic and plant resistance, as well as minimal use of chemical insecticides, have been widely adopted.

The use of botanicals for pest control is an age-long traditional practice, but was neglected at the advent of synthetic insecticides. With the production of Dichloro-diphenyl-trichloroethane (DDT) in 1941, the world saw nothing but an "ideal insecticide" capable of "dealing brutally" with pest organisms in their vast forms and numbers (Kumar, 1987). Thus, the discovery of DDT initially, though to be the universal synthetic panacea against insect attack, proved after prolonged usage to be disastrous (Jacobson, 1989). Most of these synthetic insecticides are toxic to predacious insects and leave toxic residues in food, soil and water bodies, making them unsafe (Rembold, 1994). Other problems associated with indiscriminate use of synthetic pesticides are the destruction of natural enemies of certain insect pests, development of resistant strains of pest species and the high cost of treatment. Carson (1962) warned of the dangers of synthetic insecticides and signaled DDT's practical elimination of living organisms due to high persistence, toxicity, biomagnifications, tendency to cause malignancy, development of resistance in pest

organisms and environmental degradation. Considering the above dangers of synthetic chemical insecticides, attention was once again turned to phytochemicals (van Emden, 1989)

Besides the treatment of grain, the application of residual sprays to grain storage facilities is an integral part of good pest control practice (Williams *et al.*, 1982; Giga and Canhao, 1992). Insecticides, when properly used, will continue to play an important role in reducing storage losses due to insect pest activities (Menn, 1983; Redlinger *et al.*, 1988). Among small-scale farmers in the developing countries, insecticides available on the market are rather expensive and are often not economic to use. The use of conventional synthetic chemicals by farmers therefore is not sustainable and the greatest challenge in stored products protection is to find alternative methods for protecting commodities (Golob, 1997). In West Africa, farmers are resorting to using phosphine to control insect pests. Evidence from Ghana indicates that the use of phosphine is being carried out with no consideration to safety or efficacy. Users have no training and together with their suppliers, usually small-scale wholesalers and retailers, are putting people at risk and greatly increasing the chance of resistance developing (Golob, 1997).

There is a growing interest in the use of natural products to control insects (Cutler, 1988; Hedin, 1990). In stored products, this interest is driven by a need for alternatives to traditional fumigants and residual insecticides that are becoming ineffective due to resistance in insect populations or are no longer available due to regulatory controls or are too expensive (Civerolo *et al.*, 1993).

The plant origin is a vast storehouse of chemicals and offers a wealth of compounds known for their medicinal and insecticidal properties. Natural plant compounds used in the control of insect pests are as varied as the plants from which they have been isolated (Dongdem, 1997). Plants in the families Meliaceae, Labitae, Asteracea, Canellaceas; have been studied extensively for their insecticidal properties (Jacobson, 1989).

To protect extinction, plants have been waging biochemical warfare for thousands of years against insects and herbivores (Alkofahi *et al.*, 1989). Perhaps many plant species, which failed to develop such protective "secondary metabolites", were consumed and made extinct. Thus, plant resistance, one of the main factors of survival of wild plants, can be attributed to several chemical mechanisms. These include the action of toxic substances, hormone mimics, anti-hormones, antifeedants and repellents (Marinibettolo, 1983).

Although there is increasing research into botanicals used for the protection of stored food, these efforts are still inadequate (Dales, 1996). There are difficulties in recommending botanicals as a replacement for chemical insecticides because efficacy levels of botanicals often vary among storage pests, application methods, and stored products (Cobbinah *et al.*, 1999).

Protection of stored products generally involves mixing grains with protectants derived from local plants (Hassanali *et al.*, 1990). Botanical insecticides tend to have broad-spectrum activity, are relatively specific in their mode of action and easy to

process and use (McDonald *et al.*, 1970; Talukder and Howse, 1994). They are also safe to higher animals and the environment (Anon., 1991). Resource-poor farmers and small-scale industries can often easily produce botanical insecticides at the farm level.

2.2 Storage Losses

Insect pest damage to stored grain results in major economic losses to farmers throughout the world (Obeng-Ofori *et al.*, 1997). These losses are diverse and intense, and it is estimated that approximately one-third of the world's food crop is damaged or destroyed by insect pests during growth, harvest and storage (Jacobson, 1985). Insect pests constitute a single most important cause of post-harvest losses in the tropics (Prempeh, 1971), which have been estimated at 20-30% (Dick, 1988). Damage to stored produce cannot be retrieved, thus leading to direct monetary loss, estimated at more than 500 million dollars in the U.S. annually (Oldroyd, 1960).

In the developing countries, food grain production often falls below demand as a result of post-harvest losses caused by pests, poor transportation, handling and processing. The prevailing high temperatures and humid conditions also favour the rapid growth, development and proliferation of storage pests and fungal diseases that cause considerable damage in storage (Mutlu and Hountondji, 1990). In Africa, where subsistence grain production supports majority of the population, grain losses caused by storage insect pests such as *Sitophilus zeamais* and *Callosobruchus maculatus* can be critical (Golob and Tyler, 1994).

Furthermore, approximately 70% of agricultural products in Africa are stored on-farm for periods extending from one harvest to the next and sometimes longer (Golob, 1997). During storage, the produce is susceptible to attack by many different pests of which insects are the most important. In Ghana, about 20% of annual maize and cowpea production of 750 and 300 metric tons respectively are lost to insects (Owusu-Akyaw, 1991).

In the Sahel region, post harvest losses are significant for bagged maize and sorghum because of damage caused by insects and rodents (Alzouma, 1990). On the other hand, beetles cause up to 40% loss of the region's legume production. Despite the fact that cereal production in North Africa is insufficient, this problem is compounded due to losses during post harvest operations, particularly because of pest infestation in storage (Bartali, 1990). In spite of major technological advances in agriculture, the world food deficit situation remains serious (Anon., 1982).

Stored product beetles and moths can cause losses to grain in storage, either directly through consumption of grain, or indirectly by producing "hot spots", causing loss of moisture, and thereby making grain more susceptible to attack by other pests (Longstaff, 1986; Talukder and Howse, 1994). The ability to detect insect pests is fundamental to most recent strategies of stored product insect pest control (Giga and Canhao, 1992). Early warning of pest presence can be used to prevent damage and an efficient detection programme can lead to a reduction in losses and pesticides use.

2.3 *S. ZEAMAIS*

2.3.1 TAXONOMY AND DESCRIPTION OF *S. ZEAMAIS.*

The maize weevil *S. zeamais* Motschulsky (Plate 1) is a member of a triumvirate species in the family *Curculionidae*, sub-family *Calandrinae,* genus *Sitophilus* (Hill, 1983). The body size ranges from 2.4 to 2.5 mm. Body colour ranges from light brown to black with four reddish orange elongate spots on the elytra. The antennae have eight segments and are often carried in extended position when the insect is walking. They have metathoracic flight wings (Dobie, 1991). Both males and females have characteristic rostrum but the latter could be distinguished from the former by the shape and texture of the rostrum, which is smoother, longer, and more curved in the female (Plate 2a) than in the male (Plate 2b) (Kiritani, 1965).

2.3.2 DISTRIBUTION AND DISPERSAL OF *S. ZEAMAIS.*

S. zeamais has a cosmopolitan distribution throughout the tropics and sub-tropics (Southgate *et al.*, 1956). In the field, they are unevenly distributed. Dix and All (1985) carried out intensive sampling of maize fields and reported a clumped distribution of both weevil population and of weevil-infested ears. They suggested that clumping is a response to the release of aggregation pheromone by the first male to colonize the maize plants (there was a male-to-female ratio of 1.6: 1.0 in the weevil population collected from cobs sampled two months before harvest). In most of the fields studied, the weevil-infested ears were in a linear pattern across the field. This may again have resulted from down-wind dispersal of aggregation pheromone from colonizing males. A marked 'edge of field' effect had been noted in some studies of field infestation of *S. zeamais*. Numbers of adult weevils dropped

dramatically 15-30 m from the field border (Giles and Ashman, 1971). Surveys of a number of fields indicated that, even at the margins, the distribution of insects was uneven and was generally determined by the direction and proximity of infested maize stores to the growing crop(Giles and Ashman, 1971). Chesnut (1972) studied the dispersal of *S. zeamais* from a source of infestation using adults marked with a fine paint spray. No marked adults were found on the cobs located more than 400 m from the release point.

2.3.3 FACTORS AFFECTING PRE-HARVEST INFESTATION OF *ZEA MAIS* BY *S. ZEAMAIS*.

2.3.3.1 *Maturity of maize grains*

The ability of *S. zeamais* and other storage pests to infest growing maize plants is influenced by factors related to the maturity of the grains. In Kenya, Giles and Ashman (1971), artificially pollinated maize plants of several varieties, covered the developing ears with cloth bags, and then introduced marked adult *S. zeamais* into the bags at different times after pollination. They observed that the developing period decreased as the crops matured.

2.3.3.2 *Moisture content of maize*

Infestation is high when the moisture content is well above 30%. As the moisture content drops towards the end of the growing season, only damaged grains remain susceptible to attack by the pests. In southwest Nigeria, Markham (1981) examined cobs from a field of maize 3 weeks before the dry-season harvest (late November). He found no evidence of *S. zeamais* infestation of the grains, which had mean

moisture content of 57%. Three weeks later, 45% of the harvested cobs were infested by *S. zeamais*; the moisture content of the grain had by then dropped to 30%. At the wet-season harvest, mean grain moisture was again 30%. However, only 28% of the cobs were infested.

2.3.3.3 *Husk cover*

Another important factor affecting pre-harvest infestation of maize by storage species is the degree to which the maize grains are exposed because of incomplete husk cover. In Kenya, Giles and Ashman (1971) examined maize ears 2 months before harvest. On the average, 7% were infested with *S. zeamais*. When the cobs were divided into categories depending on the degree of protection afforded by the husk, only 1% of the cobs with complete husk cover were infested, whereas 20% of those in which grains could be observed at the tip were infested. Exposing cobs by opening the sheaths at the tips greatly increased the number of weevils caught in the suction trap placed in a maize field (Taylor, 1971). Taylor concluded that exposed ears induced flight activity of *S. zeamais* and thus increased the probability that cobs with short husks would become infested.

2.3.4 LOSSES CAUSED BY *S. ZEAMAIS*

The pest destroys about 8-10% of the world's stored grains (Hill, 1983). The larvae cause the greatest damage because they spend their entire life within the grain by eating voraciously to prepare for the quiescent pupa stage (Dobie *et al.*, 1991).

2.3.5 LIFE HISTORY AND BEHAVIOUR OF *S. ZEAMAIS*.

Hill (1981) reported that the eggs are laid throughout the life of the insect. Fifty per cent may be laid in the first 4-5 weeks. The eggs are laid individually in small cavities chewed into cereal grains by the female and each cavity is sealed and protected by a gelatinous waxy secretion usually referred to as "egg plug" produced by the female. Oviposition rates are at maximum at 70% relative humidity, 20-30 °C and above 10% of moisture content (Dobie, *et al.*, 1991). The eggs hatch into apodous (legless) larvae in 6-7 days after oviposition and begin to feed inside the grain; excavating a tunnel as it develops (Dobie, *et al.*, 1991). The larvae go through 4 instar stages and take 21 days to change into the pupa. The adult develops in about 35 days. The total developmental period ranges from 35 days under optimal conditions of 25°C and 70% relative humidity to over 110 days in unfavourable conditions (Haines, 1991).

2.3.6 CONTROL OF *S. ZEAMAIS*.

2.3.6.1 Chemical control

The use of insecticides to control or reduce storage losses to food crops has become increasingly common. In southern United States, applications of insecticides on growing maize plants, 3 weeks and 7 weeks before harvest, reduced by 90% the number of ears infested with the predominant pest, *Sitophilus zeamais* in comparison with untreated control plants (Evans, 1985). In Zambia, Hindmarsh and MacDonald (1980) reported that admixture of malathion 1% dust, tetrachlorvinphos 3% dust, pirimiphos-methyl 2% dust or fenitrothion 1% dust (2ppm) reduced the percentage of shelled grains with visible insect damage to less than 5%, over a 7 –

month storage period. However, trials in West Africa carried out to test the use of insecticides with improved crib designs, permethrim dust applied to dehusked cobs proved more effective than lindane, bromophos, malathion or pirimiphos-methyl but all treatments resulted in more than 5% damage to grains after 5 months in store (FAO, 1985). Deltamethrin has also been found to be very effective in controlling *S. zeamais* (Evans, 1985).

2.3.6.2 Biological control

A number of species of natural enemies are associated with the indigenous pest found in African maize stores. In an experimental maize crib in Nigeria, distributions of two commonest hymenopteran parasites present, *Chaetospila elegans* and *Cerocephalia dinoderi* (both Pteromalidae) were positively correlated with that of *S. zeamais* and they prey very well on *S. zeamais* (Markham, 1981). Pteromalid, *Anisopteromabus calandrae* (Howard), *Lariophagus distinguendus* (Foster) are also common parasites of *S. zeamais* (Hill, 1983). Dobie (1974) investigated inherent resistance to attack by *S. zeamais* of a large number of genotypes held at Centro International de Majoramiento de Maiz y Trigo (CIMMYT)'s maize seed bank in Mexico. He found out that selection of new, high-yielding cultivars with the 'opaque-2' gene in their genome (conferring to a high lysine and tryptophan content, as well as soft pericarp) is likely to increase the susceptibility of stored maize to *S. zeamais*.

2.3.6.3 Traditional and cultural control of *S. zeamais.*

In India, Su (1977) reported that powdered rhizomes of turmeric, *Curcuma longa* mixed with maize repel *S. zeamais* from eating the maize. Turmeric contains pungent, odoriferous oils and oleoresins but the repellent components are turmerone and ar-turmerone (Su *et al.*, 1982). *Azadirachta indica,* which contains Triterpenoid *azadirachtin* and other related compounds, is reported to have repellent actions against *S. zeamais* (Schumutterer, 1995). In Ghana, storage containers made from large woven baskets, set on poles and covered with a thatched roof reduces field infestation of *S. zeamais* on harvested maize crops (Kumar, 1987). Ground and whole pepper fruits have been used to protect stored products from insect damage (Mould, 1973). Su (1977) found black pepper to be a safe and promising source of naturally occurring insecticide for the control of *S. zeamais* by reducing oviposition and adult emergence. Heating and smoking had been used to control *S. zeamais* in households in Ghana and is achieved by heating to 64 °C for 10 min and cooling at 18 °C for 4 days (Kumar, 1987). Control of some insect pests is achieved by following the principle of growing crops at a time when pests are absent or their numbers are not high. As a result, the most susceptible stage of a crop's development coincides with the time when the pest is least abundant (Kumar, 1987). Endrody-Younga (1968) carried out an extensive study on maize infestation in Central Ashanti, Ghana. He concluded that maize planted at the start of the first rainy season (February through April, when pest numbers are very low), without fertilizer use, insecticide application or irrigation gave higher yield than the average given by FAO (above 1000-kg ha^{-1}) for the country as a whole.

2.4 *C. MACULATUS*

2.4.1 TAXONOMY AND DESCRIPTION OF *C. MACULATUS* (*Coleoptera:Bruchidae*)

The cowpea weevil *C. maculatus* (Plate 3) belongs to the sub-family Bruchinae (Hill, 1983). The body size ranges from 1.9 mm to 2.0 mm, has a brownish colour and a pair of emarginated eyes (Hill, 1983). The insect has strait elytra, which is not able to cover the posterior part of the abdomen completely. The antennae have ten segments but are not capable of being flexed backwards when walking (Dobie, *et al.*, 1991). They have a pair of distinct ridges (inner and outer) on the ventral side and each ridge bears a tooth near the apical end. The inner tooth is triangular and equal to (or slightly longer than) the outer tooth (Booker, 1967). The female can be distinguished from the male by a more smoother and curving antennal segments and strong markings on the elytra consisting of two large lateral dark patches, mid way along the elytra and smaller patches at the anterior and posterior ends, leaving a paler brown cross shaped area covering the rest of the body (Dobie *et al*, 1991).

2.4.2 DISTRIBUTION AND DISPERSAL OF *C. MACULATUS*

C. maculatus has a cosmopolitan distribution throughout the tropics and sub-tropics (Southgate *et al.*, 1957). In the field, they are unevenly distributed and could be aggregated which result from the release of aggregation pheromones from colonizing males or scattered mainly along the margins (Dobie, *et al.*, 1991).

2.4.3 INFESTATION OF *C. MACULATUS*

Field infestation takes place when the grains are matured usually 2-3 weeks before harvest of cowpea and also when the grain moisture is well above 30% (Dobie *et al.*, 1991). According to Southgate (1978), pre-harvest infestation is increased when the grains are exposed as a result of incomplete shell cover.

2.4.4 LOSSES CAUSED BY *C. MACULATUS*

The pest destroys 6-8% of the world's stored cowpea (Hill, 1983). The larvae cause the greatest damage because they can attack very hard grain testa and spend their entire life eating voraciously within the grain to prepare for the quiescent pupa and feedless larvae stages (Dobie *et al.*, 1991).

2.4.5 LIFE HISTORY AND BEHAVIOUR OF *C. MACULATUS*

The adult beetle, which does not feed on stored products, is very short-lived (usually no more than 12 days under optimum conditions) (Hill, 1983). The female can lay as many as 115 small, grey and inconspicuous eggs firmly glued to the surface of the host seed, mostly cowpea (Dobie *et al.*, 1991). Oviposition rates are at maximum at temperatures ranging between 30-35 °C and as the eggs are laid, they are firmly glued to the surface of the host seed (Booker, 1967). Smooth seeded varieties are suitable for oviposition than rough seeded varieties (Haines, 1991). The eggs hatch into scarabaeiform (C-shaped and fat) larvae and bites through the base of the eggs, into the cotyledons. There they feed voraciously within and excavate a chamber as they grow (Dobie *et. al.*, 1991). The larvae develop into the pupae after 20 days and the adult normally emerges after 7 days at optimum conditions (Hill,

1983). The total developmental period ranges from 28 days under optimal conditions of 32°C and 90% relative humidity to 35 days in unfavourable conditions and about six or seven generations in a year are usual (Hill, 1983).

2.4.6 CONTROL OF *C. MACULATUS*

2.4.6.1 *Chemical control*

According to Hill (1983), fumigation with methyl bromide is an effective method of control. However, following an outbreak in Costa Rica in 1974, a more comprehensive investigation of insecticide efficacy against the pest was undertaken. It was found that permethrim, fenvalerate and cypermethrin were very effective in controlling the pest (Dick, 1988).

2.4.6.2 *Biological control*

C. maculatus in commonly parasitised by *Grapholitha glycinivorella* (Hill, 1983). In an experimental bean crip, Southgate (1978) found out that two common parasitic Pteromalid Hymenoptera attack the larvae of *C. maculatus*. These two parasites are *Anisopteromalus calandrae* (Howard) and *Dinarmus basalis* (Rondani).

2.4.6.3 TRADITIONAL AND CULTURAL CONTROL OF *C. MACULATUS*

Ash and sand are some of the local materials used in the control of storage pests in South and West Africa for the protection of cowpea (Poswal and Akpa, 1991). The use of mixture of dried sand and dung ash was capable of causing 80% mortality of *C. maculatus* (Poswal and Akpa, 1991). Ash and sand have no insecticidal properties but fill the space between grains, restricting the movements of adults for egg laying.

They also act as desiccants thus decreasing infestation levels. An ancient method of storing cowpea seeds practiced by the Sayawa people of Bauchi State of Nigeria is by smoking. Cowpea pods are suspended in the kitchen and the smoke completely prevents storage pests from attacking the seed (Poswal and Akpa, 1991). They also observed that a low concentration of powder of *Piper guineenses* significantly reduced oviposition and adult emergence, while oviposition was completely suppressed at concentrations of 42%. Neem extracts have repellent, antifeedant and insecticidal properties, which effectively control *C. maculatus.* Drying of the cowpea in direct sunlight in Ghana reduces the moisture content and appears to be largely effective in minimizing infestation by *C. maculatus* (Obeng-Ofori, 1998).

2.5 INTEGRATED MANAGEMENT OF *C. MACULATUS* AND *S. ZEAMAIS.*

This is an all inclusive term that describes man's continued efforts to control populations of pest species at levels that are advantageous to his well being (Anonymous, 1972). It involves maximum reliance on natural pest population controls along with a combination of techniques such as biological, chemical, traditional and other control methods that lead to the suppression of pests (Kumar, 1987). Dick (1988) reports that the judicious use of contact insecticides such as permethrin and fenvalerate, pheromone-baited traps such as (Z)-9-tetradecenyl and (Z)-9, (E)-12-tetradecadienyl acetate for monitoring, and possibly for control, thermal disinfestations by solar drying, and the use of biological control insecticides such as neemol and pyrithrum (botanicals), *Chaetospila elegans* and *Grapholitha glycinivorella*, as the control techniques in both cowpea and maize farms can produce the greatest results in controlling *C. maculatus* and *S. zeamais.*

2.6 OTHER PESTS OF STORED MAIZE AND COWPEA

Stored maize and cowpea are also attacked by the several insect pests such as *Sitophilus oryzae* (L.), *Rhizopertha dominica* (F.), *Cathartus quandricollis* (Guer), *Gnatocerus maxillosus* (F.), *Tribolium castaneum* (Herbst), *Palorus subdepressus* (Woll), *P. ratzburgii* (Deg), *Araecerus fasciculatus* (Deg.), *Oryzaephilus mercator* (Fauv.), *Brachypeplus pilosellus* Murray, *Sitotroga cerealella* (Oliv.), *Prostephanus truncates* (Horn), *Bruchidius atrolineatus* (Pic.), *Piezotrachelus varium* (Wagner), *P. ratzburgii* (Wissm.), *Tenebroides mauritanicus* (L.), *Plodia interpuctella* (Hubn.), *Lasioderma serricorne* (F.) (Obeng- Ofori, 1998).

2.7 THE CANDLEWOOD, *ZANTHOXYLUM XANTHOXYLOIDES*

2.7.1 Taxonomy, distribution and ecology

The candlewood, *Zanthoxylum xanthoxyloides* Lam., (Plate 4), belongs to the family Rutaceae, which contains about 1700 species placed in 161 genera. It is a shrub that grows to a small tree up to 1.25 m high and 0.13 m girth (Irvine, 1961). The trunk is gray with large woody thorns. The large woody thorns falls later and the trunk becomes covered with thick corky and woody thorns only on older branches. The bark is acid to taste initially and rapidly becomes hot with peppermint aftertaste (Hawthorne, 1990). The leaves when crushed give off an aromatic spicy scent (Irvine, 1961). The seeds are widely used as spices in local cuisines in Asia (Katzer, 2000) that is why the closely related Asian species *Z. pipertitum* is called Sichuan pepper. American *Zanthoxylum* spices have not yet been put to culinary use (Katzer, 2000). The twigs are very thorny and the leaves are pinnate, with three and four pairs of shinning, glabrous, aromatic leaflets that are elliptic to oblong, obtuse and entire with rachis of 10 X 3075 cm and recurred thorns. The midribs are also thorny (Irvine, 1961). The plant flowers between December to March. The flowers are small, numerous and white with dense terminal panicles. The fruits are brown and often split into two to produce one shinny blue-black seed that has a spicy taste (Irvine, 1961).

The tree is widely grown in closed and savanna forest habits, and sometimes in coastal thickets (Nakanishi and Suzuki, 1998). It also thrives well on drier and well-drained soils (Neumann and MullerHaude, 1999).

Local names mostly reflect the potential of the species in this genus (Table 1). Most importantly, in Hausa, *Z. xanthoyloides* is called 'Fasa Kwari' which means 'Kills insects' (Gazama, pers. Comm) (Table 1). The plant is very medicinal, being used to treat many ailments (Dalziel, 1937; Keharo and Bouquet, 1950 and Irvine, 1961).

Several plant metabolites have been identified in *Z. xanthoxyloides* (Table 2)

The insecticidal property of candlewood was first reported against *C. maculatus* (Escoubas *et al.*, 1994; Ogunwolu and Idowu, 1994; Ogunwolu and Odunlami, 1996). Following this, promising results were obtained in a trial against several stored product pests (Osafo, 1998). Based on these results, Udo (2000) set out to investigate the efficiency of candlewood against three stored product pests: *S. zeamais, C. maculatus* and *T. castaneum*. This study showed that the bark and roots were the most effective plant parts, against the above-mentioned pests providing up to 100% protection of cowpea and maize.

2.7.2 UTILIZATION OF *Z. XANTHOXYLOIDES*

The seeds of *Z. xanthoxyloides* are used for making necklaces in Senegal (Irvine, 1961). The ripe seeds serve as pepper and for flavouring butter, while the dried and pulverised leaves are sometimes used in West Africa to flavour food in Cote d'Ivoire (Dalziel, 1937). The leaves are fed to sheep in certain Ga villages in Ghana (Irvine, 1961). The wood is yellow, hard, durable and resistant to termites

and as such used for building purposes. It makes excellent firewood as it contains an inflammable resin. The young shoots are used as chewing sticks and as bitters.

The medicinal values of the plant have long been known as various parts of the plants have long been used to treat many ailments. The pounded roots, sometimes mixed with guinea grass or capsicum peppers, are used to control stomachaches. The powdered roots are used in French West Africa against ulcers, sores, including syphilitic sores, and leprous ulceration (Kerharo and Bouquet, 1950). The roots are boiled with cereals and used for the treatment of fever, as vermifuge and with other drugs to treat paralysis. Pulverized roots, sometimes mixed with other hot species are, commonly placed in carious teeth as a remedy for toothache. The bark can also be made into poultice and applied against rheumatism and swellings (Dalziel, 1937).

In Ghana, post-delivery pains are relieved by an extract of the root in rum (Irvine, 1961). The plant has antiseptic and analgesic properties. It has been reported that the bark decoction is used as an enema for an unspecified purpose and the juice of the bark for eye diseases, especially purulent conjunctivitis (Irvine, 1961).

TABLE 1

Vernacular names of *Z. xanthoxyloides*

Tribe	Local name	Source
Twi	Okanto, Yea, Bebun	Tufour, pers. comm.
Fanti	Kanfu	Kuukua, pers. comm.
Ga	Haatsho	Lydia, pers. comm.
Ewe	Xe, Xeti	Micheal, pers. comm.
Nzema	Ayenle, Ayinle	Fiifi, pers. comm.
Hausa	Faskori, Fasa Kwari	Gadzama, pers comm

Table 2

Secondary Plant metabolites in *Z. xanthoxyloides.*

Secondary Metabolite	**Source**
Alkaloids	Henry (1949)
Atarine	Henry (1949)
Fagaridine	Irvine (1961)
Pseudo-fagarol	Irvine (1961)
Tannin & Saponin	Irvine (1961)
Zantocylol	Elujoba & Nagels (1985)
Pellitorine	Ginesta *et. al* (1994)
Fagaramide	Ginesta *et. al* (1994)

PLATE 1 *SITOPHILUS ZEAMAIS* ADULT

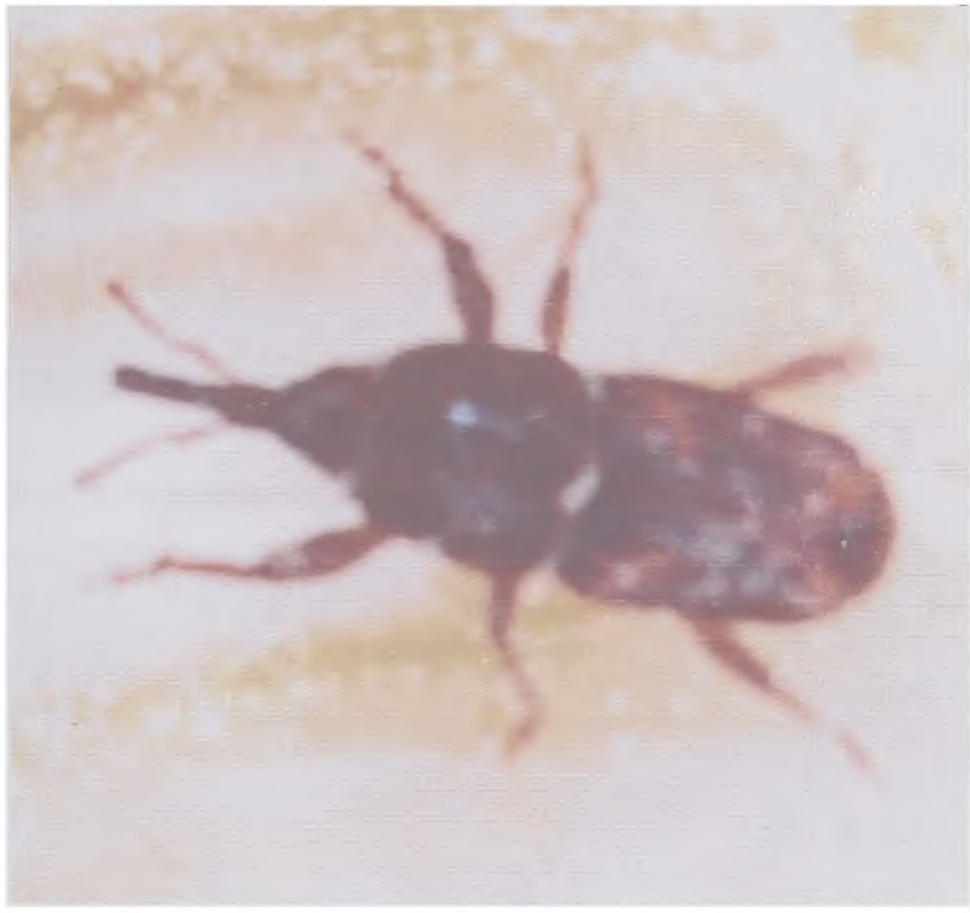

PLATE 2a ROSTRUM OF FEMALE *SITOPHILUS ZEAMAIS*

PLATE 2B ROSTRUM OF MALE *SITOPHILUS ZEAMAIS*

PLATE 3 *CALLOSOBRUCHUS MACULATUS* ADULT

PLATE 4 LEAVES AND THORNY WOODY STEMS OF CANDLEWOOD
ZANTHOXYLUM XANTHOXYLOIDES

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 GRAINS

Maize and cowpea used for this investigation were bought from the Madina Market in Accra. The grains were sterilized in an oven at 40°C for six hours and then kept in the freezer at –4°C till when they were used, to prevent any reinfestation (Owusu, pers. comm.).

The quantity to be used was removed and kept in the rearing room where the environment was controlled for one week under culture conditions of 28± 2°C, 68 ± 2% RH and 12L:12D photo regime. This was to allow the grains to equilibrate. (Weaver *et al.*, 1994; Osafo, 1998; Udo 2000).

3.2 CULTURING OF INSECTS

3.2.1 *S. ZEAMAIS*

Insects were collected from a stock culture kept in a laboratory at the Department of Zoology of the University of Ghana.

About 500 insects were introduced into 500g of pre-equilibrated grains in a kilner jar (Plate 5) and covered with muslin cloth held in place by rubber band. The set up was left in the controlled environment room at 28± 2°C, 68% R.H and 12L: 12D photo regime (Weaver, 1994; Osafo, 1998; Udo, 2000).

After two weeks of oviposition, the adults were sieved out with an impact test sieve. This was to enable the production of progeny that was to be used to establish a main culture with subsequent reculturing after every eight weeks, so that insects of about the same age were always available for the various experiments.

3.2.2 *C. MACULATUS*

C. maculatus were collected from stock cultures kept at the same laboratory at the Department of Zoology of the University of Ghana.

About 500 insects were introduced into 500 g of sterilized and pre-equilibrated cowpea in a kilner jar (Plate 6) covered with muslin cloth and held in place with rubber band. The cultures were left undisturbed in the insectary, maintained at 28± 2°C, 68 ±2% RH and 12L: 12D photo regime. The adults were removed after two weeks, by which time they had laid eggs. Progeny that emerged were sieved and used for subcultures for the various experiments.

3.3 COLLECTION AND PREPARATION OF PLANT MATERIALS

Leaves, roots and bark of *Z. xanthoxyloides* were collected from the University of Ghana farm at Legon, Accra. The materials were dried in a room and pounded into smaller pieces using a mortar and pestle. The poundered pieces were further milled into powder using a milling machine at the Nutrition and Food Science Department, University of Ghana. The powdered materials were then

sieved with an impact test sieve with mesh size of 710μ to obtain fine powder for the different tests (Plate 7).

3.3.1 PROPORTIONS

The powdered materials were used as dusts mixed with grains at 5% concentrations (wt/wt) (Udo, 2000).

The proportions were in the form of mixtures of:
(i).

Leaves (%)	Roots (%)
60	40
70	30
80	20
90	10
100	0
0	100

(ii).

Leaves (%)	Bark (%)
60	40
70	30
80	20
90	10
0	100

These were tested at 5% concentrations (wt/wt) against 40 mixed sex adults of *S. zeamais* and *C. maculatus* in 5 kg. of maize and cowpea respectively in jute sacks in the laboratory (Plate 8). Each proportion was replicated five times and mortality was observed daily for one week. The observation was done by sieving out each of the five replicates for each treatment using an impact test sieve and then counting the number of dead and alive insects. Insects were considered

dead if they did not respond to three probings of a blunt forceps. Loss assessment of the grains was determined using the F.A.O. (1985) count and weigh method:

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

Where U = weight of undamaged grains

D = weight of damaged grains

Nd = No. of damaged grains

Nu = No. of undamaged grains

The most effective proportions were then tested in an on-farm storage facility at the same concentration where mortality and loss due to insect damage were assessed weekly for one month.

The proportions that proved most effective in the field were further prepared in suitable formulations for application. In this case, the materials were applied as tablets.

3.3.2 PREPARATION OF TABLETS

The tablets were prepared at the Zoology Department of the University of Ghana. Roots, bark and leaves of *Z. xanthoxyloides* were chopped into smaller pieces and 250 g of each of these parts was mixed with 70% methanol in a 500-litre glass jar. The mixture was left in darkness for three days. The methanol

solution was evaporated using a rotary evaporator (Plate 9) to remove the methanol at 30°C-40°C with rotary speed of 3-6 rpm for 8 hours according to the procedure of Godefroot *et al.* (1981). The extracts were stored in a refrigerator at 8°C (Ofuya and Okuku, 1994).

Some 3% of agar was prepared as follows: 3 g of agar was boiled with 100ml of distilled water in a water bath for 30 minutes. Based on concentrations used by Udo (2000) and also concentrations used in earlier trials carried out in the laboratory, the extracts were mixed up in proportions of:

(i) leaves and roots, in ratios of (2.2ml leaves to 1.8ml roots), (2.4ml leaves to 1.6ml roots), (2.6ml leaves to 1.4ml roots) and (2.8ml leaves to 1.2ml roots).

(ii) leaves and bark, in ratios of (2.2ml leaves to 1.8ml bark), (2.4ml leaves to 1.6ml bark), (2.6ml leaves to 1.4ml bark) and (2.8ml leaves to 1.2ml bark).

The mixtures were then poured in small airtight containers with dimensions of 3.5cm in diameter and 3.0cm in height. One millilitre of the hot agar solution was mixed with each of the extracts in the airtight containers. The mixtures were then left to cool down at room temperature into solid tablets with the containers tightly closed (Plate 10). The weight of the tablet was

10.0 g; the weight of the extracts in each tablet was 8.0 g and the weight of the agar in each tablet was 2.0g. The tablet had a diameter of 3.5cm and a width of 1cm (Plate 11).

The type of agar used was LAM M™ Agar No. 1 MC 2 manufactured by the International Diagnostic Group plc. It had a weight of 500g with the typical analysis as presented in Table 3. Five tablets of the various concentrations were placed at the bottom of the sacks containing the grains and then left in the controlled experimental room (Plate 8). Mortality was observed daily for one week to determine the effective tablet concentration.

3.4 ON- FARM STORAGE FACILITY.

This is a ventilated crib made of wooden strips of about three meters tall and divided into four compartments of one meter wide. It is situated on the University of Ghana farm, Legon. (Plate 12). The following tests described earlier were carried out in the crib: persistency test, testing of effective proportions of the dust and the tablets, testing for the effects of the dust and the tablets on the eggs and immature stages of the insects, and experiments to determine the protection ability of the dust and the tablets on the grains against insect attack.

3.5 TESTS OF DUST AND TABLETS

3.5.1 PERSISTENCY TEST

Five kilograms of maize and cowpea were each admixed with the effective powdered dusts at 5% concentrations wt/wt. This was placed in a 35 cm by 45 cm jute bags and placed in the laboratory and in the crib.

Each treatment was replicated five times in the laboratory and in the crib. Two other sets of replicates of both the maize and cowpea treatments were also placed in the laboratory and in the crib. 20 *S. zeamais* adults were put into one set of replicates of the maize treatments and *20 C. maculatus* adults were also put into one set of replicates of the cowpea treatments. These were left in the laboratory and in the crib for one month after which the insects were sieved out and the number of dead and alive insects recorded. Twenty new *S. zeamais* and *C. maculatus* adults were put in the second set of replicates of the maize and cowpea treatments respectively and the insects were sieved out after another one month. The numbers of dead and alive insects were also recorded. The same procedure was repeated for the third set of replicates of both the maize and cowpea treatments after the second month, until such period that the treatments were no longer effective in controlling the insects. The period was recorded.

The same procedure was used to test the persistency of the tablets but in this case five tablets were put in each jute bag and the testing period was done weekly for three weeks in the laboratory.

3.5.2 EFFECT OF THE DUST ON EGGS.

Five kilograms each of the equilibrated maize and cowpea placed in the jute sacs were infested with 100 adults of *S. zeamais* and *C. maculatus* respectively to allow for egg laying. The parent adults were removed after seven days. The grains were then treated with the effective powdered proportions the following day. Each treatment was replicated three times. No treatment was added to the control. Adults emerging subsequently were sieved and counted after four weeks (Su, 1977). This was done both in the laboratory and on the field.

3.5.3 EFFECT OF THE DUST ON LARVAE

Five kilograms each of the equilibrated maize and cowpea placed in the jute sacs were infested with 100 adults of *S. zeamais* and *C. maculatus* respectively to allow for egg laying. The parent adults were removed after seven days. The grains were then treated with the effective powdered dust proportions after one week. Each treatment was replicated three times. No treatment was added to the control. Adults emerging subsequently were sieved and counted after four weeks (Su, 1977). This was done both in the laboratory and on the field.

3.5.4 EFFECT OF THE DUST ON PUPAE

Five kilograms each of the equilibrated maize and cowpea placed in the jute sacs were infested with 100 adults of *S. zeamais* and *C. maculatus* respectively to allow for egg laying. The parent adults were removed after seven days. The grains were then treated with the effective powdered dust proportions after twenty-eight days in the case of *S. zeamais* and after twenty days in the case of *C. maculatus*. Each treatment was replicated three times. No treatment was added to the control. Adults emerging subsequently were sieved and counted after four weeks (Su, 1977). This was done both in the laboratory and on the field.

3.5.5 REPELLENCY TEST OF TABLETS

Repellency test was assessed in a choice bioassay method using grains treated with the *Z. xanthoxyloides* tablets. Ten grammes of the grains were treated with the tablets and a control of another 10 g of grains was placed on a clean filter paper adjacent to each other. This was replicated twice. Some 10 adult *S. zeamais* and *C. maculatus* were introduced onto each experimental set separately. The number of insects present on the control (N_c) and treated (N_t) grains were recorded after one hour. Percentage repellency (PR) was computed as:

$$PR = \frac{Nc - Nt}{Nc + Nt} \times 100$$

The data were analysed using ANOVA after transformation into arcsine values. All negative PR values were treated as zero (Obeng-Ofori *et al.*, 1997).

3.6 MORTALITY ASSESSMENT

Each replicate of the various treatments was sieved out and the number of dead and alive insects counted. Percentage mortality was calculated from the formula:

$$\frac{\text{Number of dead insects}}{\text{Total number of insects}} \times 100\%$$

The percentage mortalities were corrected using the Abbott's (1925) formula:

$$P = \frac{O - C}{100 - C} \times 100\%$$

where, P = corrected mortality

O = observed mortality

C = 'controlled mortality'

3.7 DATA ANALYSIS

Data involving counts were transformed using square root ($Y = \sqrt{x}$) while those involving percentages were transformed using arcsine $Y = \text{Sin}^{-1}(\sqrt{x}/100)$ transformation before the data was analyzed using ANOVA (Udo, 2000). The transformation was to avoid the effect of zero counts and extreme values on the analysis. In all cases, mean separation was done using LSD.

TABLE 3

TYPICAL ANALYSIS OF AGAR

Gel strength (Nika)	650-100g/m^2
Melting point	88-95 °C
Setting point	32-35 °C
pH	7.0 7.4
Moisture	6 - 8 %
Total ash	2 – 3 %
Calcium	< 0.02 %
Magnesium	< 0.03 %
Sodium chloride	< 0.05 %

PLATE 5 *SITOPHILUS ZEAMAIS* REARED ON MAIZE

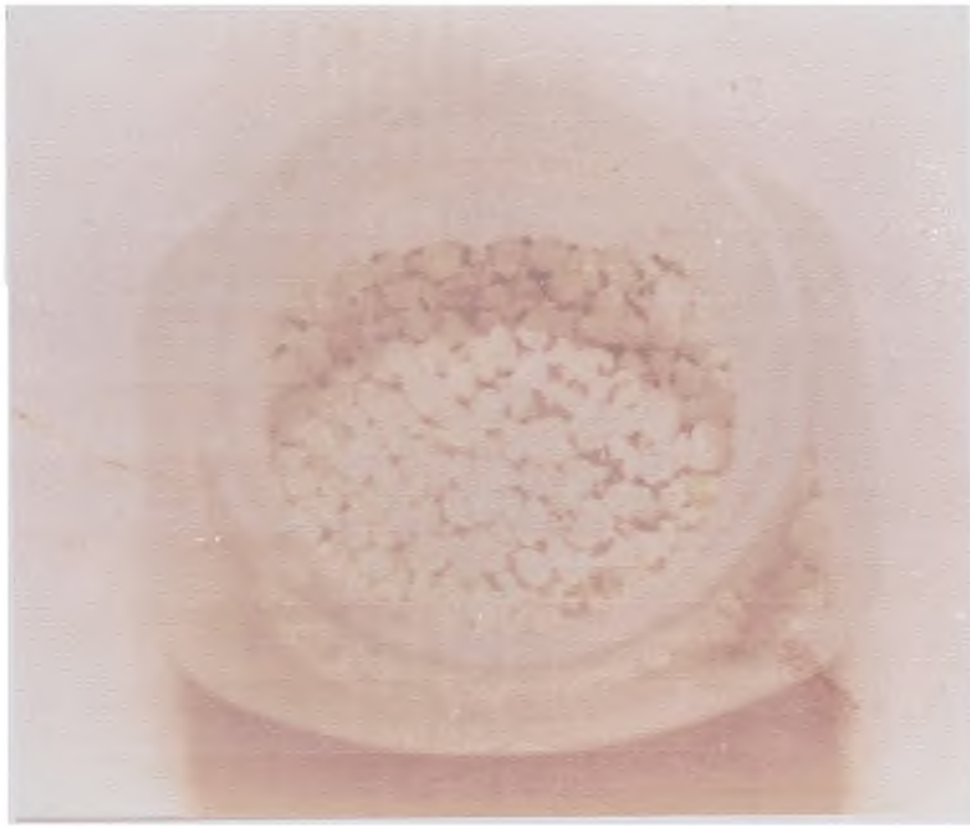

PLATE 6 *CALLOSOBRUCHUS MACULATUS* REARED ON COWPEA

PLATE 7

POWDERED *Z. XANTHOXYLOIDES* STORED IN AIR TIGHT BOTTLES

PLATE 8

CONTROLLED EXPERIMENTAL ROOM SHOWING JUTE BAGS CONTAINING GRAINS ARRANGED ON SHELVES.

PLATE 9

ROTARY EVAPORATOR USED FOR EVAPORATING *Z. XANTHOXYLOIDES* EXTRACTS.

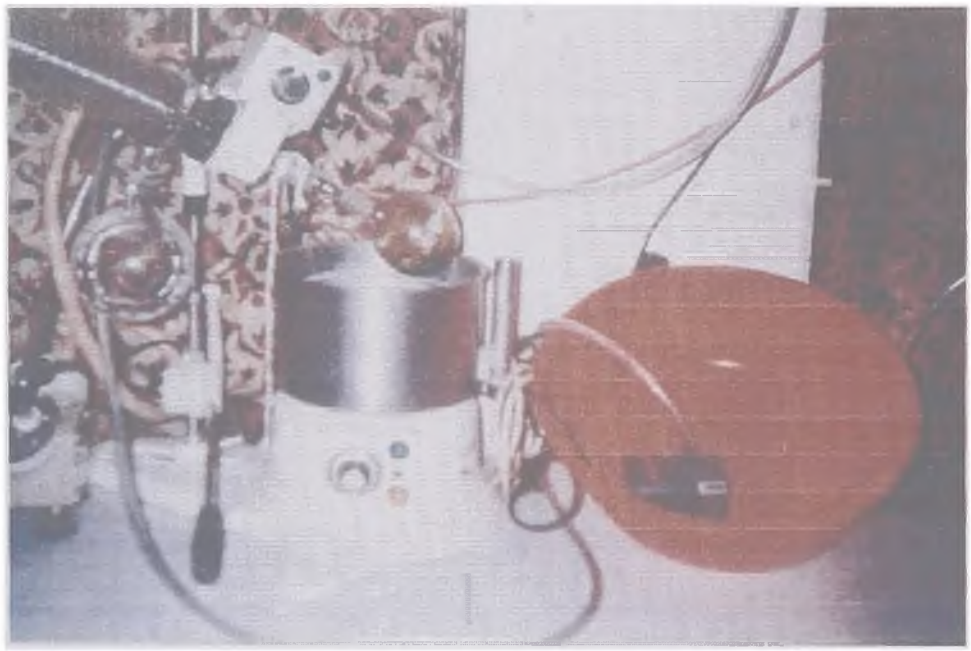

PLATE 10

AIR-TIGHT CONTAINERS USED IN PREPARING THE *Z. XANTHOXYLOIDES* TABLETS

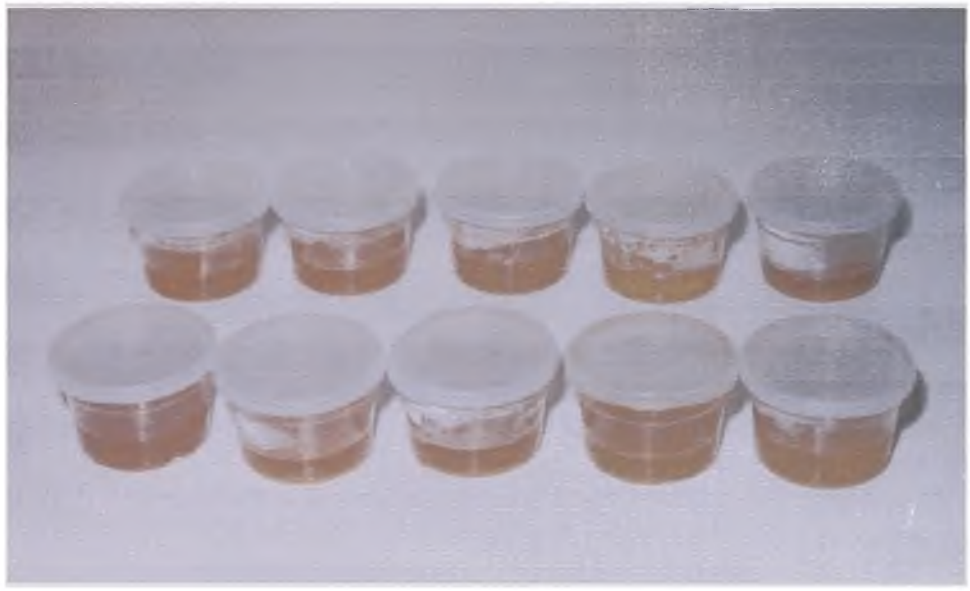

PLATE 11

***Z. XANTHOXYLOIDES* TABLETS REMOVED FROM THEIR CONTAINERS AND DISPLAYED ON A PLAIN SHEET**

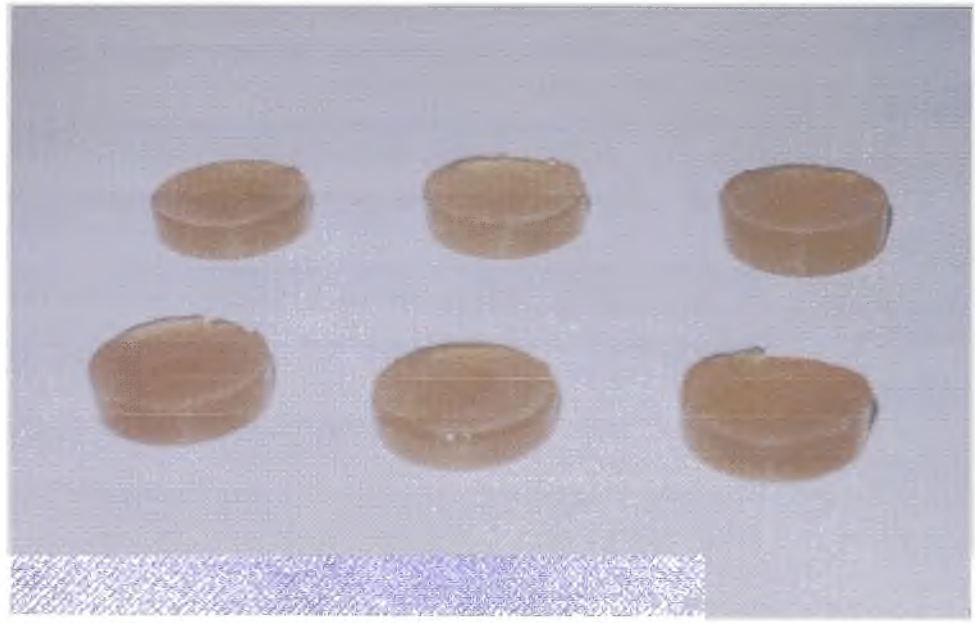

PLATE 11

***Z. XANTHOXYLOIDES* TABLETS REMOVED FROM THEIR CONTAINERS AND DISPLAYED ON A PLAIN SHEET**

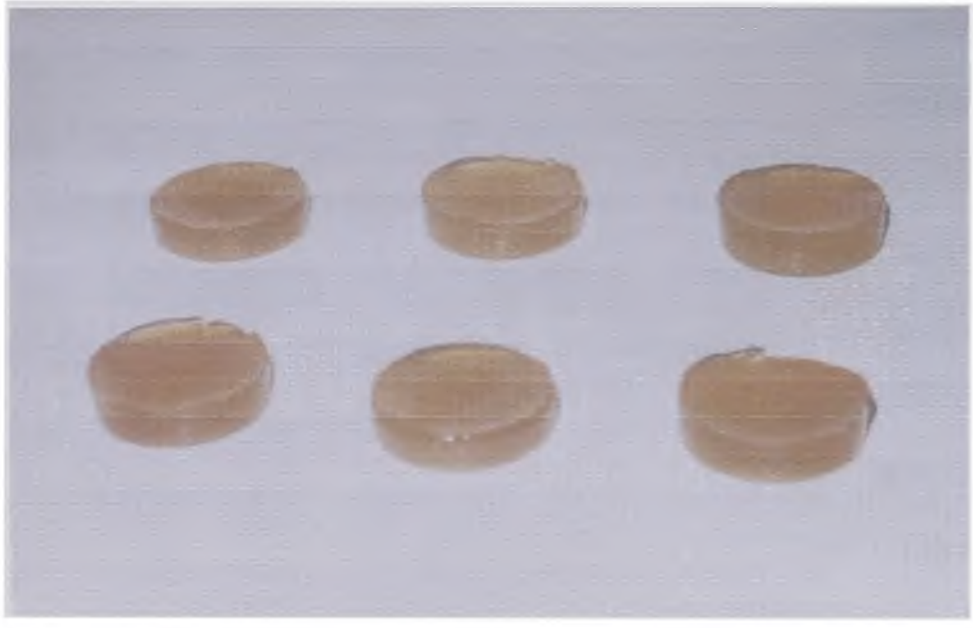

PLATE 12

ON-FARM STORAGE FACILITY (WOODEN CRIB) USED FOR STORING GRAINS ON THE FARM.

CHAPTER 4

4.0 RESULTS

4.1 Yield of extracts

The percentage yield of methanol extracts from the various parts of *Z. xanthoxyloides* is shown in Fig.1. The extracts were insoluble in acetone but soluble in water. The roots gave the highest yield of 31%. This was followed by the bark, which gave 24%, and then the leaves gave 19%. Estimation of the yield was done by first weighing the various parts of the plant from which the extracts were taken. It was then concentrated by evaporating to dryness and the concentrate weighed to determine the percentage of the product present.

4.2 Toxicity of various proportions of dry ground plant material

Comparing the control to the various proportions in Table 4, it can be observed that all the proportions showed various levels of bioactivity against *S. zeamais* and *C. maculatus*. There was a significant difference ($P < 0.001$) in mortality of both insects against the various treatments with the roots and bark causing above 70% mortality. Further tests conducted on the adult *S. zeamais* and *C. maculatus* using various proportions showed that 60% leaves and 40% bark, 70% leaves and 30% bark, 60% leaves and 40% roots, and 70% leaves and 30% roots induced 60% mortality after 1 week.

4.3 Toxicity of various concentrations of the tablets

Table 5 shows the percentage mortalities of *S. zeamais* and *C. maculatus* in grains treated with different concentrations of *Z. xanthoxyloides* tablets. The various tablet concentrations showed some level of bioactivity against the two insect pests. Toxicity increased with increasing concentrations of the bark and root extracts. There was a significant difference ($P < 0.001$) in mortality of both insects against the various treatments with the 2.2 ml leaves and 1.8 ml roots, 2.4 ml leaves and 1.6 ml roots, 2.2 ml leaves and 1.8 ml bark and 2.4 ml leaves and 1.6 ml bark tablet concentrations being the most effective. The 2.2 ml leaves and 1.8 ml roots induced the highest mortality of nearly 50 percent and the 2.8 ml leaves and 1.8 ml bark gave a mortality of almost 10 percent.

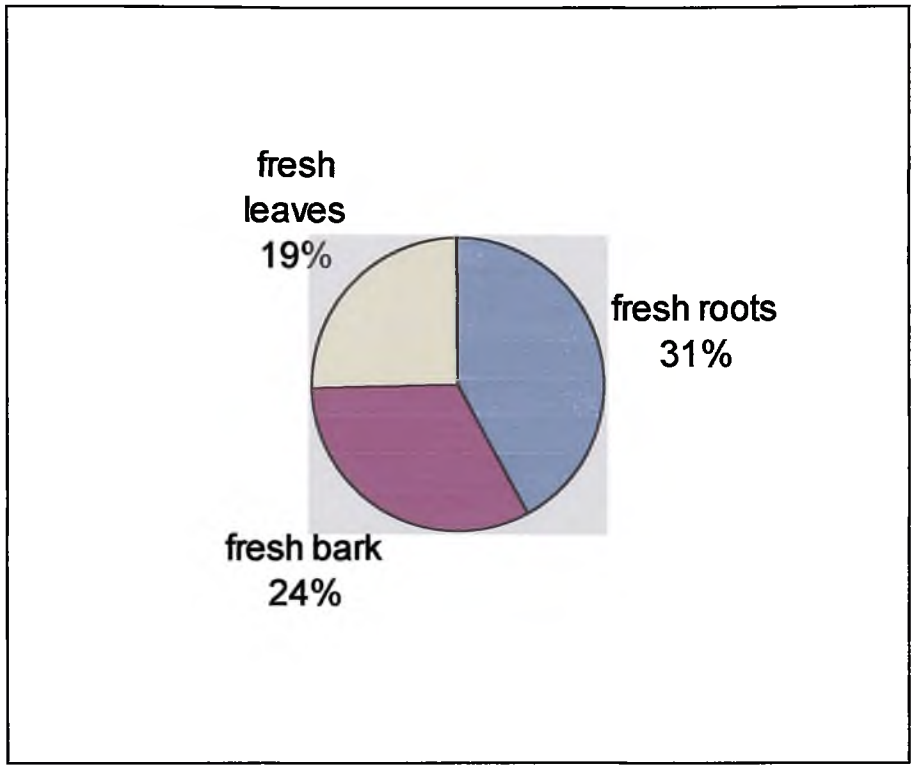

FIG. 1 PERCENTAGE YIELD OF EXTRACTS OF DIFFERENT PARTS OF THE *Z. XANTHOXYLOIDES*

TABLE 4

PRELIMINARY INVESTIGATION OF THE MOST TOXIC DUST PROPORTION OF *Z. XANTHOXYLOIDES.*

MORTALITY ON THE SEVENTH DAY OF APPLICATION OF *Z. XANTHOXYLOIDES* POWDER

LABORATORY RESULTS

Treatment	Mean percentage mortality ± S.E *S. zeamais*	*C. maculatus*
60% L, 40% B	57.0 ± 3.4	78.0 ± 2.5
70% L, 30% B	51.0 ± 4.0	70.0 ± 2.2
80% L, 20% B	26.0 ± 1.9	56.0 ± 4.8
90% L, 10% B	21.0 ± 1.9	31.0 ± 1.9
60% L, 40% R	55.0 ± 3.5	67.0 ± 2.0
70% L, 30% R	69.0 ± 4.3	66.0 ± 4.3
80% L, 20% R	18.0 ± 1.2	32.0 ± 2.5
90% L, 10% R	11.0 ± 1.9	20.0 ± 3.5
100% L	10.0 ± 2.7	20.0 ± 1.6
100% B	70.0 ± 1.6	71.0 ± 2.9
100% R	72.0± 2.5	70.0 ± 1.6
Control	2.00 ± 1.2	2.0 ± 1.2
LSD (P< 0.001)	7.72	8.00

FIELD RESULTS

Treatment	Mean percentage mortality (± S.E) *S. zeamais*	*C. maculatus*
60% L, 40% B	63.0 ± 2.0	67.0 ± 3.0
70% L, 30% B	56.0 ± 3.3	65.0 ± 3.5
60% L, 40% R	65.0 ± 3.2	68.0 ± 2.5
70% L, 30% R	58.0 ± 4.1	65.0 ± 3.7
Control	2.0 ± 1.2	2.0 ± 1.2
LSD (P < 0.01)	8.13	8.65

Mean of five replicates of 20 insects.

60%L, 40%B= concentration of 60 percent leaves and 40 percent bark,
70%L, 30%R= concentration of 70 percent leaves and 30 percent root,
100%B = concentration of 100 percent bark.

TABLE 5

PRELIMINARY INVESTIGATION OF THE MOST TOXIC *Z. XANTHOXYLOIDES* TABLET.

MORTALITY ON THE SEVENTH DAY OF APPLICATION OF *Z. XANTHOXYLOIDES* TABLET

Treatment	LABORATORY RESULTS Mean percentage mortality ± S.E *S. zeamais*	*C. maculatus*
2.2 ml L, 1.8 ml R	37.60 ± 2.80	47.20 ± 1.90
2.4 ml L, 1.6 ml R	30.20 ± 3.00	41.80 ± 4.30
2.6 ml L, 1.4 ml R	17.80 ± 1.70	35.00 ± 3.60
2.8 ml L, 1.2 ml R	10.80 ± 1.60	12.80 ± 1.10
2.2 ml L, 1.8 ml B	39.60 ± 2.90	44.80 ±3.50
2.4 ml L, 1.6 ml B	34.40 ± 3.80	40.20 ± 3.00
2.6 ml L, 1.4 ml B	13.40 ± 2.00	20.20 ± 2.00
2.8 ml L, 1.2 ml B	9.60 ± 1.00	15.60 ± 1.80
Control	0.20± 0.20	0.40 ± 0.40
LSD (P < 0.001)	6.79	8.38

Mean of five replicates of 20 insects.

2.2 ml L, 1.8 ml R= tablet concentration of 2.2 ml leaves and 1.8 ml root extracts,
2.8 ml L, 1.2 ml B= tablet concentration of 2.8 ml leaves and 1.2 ml bark extracts,
2.4 ml L, 1.6 ml R= tablet concentration of 2.4 ml leaves and 1.6 ml root extracts.

4.4 Damage assessment of *Z. xanthoxyloides* dust .

Grains treated with dry ground material showed significant difference ($P < 0.001$) among the treatments in the reduction of the damage caused by *S. zeamais* and *C. maculatus* (Table 6). The control recorded a damage of over 12% during the trial period. Dry bark and roots provided almost complete protection to the grains against infestation by the two stored product pests by providing about 99% protection. Other tests conducted using 60% leaves and 40% bark, 70% leaves and 30% bark, 60% leaves and 40% roots, and 70% leaves and 30% roots provided about 96% protection to the grains in both the laboratory and on the field.

4.5 Damage assessment of *Z. xanthoxyloides* tablets .

The protective potential provided by the *Z. xanthoxyloides* tablets is shown in Table 7. There was a significant difference ($P < 0.001$) between the treatments in the reduction of the damage caused by the two stored product pests. The 2.2 ml leaves and 2.8 ml root tablets provided the highest protection of 96 percent and the 2.8 ml leaves and 1.2 ml bark provided the lowest protection of 91 percent. Percentage weight loss due to insect activities was used to determine the control.

TABLE 6

Effect of *Zanthozylum xanthoxyloides* on damage caused by *S. zeamais* and *C. maculatus*

LABORATORY RESULTS

Treatment	Mean percentage weight loss ± S.E *S. zeamais*	*C. maculatus*
60% L, 40% B	3.81 ± 0.50	3.85 ± 0.54
70% L, 30% B	4.70 ± 0.53	4.11 ± 0.42
60% L, 40% R	3.96 ± 0.42	3.75 ± 0.44
70% L, 30% R	4.29 ± 0.23	4.33 ± 024
100% L	8.12 ± 0.31	7.70 ± 0.33
100% B	0.98 ± 0.13	1.00 ± 0.13
100% R	1.05 ± 0.11	1.06 ± 0.34
Control	12.94 ± 0.24	12.63 ± 0.22
LSD (P< 0.01)	0.96	0.98

FIELD RESULTS

Treatment	Mean percentage weight loss (± S.E) *S. zeamais*	*C. maculatus*
60% L, 40% B	4.29 ± 0.41	4.17 ± 0.23
70% L, 30% B	4.58 ± 0.14	4.42 ± 0.20
60% L, 40% R	4.31 ± 0.23	4.34 ± 0.22
70% L, 30% R	4.30 ± 0.24	4.50 ± 0.20
100% L	8.49 ± 0.21	8.24 ± 0.24
100% B	1.12 ± 0.13	1.06 ± 0.14
100% R	1.67 ± 0.10	1.32 ± 0.22
Control	13.65 ± 0.60	14.74 ± 0.73
LSD (P < 0.01)	0.87	0.89

Mean of four replicates of 20 insects.

60%L, 40%B= concentration of 60 percent leaves and 40 percent bark,
70%L, 30%R= concentration of 70 percent leaves and 30 percent root,
100%B = concentration of 100 percent bark.

Table 7

Effect of *Z. xanthoxyloides* tablets on damage caused by *S. zeamais* and *C. maculatus*

Laboratory results
Mean percentage weight loss (± S.E)

Treatment	*S. zeamais*	*C. maculatus*
2.2 ml L, 1.8 ml R	4.83 ± 0.3	5.18 ± 0.3
2.4 ml L, 1.6 ml R	5.70 ± 0.2	5.73 ± 0.1
2.6 ml L, 1.4 ml R	7.08 ± 0.3	7.63 ± 0.3
2.8 ml L, 1.2 ml R	7.95 ± 0.3	8.20 ± 0.2
2.2 ml L, 1.8 ml B	5.35 ± 0.2	5.25 ± 0.3
2.4 ml L, 1.6 ml B	6.50 ± 0.4	6.35 ± 0.2
2.6 ml L, 1.4 ml B	8.03 ± 0.2	7.48 ± 0.3
2.8 ml L, 1.2 ml B	7.90 ± 0.4	8.05 ± 0.2
Control	12.68 ± 0.2	12.80 ± 0.2
LSD (P < 0.001)	0.81	0.69

Mean of five replicates of 20 insects.

2.2 ml L, 1.8 ml R= tablet concentration of 2.2 ml leaves and 1.8 ml root extracts,
2.8 ml L, 1.2 ml B= tablet concentration of 2.8 ml leaves and 1.2 ml bark extracts,
2.4 ml L, 1.6 ml R= tablet concentration of 2.4 ml leaves and 1.6 ml root extracts.

4.6 Effect of *Z. xanthoxyloides* dust on eggs and immature stages

Grains treated with dry ground plant material significantly ($P < 0.001$) affected the eggs and the immature stages of both insects in the laboratory and on the field as summarized in (Tables 8a and 8b). Maize treated after 28 days of adult removal and cowpea treated after 20 days of adult removal, recorded the highest number of emergence than in treatments applied earlier than 28 days and 20 days respectively.

TABLE 8 a

MEAN NUMBERS OF *S. ZEAMAIS* AND *C. MACULATUS* ADULTS THAT EMERGED FROM GRAINS TREATED WITH *Z. XANTHOXYLOIDES* DUST AFTER DIFFERENT DAYS OF ADULT REMOVAL

LABORATORY RESULTS

(DAYS):	1	7	28
S. zeamais			
Control	1137.5 ± 108.7	1078.0 ± 67.6	1505.2 ± 167.9
60% L, 40% B	57.0 ± 8.7	63.7 ± 3.8	118.2 ± 6.8
70% L, 30% L	63.7 ± 3.7	74.2 ± 3.41	135.0 ± 3.5
60% L, 40% R	46.5 ± 7.1	51.7 ± 9.8	126.0 ± 7.6
70% L, 30% R	60.7 ± 11.1	49.0 ± 10.1	133.0 ± 9.3
100% L	148.5 ± 5.8	147.8 ± 4.8	292.8 ± 16.3
100% B	17.5 ± 1.7	8.5 ± 1.0	64.7 ± 5.6
100% R	12.3 ± 1.3	14.5 ± 1.6	48.5 ± 10.6
LSD (P< 0.01)	113.6	71.7	175.1

C. maculatus

(DAYS):	1	7	20
Control	1447.0 ± 134.1	1112.0 ± 84.3	1688.5 ± 31.9
60% L, 40% B	53.7 ± 6.8	61.7 ± 5.6	96.2 ± 2.5
70% L, 30% B	53.2 ± 6.5	49.7 ± 4.9	110.5 ± 13.8
60% L, 40% R	57.0 ± 8.1	39.0 ± 9.9	99.7 ± 10.4
70% L, 30% R	53.5 ± 4.1	49.5 ± 5.5	126.0 ± 8.8
100% L	132.0 ± 4.5	130.0 ± 6.8	234.3 ± 38.5
100% B	14.0 ± 1.9	12.3 ± 1.7	50.5 ± 4.1
100% R	14.3 ± 1.3	14.5 ± 2.3	43.7 ± 7.6
LSD (P< 0.01)	139.2	88.5	56.1

Mean of four replicates of 20 insects.

60%L, 40%B= concentration of 60 percent leaves and 40 percent bark,
70%L, 30%R= concentration of 70 percent leaves and 30 percent root,
100%B = concentration of 100 percent bark.

TABLE 8 b

MEAN NUMBERS OF *S. ZEAMAIS* AND *C. MACULATUS* ADULTS THAT EMERGED FROM GRAINS TREATED WITH *Z. XANTHOXYLOIDES* DUST AFTER DIFFERENT DAYS OF ADULT REMOVAL

FIELD RESULTS

(DAYS):	1	7	28
S. zeamais			
Control	1267.7 ± 112.3	1235 ± 113.1	1564.0 ± 45.1
60% L, 40% B	58.5 ± 7.8	62.0 ± 6.5	128.8 ± 8.9
70% L, 30% B	60.7 ± 5.3	57.7 ± 4.6	196.8 ± 39.1
60% L, 40% R	60.5 ± 7.4	47.5 ± 5.1	130.3 ± 6.1
70% L, 30% R	53.0 ± 8.9	53.7 ± 8.3	128.3 ± 9.2
100% L	139.3 ± 12.9	131.8 ± 14.1	323.3 ± 23.7
100% B	15.0 ± 1.3	10.5 ± 1.6	45.5 ± 2.9
100% R	13.5 ± 1.9	14.5 ± 2.9	55.0 ± 5.5
LSD (P< 0.01)	117.7	118.3	68.2

(DAYS):	1	7	20
C. maculatus			
Control	1039.8 ± 77.6	1159.0 ± 75.3	1479.5 ± 215.5
60% L, 40% B	47.5 ± 6.1	50.5 ± 5.6	96.5 ± 7.2
70% L, 30% B	50.5 ± 5.9	45.5 ± 5.3	104.8 ± 9.5
60% L, 40% R	46.8 ± 6.4	50.3 ± 6.9	133.0 ±10.3
100% L	128.8 ± 5.0	133.0 ± 4.7	288.0 ± 22.0
100% B	17.5 ± 1.0	19.3 ± 0.85	64.3 ± 3.4
100% R	15.3 ± 1.3	18.3 ± 1.3	53.8 ± 12.8
LSD (P < 0.01)	81.9	79.3	224.9

Mean of four replicates of 20 insects.

60%L, 40%B= concentration of 60 percent leaves and 40 percent bark,
70%L, 30%R= concentration of 70 percent leaves and 30 percent root,
100%B = concentration of 100 percent bark.

4.7 Repellency bioassay of tablets

The various concentrations of the tablets showed various levels of repellence to both *S. zeamais* and *C. maculatus* (Table 9). *S. zeamais* was least repelled with the highest repellence of 32% in the 2.2ml leaves and 1.8ml roots tablet and the lowest repellence of 9% in the 2.8ml leaves and 1.2ml bark tablet. *C. maculatus* was repelled most. It recorded its highest repellence of 69% in the 2.2ml leaves and 1.8ml bark tablet and its lowest repellence of 19% in the 2.8ml leaves and 1.2ml roots tablet.

TABLE 9

Mean % repellency (pr) values for the tablets against *S. zeamais* and *C. maculatus* in the choice test

	Mean % repellency (PR)	
TABLET CONCENTRATION	***S. ZEAMAIS***	***C. MACULATUS***
2.2ml leaves and 1.8ml roots	32 ± 0.23	62 ± 0.31
2.4ml leaves and 1.6ml roots	30 ± 1.21	56 ± 1.06
2.6ml leaves and 1.4ml roots	30 ± 0.11	28 ± 0.92
2.8ml leaves and 1.2ml roots	16 ± 0.14	19 ± 1.04
2.2ml leaves and 1.8ml bark	23 ± 1.15	69 ± 0.05
2.4ml leaves and 1.6ml bark	19 ± 0.01	57 ± 1.39
2.6ml leaves and 1.4ml bark	10 ± 0.62	50 ± 0.93
2.8ml leaves and 1.2ml bark	9 ± 1.80	44 ± 1.68
LSD (P< 0.05)	5.32	13.98

2.2 ml L, 1.8 ml R= tablet concentration of 2.2 ml leaves and 1.8 ml root extracts,
2.8 ml L, 1.2 ml B= tablet concentration of 2.8 ml leaves and 1.2 ml bark extracts,
2.4 ml L, 1.6 ml R= tablet concentration of 2.4 ml leaves and 1.6 ml root extracts.

4.8 PERSISTENCY TESTS OF *Z. XANTHOXYLOIDES* DUST

Ground *Z. xanthoxyloides* powder was able to protect the grains for two months. From Tables 10a and 10b, the 100% leaves treatments provided the lowest protection to both the maize and cowpea in both the laboratory and on the field while the greatest protection was provided by the 100% roots treatments in the first and the second months. During the third month, the number of insects found alive in all the treatments was almost the same as the control at $P<0.001$.

4.9 PERSISTENCY TESTS OF *Z. XANTHOXYLOIDES* TABLETS

All the *Z. xanthoxyloides* tablets were toxic and repellent to both *S. zeamais* and *C. maculatus* during first week of application irrespective of the dosage. The effectiveness of the tablets was significantly ($P< 0.001$) reduced to approximately zero during the second and third week of application irrespective of the dosage. From Table 11, there was no significant mortality in the insect pests after the second and third week as compared to the control.

TABLE 10 a

PERSISTENCY TEST OF *Z. XANTHOXYLOIDES* DUST

MEAN NUMBER OF ADULTS FOUND ALIVE AFTER EACH MONTH

LABORATUORY RESULTS

	FIRST MONTH	SECOND MONTH	THIRD MONTH
S. zeamais			
Control	86.80 ± 3.10	76.80 ± 6.70	86.21 ± 3.10
60% L, 40% B	4.40 ± 1.20	9.80 ± 0.90	68.2 0± 3.30
70% L, 30% B	4.60 ± 2.10	9.20 ± 1.10	68.40 ± 4.10
60% L, 40% R	6.60 ± 1.90	10.00 ± 0.70	69.60± 4.60
70% L, 30% R	6.00 ± 1.50	8.00 ± 1.30	61.20± 4.30
100% L	10.80 ± 0.9	11.80 ± 1.40	81.60 ± 5.20
100% B	1.80 ± 0.7	5.80 ± 1.10	69.80± 5.70
100% R	1.20 ± 0.6	5.20 ± 0.90	68.00± 4.60
LSD (P< 0.01)	4.87	7.38	12.74

MEAN NUMBER OF ADULTS FOUND ALIVE AFTER EACH MONTH

LABORATORY RESULTS

	FIRST MONTH	SECOND MONTH	THIRD MONTH
C. maculatus			
Control	80.80± 3.70	81.20± 5.90	82.80 ± 3.80
60% L, 40% B	2.20 ± 1.10	7.40 ± 1.10	61.60± 4.30
70% L, 30% B	2.00 ± 0.70	9.00 ± 0.80	63.00 ± 4.70
60% L, 40% R	1.00 ± 0.80	7.40 ± 1.10	61.60± 6.30
70% L, 30% R	1.60 ± 0.50	8.60 ± 1.20	60.40± 5.20
100% L	9.40± 1.20	15.00 ± 1.00	78.80 ± 3.90
100% B	0.80 ± 0.60	9.60± 1.00	50.40± 4.90
100% R	1.40 ± 0.70	9.20± 1.20	44.80± 3.80
LSD (P< 0.01)	4.39	6.65	13.53

60%L, 40%B= concentration of 60 percent leaves and 40 percent bark,
70%L, 30%R= concentration of 70 percent leaves and 30 percent root,
100%B = concentration of 100 percent bark.

TABLE 10 b

FIELD RESULTS

MEAN NUMBER OF ADULTS FOUND ALIVE AFTER EACH MONTH

	FIRST MONTH	SECOND MONTH	THIRD MONTH
S. zeamais			
Control	83.40 ± 4.30	78.40± 6.90	87.40± 3.30
60% L, 40% B	1.80 ± 0.70	9.00 ± 0.70	68.00± 8.10
70% L, 30% B	2.00 ± 1.00	8.20± 1.50	75.60 ± 3.70
60% L, 40% R	5.20± 1.70	8.40± 0.90	69.00± 6.10
70% L, 30% R	6.40 ± 1.60	8.00 ± 0.80	69.40± 5.00
100% L	9.80 ± 1.10	14.00± 0.70	78.40± 6.50
100% B	2.20 ± 0.90	9.20 ± 1.20	60.60± 5.10
100% R	1.40 ± 0.70	8.00± 1.10	87.40± 8.70
LSD (P< 0.01)	5.35	7.59	17.54

FIELD RESULTS

MEAN NUMBER OF ADULTS FOUND ALIVE AFTER EACH MONTH

	FIRST MONTH	SECOND MONTH	THIRD MONTH
C. maculatus			
Control	80.20± 4.70	83.60± 6.50	82.80± 3.30
60% L, 40% B	2.20 ± 0.90	8.60 ± 1.40	61.60± 7.80
70% L, 30% B	2.00 ± 0.70	9.60± 1.60	63.00 ± 5.10
60% L, 40% R	1.00± 0.50	9.00± 1.40	61.60± 5.60
70% L, 30% R	2.40 ± 0.50	9.80 ± 1.40	60.40± 6.40
100% L	9.40± 1.60	14.00± 0.70	78.80± 4.50
100% B	2.20 ± 0.60	11.40 ± 1.30	50.40± 7.60
100% R	2.00 ± 0.70	7.80± 0.70	44.80± 3.50
LSD (P< 0.01)	5.35	7.47	13.53

60%L, 40%B= concentration of 60 percent leaves and 40 percent bark,
70%L, 30%R= concentration of 70 percent leaves and 30 percent root,
100%B = concentration of 100 percent bark.

Table 11
PERSISTENCY OF *Z. XANTHOXYLOIDES* TABLETS
Laboratiory results
MEAN NUMBER OF ADULTS FOUND ALIVE AFTER EACH WEEK

S. zeamais

Treatment	First week	Second week	Third week
2.2 ml L, 1.8 ml R	9.00 ± 1.50	19.67 ± 0.30	20.00 ± 0.00
2.4 ml L, 1.6 ml R	10.33 ± 1.20	20.00 ± 0.00	20.00 ± 0.00
2.6 ml L ,1.4 ml R	12.33 ± 0.30	20.00 ± 0.00	19.67 ± 0.30
2.8 ml L, 1.2 ml R	13.67 ± 0.90	20.00 ± 0.00	20.00 ± 0.00
2.2 ml L, 1.8 ml B	7.33 ± 0.90	20.00 ± 0.00	20.00 ± 0.00
2.4 ml L, 1.6 ml B	8.67 ± 1.20	19.67 ± 0.30	20.00 ± 0.00
2.6 ml L, 1.4 ml B	13.00 ± 0.60	20.00 ± 0.00	20.00 ± 0.00
2.8 ml L, 1.2 ml B	17.00 ± 0.60	19.67 ± 0.30	20.00 ± 0.00
Control	20.00 ± 0.00	20.00 ± 0.00	19.33 ± 0.70
LSD (P < 0.001)	2.72	0.57	0.74

C. maculatus

MEAN NUMBER OF ADULTS FOUND ALIVE AFTER EACH WEEK

Treatment	First week	Second week	Third week
2.2 ml L, 1.8 ml R	7.00 ± 0.60	20.00 ± 0.00	20.00 ± 0.00
2.4 ml L, 1.6 ml R	8.67 ± 1.80	20.00 ± 0.00	20.00 ± 0.00
2.6 ml L ,1.4 ml R	11.00 ± 1.50	19.67 ± 0.30	20.00 ± 0.00
2.8 ml L, 1.2 ml R	16.33 ± 1.50	20.00 ± 0.00	20.00 ± 0.00
2.2 ml L, 1.8 ml B	7.33 ± 1.30	20.00 ± 0.00	20.00 ± 0.00
2.4 ml L, 1.6 ml B	8.33 ± 1.50	20.00 ± 0.00	20.00 ± 0.00
2.6 ml L, 1.4 ml B	14.67 ± 1.80	20.00 ± 0.00	20.00 ± 0.00
2.8 ml L, 1.2 ml B	16.33 ± 1.50	20.00 ± 0.00	20.00 ± 0.00
Control	20.00 ± 0.00	19.67 ± 0.30	20.00 ± 0.00
LSD (P < 0.001)	4.08	0.47	0.00

Mean of five replicates of 20 insects.

2.2 ml L, 1.8 ml R= tablet concentration of 2.2 ml leaves and 1.8 ml root extracts,

2.8 ml L, 1.2 ml B= tablet concentration of 2.8 ml leaves and 1.2 ml bark extracts,

2.4 ml L, 1.6 ml R= tablet concentration of 2.4 ml leaves and 1.6 ml root extracts.

CHAPTER 5

5.0 DISCUSSION

5.1 Toxicity of ground materials

The dry ground materials obtained from the leaves, bark and roots of *Z. xanthoxyloides* were toxic to *S. zeamais* and *C. maculatus.* According to Adesina (1986), the high toxicity of the dry root and bark may be attributed to the presence of secondary metabolites, which are highly pungent. The toxicity of the secondary metabolites was evident in the various proportions prepared since the effective ones were the 60% leaves and 40% roots; 70% and 30% roots; 60% leaves and 40% bark and 70% leaves and 30% bark (Table 4). Zanthoxylol (Elujoba and Nagels, 1985) has been identified as a phenolic compound known for insecticidal activities (Wongo, 1998). Phenols are generally known to be an important source of potent bactericides, herbicides, fungicides and insecticides for pest control (Obeng-Ofori *el al.*, 1997). According to Bekele (1994), some secondary plant metabolites may act as both insecticides and antifeedant. Thus, a combination of more leaves and less bark or roots of *Z. xanthoxyloides* can be used to achieve maximum control of insect pests without destroying the plant. This can therefore be used to reduce the overuse of harmful synthetic insecticides to control stored maize and cowpea.

5.2 Antifeedant activity of *Z. xanthoxyloides*

From Table 5, it can be observed that dry, ground leaf; bark and root of *Z. xanthoxyloides* reduced the feeding activity and damage caused by *S. zeamais* and *C. maculatus* at 5% (wt/wt) concentration with the roots and bark giving nearly 100% protection of the grains. The 60% leaves and 40% roots, 70% leaves and 30% roots, 60% leaves and 40% bark, and 70% leaves and 30% bark significantly reduced insect damage and increased insect mortality and this suggests that the plant acted as an antifeedant (Nawrot *et al.*, 1988; Bekele, 1994; Niber, 1994). The lowest protection offered by the leaves suggests that probably that part of the plant has low presence of secondary plant metabolites. This shows that *Z. xanthoxyloides* can be an essential supplement for synthetic insecticides and poor resource farmers could use its powder in traditional post-harvest systems in Africa to protect grains.

5.3 Effect of *Z. xanthoxyloides* powder on eggs and immature stages

Z. xanthoxyloides powder greatly reduced the number of emergence in adults form within 7 days after oviposition. The high activity of the powder may be due to a phenolic constituent which has been reported to inhibit the development of *C. maculatus* (Wongo, 1998). The high number of adult emergence recorded in the treatment after 28 days of oviposition as in the case of *S. zeamais* and 20

days of oviposition as in the case of *C. maculatus* suggest that the secondary metabolites may not have had an effect on the beetles because at that time, majority of the eggs would have developed into pupae. The probable reason is that the pupal cases of the beetles might have offered protection against the insecticidal action of the plant. The inhibition of development of the eggs and immature stages within the grain kernels increases the protection potential of the *Z. xanthoxyloides* against insect damage in storage and can also provide poor-resource farmers an idea as to which stage of infestation they can protect their grains against, using *Z. xanthoxyloides*, since the plant has only ovicidal and lavicidal action.

5.4 Persistency of *Z. xanthoxyloides* dust

From Tables 8a and 8b, the persistence of *Z. xanthoxyloides* dust was for two months. The loss of activity after the second month may be attributed to evaporation and degradation of the chemicals in the plant. The persistency could be enhanced by developing suitable formulations or combining with natural plant oils in simple mixtures (Obeng-Ofori *et al.*, 1997). In traditional post-harvest systems in Africa however, powdered dust formulations from *Z. xanthoxyloides* may be economical since the farmers themselves can produce it locally. Thus, *Z. xanthoxyloides* could be used to reduce food insecurity caused by insects in grains on the African continent.

5.5 Toxicity of *Z. xanthoxyloides* tablets

The *Z. xanthoxyloides* tablets showed various levels of toxicity to *S. zeamais* and *C. maculatus*. The 2.2 ml leaves and 2.8 ml roots tablets induced the highest mortality of 47 percent in the *C. maculatus* and the 2.2 ml leaves and 2.8 ml bark tablets induced the highest mortality of 40 percent in the *S. zeamais.* These levels are low compared to the percentage mortalities obtained by the dust. The low levels of toxicity could be attributed to loss of some toxic volatile constituents through volatilization and during hardening of the tablets (Bekele, 1994) and extraction (Obeng-Ofori, 1997). According to Udo (2000), the reduced susceptibility of the *S. zeamais* to the toxic effect of the tablets may depend on the size of the insect, adaptive physiology and mode of action of the active component of the fumigant. The reduced susceptibility of the insects to the toxic effects of the tablets may be attributed to the fact that response of insects to toxic effects of plant metabolites depends on their sex, size, age and physiological status (Busvine, 1971). As observed in the dust, beetles killed in treated grains had their metathoracic wings unfolded and stretched outside the elytra. This, according to Obeng-Ofori *et al.* (1997), probably suggests that, toxicity was not due to only ingestion of treated grains but also due to inhalation of toxicants. Ryan and Byrne (1988) attributed the toxicity of several terpenoids, representing a wide range of functional groups including Zanthoxylol, Atarine, Gamma-fagaronine and Pseudo-fagarol to their reversible competitive inhibition

of acetyl cholinesterase by apparently occupying the hydrophobic site of the enzyme's active centre.

5.6 Effect of *Z. xanthoxyloides* tablets on feeding activity of *S. zeamais* and *C. maculatus*.

The *Z. xanthoxyloides* tablets provided different levels of activity in protecting the grains against insect attack. The 2.2 ml leaves and 2.8 ml root tablets provided the highest protection of 96 percent for the maize and the 2.8 ml leaves and 1.2 ml bark provided the lowest protection of 91 percent for the cowpea. The protection of the grains coupled with the mortalities observed suggests the antifeedant properties in the plant (Udo, 2000). The low protection observed in the tablets as compared to the dust could be attributed to the loss of toxic volatile secondary constituents during drying and extraction process of the tablets (Bekele, 1994). Though the dust offered a much higher protection than the tablets, it may not be much preferred by consumers since it leads to qualitative losses. Thus, the toxicity of the tablets could further be improved for protection against post- harvest damage caused by insects. According to Casida (1990), the bioactivity of the different parts of the plant against stored product insects may depend on several factors, including chemical composition, species susceptibility and variation in insect behaviour.

5.7 Repellency of the *Z. xanthoxyloides* tablets

The various tablets were repellent to both *S. zeamais* and *C. maculatus*. *S. zeamais* adults were least repelled as compared to *C. maculatus*. The difference in repellence may be attributed to the fact that the immature stages of the *S. zeamais* is always found within the grains whiles both the immature and mature stages of *C. maculatus* is always confined to the surface of the grains. The repellent effect of the tablet may be attributed to the presence of secondary metabolites in *Z. xanthoxyloides*. According to Bekele (1994), secondary plant metabolites have been shown to have both attractive and repellent properties. This repellent action coupled with its inhibition of development of eggs and immature stages within the grains and progeny emergence increases the protectant potential of the plant against insect damage in storage. However, a detailed investigation of the individual constituent of the plant would shed more light on the protection potential of the plant.

5.8 Persistency of *Z. xanthoxyloides* tablets

Effect from *Z. xanthoxyloides* tablets was persistent for only one week. The highly significant loss of activity after the first week (as explained earlier for the dust) may be attributed to rapid evaporation and degradation of the chemical constituents in the tablets. This may be related to the physico-chemical behaviour of the compounds to the grains. Most unprocessed foodstuffs, such as

maize and cowpea, lack polar surfaces to which treated chemical may be bound to reduce its volatilization (Weaver *et al.*, 1994).

Botanicals, represent an important potential for Integrated Pest Management Strategies in developing countries because they have a broad spectrum action, based on local materials and potentially less expensive to the traditional farmer (Obeng-Ofori *et al.*, 1997). A lot of these botanicals are safe to the environment and man, mammals and beneficial arthropods (Talukder and Howse, 1994).

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

The results obtained from this study have shown that *Z. xanthoxyloides* has insecticidal, antifeedant, ovicidal, lavicidal and repellent properties against some stored product beetle pests. The study has also shown that the dust formulation is more effective as a toxicant, grain protectant and highly persistent than the tablet formulation (fumigation). Candlewood was also found to be effective in the field. The most effective proportions of the dust were 60% leaves and 40% roots, 70% leaves and 30% roots, 60% leaves and 40% bark and 70% leaves and 30% bark. Whilst the effective tablet concentrations were 2.2 ml leaves and 1.8 ml roots, 2.4 ml leaves and 1.6 ml roots, 2.2 ml leaves and 1.8 ml bark and 2.4 ml leaves and 1.6 ml bark.

It is recommended that, an extensive study be made to improve the efficacy of the tablets since grains treated with tablets do not lead to qualitative losses as compared to those treated with the dust. An extensive work should also be made on the biological active compounds in *Z. xanthoxyloides* for the control of not only stored product pests but also other household pests. Furthermore, secondary plant metabolites do not always have the same concentration throughout the year. Research should therefore be conducted at different seasons of the year to determine the peak period of activity of the secondary metabolites.

Further work should focus on the precise mode of action of the active components, its penetration into the insect cuticle and grain as well as the metabolic targets in the insect body.

It is also recommended that since the LD_{50} of various proportions of extracts and dust mixed together cannot be determined, the LT_{50} of the effective proportions should be determined in order to get the minimum amount of the biopesticide that can achieve maximum control.

In order to incorporate the use of the plant products into Integrated Pest Management Strategies, the residue levels on crops, its effect on beneficial arthropods as well as its toxicological effect on mammals fed on treated grains need to be investigated.

Finally, local initiatives aimed at preparation of this traditional botanical insecticide that is cheap, readily available, effective, less toxic to mammals and environmental friendly at the farm level, should be promoted for resource-poor farmers who have no access to commercial pesticides or cannot afford them.

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APPENDIX

ANALYSIS FOR FIELD EXPERIMENT

***** Analysis of variance *****

Variate: % Mortality (*Sitophilus zeamais*) 7th day

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	4	13954.00	3488.50	91.80	<.001
Residual	20	760.00	38.00		
Total	24	14714.00			

***** Tables of means *****

Variate: % Mortality (*Sitophilus zeamais*) 7th day

Grand mean 48.8

Treatment	C60lvs 40bark	C70lvs 30bark	C60lvs 40roots	C70lvs 30roots
	63.0	56.0	65.0	58.0

Treatment	Control
	2.0

*** Least significant differences of means ***

Table	Treatment
rep.	5
d.f.	20
l.s.d.	8.13

***** Analysis of variance *****

Variate: % Mortality (*Callosobruchus maculatus*) 7th day

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	4	16666.00	4166.50	96.90	<.001
Residual	20	860.00	43.00		
Total	24	17526.00			

***** Tables of means *****

Variate: % Mortality (*Callosobruchus maculatus*) 7th day

Grand mean 53.6

Treatment	C60lvs 40bark	C70lvs 30bark	C60lvs 40roots	C70lvs 30roots
	67.0	65.0	68.0	66.0

Treatment	Control
	2.0

*** Least significant differences of means ***

Table	Treatment
rep.	5
d.f.	20
l.s.d.	8.65

***** Analysis of variance *****

Variate: % Mortality (*Sitophilus zeamais*) 7th day

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	11	32688.33	2971.67	80.59	<.001
Residual	48	1770.00	36.88		
Total	59	34458.33			

***** Tables of means *****

Variate: % Mortality (*Sitophilus zeamais*) 7th day

Grand mean 35.83

Treatment	C60lvs 40bark	C70lvs 30bark	C80lvs 20bark	C90lvs 10bark
	57.00	49.00	26.00	21.00

Treatment	C100lvs	C60lvs 40roots	C70lvs 30roots	C80lvs 20roots
	10.00	55.00	39.00	18.00

Treatment	C90lvs 10roots	C100roots	C100bark	Control
	11.00	72.00	70.00	2.00

*** Least significant differences of means ***

Table	Treatment
rep.	5
d.f.	48
l.s.d.	7.722

***** Analysis of variance *****

Variate: % Mortality (*Callosobruchus maculatus*) 7th day

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	11	36854.58	3350.42	84.64	<.001
Residual	48	1900.00	39.58		
Total	59	38754.58			

***** Tables of means *****

Variate: % Mortality (*Callosobruchus maculatus*) 7th day

Grand mean 48.58

Treatment	C60lvs 40bark	C70lvs 30bark	C80lvs 20bark	C90lvs 10bark
	78.00	70.00	56.00	31.00

Treatment	C100lvs	C60lvs 40roots	C70lvs 30roots	C80lvs 20roots
	20.00	67.00	66.00	32.00

Treatment	C90lvs 10roots	C100roots	C100bark	Control
	20.00	70.00	71.00	2.00

*** Least significant differences of means ***

Table	Treatment
rep.	5
d.f.	48
l.s.d.	8.001

***** Analysis of variance *****

Variate: Dry ground material (250g / 5000g) of grains)
Percentage weight loss (*Sitophilus zeamais*) (Laboratory)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	7	430.0417	61.4345	141.54	<.001
Residual	24	10.4174	0.4341		
Total	31	440.4591			

***** Tables of means *****

Variate: Dry ground material (250g / 5000g) of grains)
Percentage weight loss (*Sitophilus zeamais*) (Laboratory)

Grand mean 4.98

Treatment	C60lvs 40bark	C70lvs 30bark	C100lvs	C100bark	C60lvs 40root
	3.81	4.70	8.12	0.98	3.96

Treatment	C70lvs 30root	100root	Control
	4.29	1.05	12.94

*** Least significant differences of means ***

Table	Treatment
rep.	4
d.f.	24
l.s.d.	0.961

***** Analysis of variance *****

Variate: Dry ground material (250g / 5000g) of grains)
Percentage weight loss (*Callosobruchus maculatus*)(Laboratory)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	7	403.6545	57.6649	126.85	<.001
Residual	24	10.9105	0.4546		
Total	31	414.5651			

***** Tables of means *****

Variate: Dry ground material (250g / 5000g) of grains)
Percentage weight loss (*Callosobruchus maculatus*)(Laboratory)

Grand mean 4.80

Treatment	C60lvs 40bark	C70lvs 30bark	C100lvs	C100bark	C60lvs 40root
	3.81	4.11	7.70	1.00	3.75

Treatment	C70lvs 30root	100root	Control
	4.33	1.06	12.63

*** Least significant differences of means ***

Table	Treatment
rep.	4
d.f.	24
l.s.d.	0.984

***** Analysis of variance *****

Variate: Dry ground material (250g / 5000g) of grains)
Percentage weight loss (*Sitophilus zeamais*)(Field)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	7	455.9198	65.1314	184.29	<.001
Residual	24	8.4819	0.3534		
Total	31	464.4017			

***** Tables of means *****

Variate: Dry ground material (250g / 5000g) of grains)
Percentage weight loss (*Sitophilus zeamais*)(Field)

Grand mean 5.30

Treatment	C60lvs 40bark	C70lvs 30bark	C100lvs	C100bark	C60lvs 40root
	4.29	4.58	8.49	1.12	4.31

Treatment	C70lvs 30root	100root	Control
	4.30	1.67	13.65

*** Least significant differences of means ***

Table	Treatment
rep.	4
d.f.	24
l.s.d.	0.868

***** Analysis of variance *****

Variate: Dry ground material (250g / 5000g) of grains)
Percentage weight loss (*Callosobruchus maculatus*)(Field)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	7	540.8941	77.2706	205.95	<.001
Residual	24	9.0045	0.3752		
Total	31	549.8986			

***** Tables of means *****

Variate: Dry ground material (250g / 5000g) of grains)
Percentage weight loss (*Callosobruchus maculatus*)(Field)

Grand mean 5.35

Treatment	C60lvs 40bark	C70lvs 30bark	C100lvs	C100bark	C60lvs 40root
	4.17	4.42	8.24	1.06	4.34

Treatment	C70lvs 30root	100root	Control
	4.50	1.32	14.74

*** Least significant differences of means ***

Table	Treatment
rep.	4
d.f.	24
l.s.d.	0.894

***** Analysis of variance *****

Variate: Numbers of *Sitophilus zeamais* adults produced in dry ground materials treated grains at different times of adult removal. (Laboratory)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatmen	7	14286192.	2040885.	267.83	<.001
Residual	72	548643.	7620.		
Total	95	15381400.			

***** Tables of means *****

Variate: Numbers of *Sitophilus zeamais* adults produced in dry ground materials treated grains at different times of adult removal. (Laboratory)

Grand mean 227.7

Treatmen	C60lvs 40bark	C70lvs 30bark	C100lvs	C100bark	C60lvs 40root
	79.7	91.0	196.3	33.6	74.7

Treatment	C70lvs 30root	100root	Control
	80.9	25.1	1240.3

Days	Day1	Day7	Day14
	193.0	187.2	302.9

Treatment	Days	Day1	Day7	Day14
C60lvs 40bark		57.0	63.7	118.2
C70lvs 30bark		63.7	74.2	135.0
C100lvs		148.5	147.8	292.8
C100bark		17.5	18.5	64.7
C60lvs 40root		46.5	51.7	126.0
C70lvs 30root		60.7	49.0	133.0
100root		12.3	14.5	48.5
Control		1137.5	1078.0	1505.2

*** Least significant differences of means ***

Table	Treatment	Days
rep.	12	32
d.f.	72	72
l.s.d.	71.04	43.50

***** Analysis of variance *****

Variate: Numbers of *Callosobruchus maculatus* adults produced in dry ground materials treated grains at different times of adult removal (Laboratory)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	7	19142787.	2734684.	575.77	<.001
Residual	72	341972.	4750.		
Total	95	20225770.			

***** Tables of means *****

Variate: Numbers of *Callosobruchus maculatus* adults produced in dry ground materials treated grains at different times of adult removal (Laboratory)

Grand mean 239.3

Treatment	C60lvs 40bark	C70lvs 30bark	C100lvs	C100bark	C60lvs 40root
	70.6	71.2	165.4	25.6	65.2

Treatment	C70lvs 30root	100root	Control
	76.3	24.2	1415.8

Days	Day1	Day7	Day14
	228.1	183.6	306.2

Treatment	Days	Day1	Day7	Day14
C60lvs 40bark		53.7	61.7	96.2
C70lvs 30bark		53.2	49.7	110.5
C100lvs		132.0	130.0	234.3
C100bark		14.0	12.3	50.5
C60lvs 40root		57.0	39.0	99.7
C70lvs 30root		53.5	49.5	126.0
100root		14.3	14.5	43.7
Control		1447.0	1112.0	1688.5

*** Least significant differences of means ***

Table	Treatment	Days
rep.	12	32
d.f.	72	72
l.s.d.	56.09	34.35

***** Analysis of variance *****

Variate: Numbers of *Sitophilus zeamais* adults produced in dry ground materials treated grains at different times of adult removal (Field)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	7	17193573.	2456225.	482.85	<.001
Residual	72	366259.	5087.		
Total	95	18017865.			

***** Tables of means *****

Variate: Numbers of *Sitophilus zeamais* adults produced in dry ground materials treated grains at different times of adult removal (Field)

Grand mean 243.9

Treatmen	C60lvs 40bark	C70lvs 30bark	C100lvs	C100bark	C60lvs 40root
	83.1	105.1	198.1	23.7	79.4

Treatment	C70lvs 30root	100root	Control
	78.3	27.7	1355.6

Days	Day1	Day7	Day14
	208.5	201.6	321.5

Treatment	Days	Day1	Day7	Day14
C60lvs 40bark		58.5	62.0	128.8
C70lvs 30bark		60.7	57.7	196.8
C100lvs		139.3	131.8	323.3
C100bark		15.0	10.5	45.5
C60lvs 40root		60.5	47.5	130.3
C70lvs 30root		53.0	53.7	128.3
100root		13.5	14.5	55.0
Control		1267.7	1235.0	1564.0

*** Least significant differences of means ***

Table	Treatment	Days
rep.	12	32
d.f.	72	72
l.s.d.	58.04	35.54

***** Analysis of variance *****

Variate: Numbers of *Callosobruchus maculatus* adults produced in dry ground materials treated grains at different times of adult removal (Field)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	7	14065640.	2009377.	202.02	<.001
Residual	72	716153.	9947.		
Total	95	15289805.			

***** Tables of means *****

Variate: Numbers of *Callosobruchus maculatus* adults produced in dry ground materials treated grains at different times of adult removal (field)

Grand mean 219.

Treatment	C60lvs 40bark	C70lvs 30bark	C100lvs	C100bark	C60lvs 40root
	65.	67.	167.	34.	77.

Treatment	C70lvs 30root	100root	Control
	86.	29.	1226.

Days	Day1	Day7	Day14
	176.	191.	289.

Treatment	Days	Day1	Day7	Day14
C60lvs 40bark		48.	51.	96.
C70lvs 30bark		51.	46.	105.
C100lvs		129.	133.	238.
C100bark		18.	19.	64.
C60lvs 40root		47.	50.	133.
C70lvs 30root		63.	51.	145.
100root		15.	18.	54.
Control		1040.	1159.	1480.

*** Least significant differences of means ***

Table	Treatment	Days
rep.	12	32
d.f.	72	72
l.s.d.	81.2	49.7

***** Tables of means *****

Variate: %Mortality (*Sitophilus zeamais*)

Grand mean 21.51

Treatment	C2.2L 1.8R	C2.4L 1.6R	C2.6L 1.4R	2.8L 1.2R	2.2L 1.8B	C2.4L 1.6B
	37.60	30.20	17.80	10.80	39.60	34.40

Treatment	C2.6L 1.4B	2.8L 1.2B	Control
	13.40	9.60	0.20

*** Least significant differences of means ***

Table	Treatment
rep.	5
d.f.	36
l.s.d.	6.785

***** Analysis of variance *****

Variate: %Mortality (*Callosobruchus maculatus*)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	11212.80	1401.60	32.87	<.001
Residual	36	1535.20	42.64		
Total	44	12748.00			

***** Tables of means *****

Variate: %Mortality (*Callosobruchus maculatus*)

Grand mean 28.67

Treatment	C2.2L 1.8R	C2.4L 1.6R	C2.6L 1.4R	2.8L 1.2R	2.2L 1.8B
	41.80	35.00	12.80	44.80	40.20

Treatment	C2.4L 1.6B	C2.6L 1.4B	2.8L 1.2B	Control
	47.20	20.20	15.60	0.40

*** Least significant differences of means ***

Table	Treatment
rep.	5
d.f.	36
l.s.d.	8.376

***** Analysis of variance *****

Variate: %Weight loss (*Sitophilus zeamais*)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	172.8256	21.6032	68.78	<.001
Residual	27	8.4800	0.3141		
Total	35	181.3056			

***** Tables of means *****

Variate: %Weight loss (*Sitophilus zeamais*)

Grand mean 7.339

Treatment	C2.2L 1.8R	C2.4L 1.6R	C2.6L 1.4R	2.8L 1.2R	2.2L 1.8B
	4.825	5.750	7.075	7.950	5.350

Treatment	C2.4L 1.6B	C2.6L 1.4B	2.8L 1.2B	Control
	6.500	8.025	7.900	12.675

*** Least significant differences of means ***

Table	Treatment
rep.	4
d.f.	27
l.s.d.	0.8131

***** Analysis of variance *****

Variate: %Weight loss (*Callosobruchus maculatus*)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	175.0389	21.8799	97.81	<.001
Residual	27	6.0400	0.2237		
Total	35	181.0789			

***** Tables of means *****

Variate: %Weight loss (*Callosobruchus maculatus*)

Grand mean 7.406

Treatment	C2.2L 1.8R	C2.4L 1.6R	C2.6L 1.4R	2.8L 1.2R	2.2L 1.8B
	5.175	5.725	7.625	8.200	5.250

Treatment	C2.4L 1.6B	C2.6L 1.4B	2.8L 1.2B	Control
	6.35	7.475	8.050	12.800

*** Least significant differences of means ***

Table	Treatment
rep.	4
d.f.	27
l.s.d.	0.6862

***** Analysis of variance *****

Variate: Persistency of tablets week 1(*Sitophilus zeamais*)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	408.963	51.120	20.30	<.001
Residual	18	45.333	2.519		
Total	26	454.296			

***** Tables of means *****

Variate: Persistency of tablets week 1(*Sitophilus zeamais*)

Grand mean 12.37

Treatment	C2.2L 1.8R	C2.4L 1.6R	C2.6L 1.4R	2.8L 1.2R	2.2L 1.8B
	9.00	10.33	12.33	13.67	7.33

Treatment	C2.4L 1.6B	C2.6L 1.4B	2.8L 1.2B	Control
	8.67	13.00	17.00	20.00

*** Least significant differences of means ***

Table	Treatment
rep.	3
d.f.	18
l.s.d.	2.722

***** Analysis of variance *****

Variate: Persistency of tablets week 2(*Sitophilus zeamais*)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	0.6667	0.0833	0.75	0.649
Residual	18	2.0000	0.1111		
Total	26	2.6667			

***** Tables of means *****

Variate: Persistency of tablets week 2(*Sitophilus zeamais*)

Grand mean 19.889

Treatment	C2.2L 1.8R	C2.4L 1.6R	C2.6L 1.4R	2.8L 1.2R	2.2L 1.8B
	19.667	20.000	20.000	20.000	20.000

Treatment	C2.4L 1.6B	C2.6L 1.4B	2.8L 1.2B	Control
	19.667	20.000	19.667	20.000

*** Least significant differences of means ***

Table	Treatment
rep.	3
d.f.	18
l.s.d.	0.5718

***** Analysis of variance *****

Variate: Persistency of tablets week 3(*Sitophilus zeamais*)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	1.3333	0.1667	0.90	0.537
Residual	18	3.3333	0.1852		
Total	26	4.6667			

***** Tables of means *****

Variate: Persistency of tablets week 3(*Sitophilus zeamais*)

Grand mean 19.889

Treatment	C2.2L 1.8R	C2.4L 1.6R	C2.6L 1.4R	2.8L 1.2R	2.2L 1.8B
	20.000	20.000	19.667	20.000	20.000
Treatment	C2.4L 1.6B	C2.6L 1.4B	2.8L 1.2B	Control	
	20.000	20.000	20.000	19.333	

*** Least significant differences of means ***

Table	Treatment
rep.	3
d.f.	18
l.s.d.	0.7382

***** Analysis of variance *****

Variate: Persistency of tablets week 1(*Callosobruchus maculatus*)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	542.074	67.759	11.96	<.001
Residual	18	102.000	5.667		
Total	26	644.07			

***** Tables of means *****

Variate: Persistency of tablets week 1(*Callosobruchus maculatus*)

Grand mean 12.19

Treatment	C2.2L 1.8R	C2.4L 1.6R	C2.6L 1.4R	2.8L 1.2R	2.2L 1.8B
	7.00	8.67	11.00	16.33	7.33

Treatment	C2.4L 1.6B	C2.6L 1.4B	2.8L 1.2B	Control
	8.33	14.67	16.33	20.00

*** Least significant differences of means ***

Table	Treatment
rep.	3
d.f.	18
l.s.d.	4.083

***** Analysis of variance *****

Variate: Persistency of tablets week 2(*Callosobruchus maculatus*)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	0.51852	0.06481	0.87	0.555
Residual	18	1.33333	0.07407		
Total	26	1.85185			

***** Tables of means *****

Variate: Persistency of tablets week 2(*Callosobruchus maculatus*)

Grand mean 19.926

Treatment	C2.2L 1.8R	C2.4L 1.6R	C2.6L 1.4R	2.8L 1.2R	2.2L 1.8B
	20.000	20.000	19.667	20.000	20.000

Treatment	C2.4L 1.6B	C2.6L 1.4B	2.8L 1.2B	Control
	20.000	20.000	20.000	19.667

*** Least significant differences of means ***

Table	Treatment
rep.	3
d.f.	18
l.s.d.	0.4669

***** Analysis of variance *****

Variate: Persistency of tablets week 3(*Callosobruchus maculatus*)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	0.	0.		
Residual	18	0.	0.		
Total	26	0.			

***** Tables of means *****

Variate: Persistency of tablets week 3(*Callosobruchus maculatus*)

Grand mean 20.00

Treatment	C2.2L 1.8R	C2.4L 1.6R	C2.6L 1.4R	2.8L 1.2R	2.2L 1.8B
	20.00	20.00	20.00	20.00	20.00

Treatment	C2.4L 1.6B	C2.6L 1.4B	2.8L 1.2B	Control
	20.00	20.00	20.00	20.00

*** Least significant differences of means ***

Table	Treatment
rep.	3
d.f.	*
l.s.d.	0.000