COMPARATIVE EVALUATION OF SOME BOTANICALS AGAINST KHAPRA BEETLE *TROGODERMA GRANARIUM* EVERTS (COLEOPTERA: DERMESTIDAE) ON STORED GROUNDNUTS

By

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DECLARATION

I declare that the work in the dissertation entitled "Comparative Evaluation of Some Botanicals against Khapra Beetle, *Trogoderma granarium* Everts (Coleoptera : Dermestidae) on Stored Groundnuts" has been performed by me in the Department of Crop Protection under the supervision of Professors M .C. Dike, C. I. Amatobi and Dr. I. Onu.

The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at any university.

Musa, Abdulrasak Kannike **February 19, 2007**

…..…… ……... ……...

Name of student **Signature** **Date**

CERTIFICATION

This dissertation entitled "COMPARATIVE EVALUATION OF SOME BOTANICALS AGAINST KHAPRA BEETLE, *TROGODERMA GRANARIUM* EVERTS (COLEOPTERA:DERMESTIDAE) ON STORED GROUNDNUTS" by Musa, Abdulrasak Kannike meets the regulations governing the award of the degree of Doctor of Philosophy of Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

Khapra beetle, *Trogoderma granarium* Everts, is a serious storage insect pest of cereals and legumes in the tropical and sub-tropical regions of the world. The study was carried out in the laboratory at prevailing temperature (25±5^{0}C) and relative humidity (65±5%). Six improved groundnut varieties, which include SAMNUT 14, SAMNUT 17, SAMNUT 18, SAMNUT 21, SAMNUT 22 and SAMNUT 23 were examined for their susceptibility to *T. granarium*. Susceptibility of these varieties to the dermestid was determined with respect to kernel damage assessment, mean kernel weight loss and total larvae population. The food preference of the *T. granarium* larvae for the groundnut varieties after six months storage period was also investigated. SAMNUT 22 variety was the most susceptible while the least susceptible was SAMNUT 17. Further preliminary laboratory experiments involved screening of nine indigenous plant powders (leaves/seeds) against *T. granarium* larvae. Methanol extracts of five promising plant powders of *Ricinus communis* Linnaeus, *Hyptis suaveolens* Poit., *Annona senegalensis* Pers., *Xylopia aethiopica* Dunal and *Khaya senegalensis* Desr. were assayed for their effects on adult mortality and larval survival of *T. granarium*. Adult mortality and survival of larvae of *T. granarium* were significantly ($P<0.05$) different with increased all doses of crude extracts compared with the control. Adult mortality increased with the concentration of crude extracts and the duration of exposure of the insects on the treated groundnut kernels. The crude extracts were almost similar in their effectiveness. However, the

potency of these extracts decreased rapidly due to volatilization. The five botanicals have good potentials as post harvest insect control agents, killing 89.0% of the insect three days after treatment at 3.0 ml per 50 grams kernels. *R. communis* crude extract has detectable harm on the kernels in causing discolouration and wrinkle. The most preferred of the treatment was the groundnut kernel coated with *X. senegalensis* crude extract. These results showed that the crude extracts of these plants may be exploited for *Trogoderma* control in stored products. Chemical analysis including infrared spectroscopy revealed the presence of amines, amides, aldehydes and ketone as the organic components in the test plants. Flavonoid was identified as a constituent of all the test plants except *K. senegalensis*. The results confirmed that *X. aethiopica,* in addition contained saponins, tannins, polyphenols,, steroids, glycosides and alkaloids. All the test plants contained polyphenols. In addition, alkaloids were detected in *H. suaveolens.* The chemical components detected in *K. senegalensis* include saponins. These components may be toxic to *T. granarium.* The results suggested that powders and crude extracts of the test plants could be used to suppress the menace of *T. granarium.*

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CHAPTER ONE

INTRODUCTION

1.1 Nomenclature, origin and geographical distribution of groundnuts

Groundnut, *Arachis hypogaea* L. (Family Fabaceae) also known as peanut, is one of the world's principal oilseed crops, widely grown in areas ranging from latitude 40^0N to 40^0S (Freeman *et al.*, 1999). Groundnut is native to South America and is grown mainly in the United States of America, West and East African sub regions as well as India and China (Dung, 1999). It is a common belief that the peanut originated in Africa, but evidence suggests that South America – Bolivia – was probably its first home (The Sunday Tribune–Spectrum–Health Bites of November 3, 2002). From there through colonization, the use of peanuts spread throughout the world.

1.2 Soil and environmental requirements

Groundnut is drought tolerant and grows in regions of moderate rainfall (800 mm to 1300 mm/annum) and thrives well in well-drained soils. In the absence of drought, temperature is the most important single factor that affects its yield. In addition, the growing season is short, beginning in June and ending in September. Metcalf and Elkins (1980) showed that for high yields and superior quality, peanuts require a moderately long growing period of four to five months with a steady, rather high temperature and a moderate, uniformly distributed supply of rainfall. Adequate rainfall is needed especially during the period when the peanuts are forming, followed by dry conditions.

1.3 Production of groundnut

Groundnut is widely cultivated on a large scale in several countries of the world. Important groundnut producing countries are China, India, Indonesia, Myanmar, Thailand, and Vietnam in Asia, Nigeria, Senegal, Sudan, Zaire, Chad, Uganda, Cote D'Ivoire, Mali, Burkina Faso, Guinea, Mozambique, and Cameroon in Africa, Argentina and Brazil in South America and United States of America and Mexico in North America. India leads the world in groundnut production and about 40% of the groundnut entering the world commerce is from India (OEPP/EPPO, 1981). The major groundnut producing States in Nigeria are Kano, Kaduna, Borno, Bauchi, Adamawa, Niger and Sokoto (Misari *et al.*, 1980). Estimated annual world production of groundnut is 18 million metric tons from 18 million hectares (Egwurube and Dike, 2000). Present annual world production of unshelled nut is 35.1 million tons from about 25.2 million hectares (FAOSTAT, 2001). However, Nigeria is the eighth leading producer of groundnut globally with an average groundnut yield ranging between 500 and 800 kg/ha (Fletcher *et al.*, 1992).

1.4 Groundnut production constraints

The sustainability of groundnut production in Nigeria is threatened by a number of factors. The seeds are susceptible to *Aspergillus flavus* Link ex Fries invasion and are readily contaminated with aflatoxins (Akano *et al.*, 2002). Low yields of groundnut are in part due to infection by foliar diseases

such as early leaf spot (*Mycosphaerella arachidis* Deighton, stat: conid: *Cercospora arachidicola* Hori), late leaf spot (*Mycosphaerella berkleyi* W. A. Jenkins, stat: conid: *Cercosporidium personatum* (Berk. & Curt) Deighton) and rust *Puccinia arachidis* Speg) (Allen *et al.*,1996). The most important constraint is drought. Rosette epidemic in the mid-1970s decimated the crop as nearly three quarters of a million hectares of the crop were destroyed and regional trade worth an estimated US $250 million was wiped out (ICRISAT, 1996). The groundnut rosette is transmitted by *Aphis craccivora* Koch (Misari *et al.*, 1988).

1.5 Uses of groundnut

Groundnut is the most important food legume in Nigeria (Ezeaku and Shehu, 2003). The crop not only sustains soil fertility but is also an important source of income for small-scale farmers. It is a major source of oil for humans and the cake, after oil extraction, is a major source of protein for livestock. Groundnuts constitute an important cash crop and is only surpassed by cotton and tobacco.

Groundnut is one of the most nourishing foods available in the world. The U.S. Department of Agriculture reported that it has five important nutrients, which include food energy, protein, phosphorus, thiamine and niacin (OEPP/EPPO,1981). Apart from their nutritional value, groundnuts have considerable medicinal value.

1.6 Justification of the study

The economic damage caused by *Trogoderma granarium* Everts on grains especially oil seeds is not known in Nigeria. This might be attributed to the behaviour of the insect pest and the dearth of information available on the pest. The behaviour of the insect pest has raised the awareness to apply synthetic fumigants such as methyl bromide and phosphine when farmers are threatened by the insect. This perception has led to consequent repercussions on the farmers and environment including cost and environmental hazards or even depletion of the ozone layer. The current search for alternative control measures against *T. granarium* therefore becomes necessary and imperative.

To date, there is little research report or anectodal information on the effectiveness of plant product components on the activities of *T. granarium* in groundnuts. During storage, *T. granarium* on sorghum (Jood *et al*., 1996a), maize (Jood *et al*., 1993a), and on wheat (El Nadi *et al*., 2001) have been controlled with plant products. Larvae of *T. granarium* in large numbers, cause considerable damage to stored groundnut compared to non-feeding adults, which are less in number with short life span. This research was undertaken to examine the efficacy of well-proven biopesticides on *T. granarium* to replace the imported, more expensive and hazardous fumigants being used to control the storage pest.

The objectives of the study were to:

1. compare the susceptibility of groundnut varieties to Khapra beetle, *T. granarium* larvae
2. assess the efficacy of plant powders on the mortality of larvae of *T. granarium* on stored groundnuts.
3. assess the effects of methanol extracts of some of the promising plant powders (in 2 above) on adult mortality and emergence of larvae of *T. granarium.*
4. qualitatively identify the active ingredients of the most effective plant extracts, e.g. alkaloids, flavonoids, tannins, saponins, etc.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and distribution of Khapra beetle

The Khapra beetle, *Trogoderma granarium* Everts (Dermestidae), believed to be native to India, is a serious pest of stored grain and grain products in many parts of the world (Nair and Desai, 1972). The beetle originated in India and is now widely distributed in the tropics (Banks, 1977). *T. granarium* is established within an area broadly limited in the north by the 35^0 parallel, south by the Equator, west by West Africa and east by Myanmar, i.e. the warm dry regions along the Suez route from the Indian subcontinent to Europe (OEPP/EPPO, 1981).

Anonymous (2001) reported that Khapra beetle has been found in a wide range of cargo including non-agricultural goods, which appear to become infested through contact with infested goods, especially in containers with mixed cargo ships. The Khapra beetle breeds most rapidly under hot, dry conditions and has a potential for spread. That it spreads about the world in international trade is shown by its regular interception on oil cake and other products imported into Great Britain from Burma, Sudan, Senegal, India and Nigeria (Freeman, 1974).

Khapra beetle is a cosmopolitan, multivoltine and polyphagous pest throughout the tropics (Hill, 1983; Hill and Waller, 1988; Odeyemi, 1989). It

has preference for hot dry climate but it is ubiquitous in most warmer parts of the world.

2.2 Taxonomy of Khapra beetle

The Khapra beetle, *T. granarium*, is a member of the order Coleoptera, family Dermestidae. The adult male has two curved narrow horns which project in front of the head while adult female is without horns, but with head across back of eyes as wide as or wider than in front of eyes (Halstead, 1963; Haines, 1991). Odeyemi and Daramola (2000) reported that adults are reddish-brown, 2-3 mm in size, the females being larger that the males. The dorsal surface is covered with hairs. In the male, the apical segment of the club is much elongated in comparison with that of the female (Hadaway, 1956; Haines,1981).

Haines (1991) reported that in the male, the apical segment of the club is much elongated in comparison with that of the female. The insect has 4-6 instars (Odeyemi and Hassan, 1993). There are two genetic types of larvae; those that undergo diapause and those that do not (Odeyemi and Daramola, 2000). Infestations are generally limited to the upper 60 cm of grain in bulk storage. Although adults have functional wings, they are not known to fly and generally only live for five to ten days. Larvae of *T. granarium* can live for a number of years (Anonymous, 2001).

The male antennae of Khapra beetle are filiform and often larger than half of the body length while female antennae are shorter than half the body length

(Lefkovitch, 1962; Halstead, 1963). Larvae are hairy, 1.6 mm to 5 mm long when fully matured.

2.3 Insect pests of groundnut

2.3.1 Field pests

Misari and Raheja (1976) classified the major arthropod pests of groundnut into three groups, namely:

- Shoot and foliage feeders
- Flower feeders
- Root and pod feeders

Shoot and foliage pests include the cowpea or groundnut aphids: *Aphis craccivora* Koch, several species of Cicadelid leaf hoppers notably the cotton jassids, *Empoasca dolichi* Pooli and *E. fascialis* Jac. Others include *Monolepta* spp., *Luperodes* spp., *Ootheca mutabilis* (Sahlb) and leaf eating caterpillars, which include *Euproctis fasciata* Walker, *Syntomis cerberra* (L.) and *Amsacta flaviscota* (Hamps). The main importance of *A. craccivora* is its ability to transmit virus diseases such as groundnut rosette (Misari *et al*., 1988), peanut, stunt, peanut stripe, peanut mottle (NRI, 1996), cowpea aphid-borne mosaic, black eye cowpea mosaic (Taiwo and Gonslaves, 1982), and soyabean mosaic (Alegbejo, 1999).

Flower feeders encountered on groundnut plant include *Thrips* spp: *Frankliniella schultzei* Trybom, *Megalurothrips sjostedti* Trybom and Meloid beetles – *Mylabris bifaciata* Deg. and *Coryna hermanniae* Fab.

Root and pod feeders encountered include the termites and millipedes (Myriapoda: Odontopygidae). Onu (1982) observed that the most common termite species attacking the root system of groundnut at Samaru was *Microtermes* spp. He also noticed *Microtermes* spp attacking the pegs and subsequently the pods of groundnut. Sands (1966) and Johnson *et al*. (1981) found out that plant mortality due to this cause alone amounted to 30 to 40% in northern Nigeria. *Odontotermes* spp and *Microtermes subhyalinus* (Rambur) were observed attacking foliage of already wilted and dead stands. The attack resulted in the reduction of the quantity of haulms obtained at harvest (Onu, 1982).

At Samaru, Onu 1982 reported that the damage done by millipedes to groundnut could be at two distinct developmental phases of the crop, germination and pod formation. The openings left by millipedes damage, predisposes the plant to the entry of fungal pathogens. During pod formation, the immature stages of millipedes (*Peridontopyge* spp) penetrate the shell leaving a small round hole, 1 to 4 mm in diameter. They feed on the inner lining of the shell and the developing kernels. Studies by Misari (1981) showed that the percentage pod damage by millipedes ranged from 1 to 39% and varied from place to place, from year to year and among varieties.

A very large number of insect species have been recorded as causing damage to groundnut in the field (Smith and Barfield, 1982; Wightman and Amin, 1988 and Wightman, 1989). In Africa, ten arthropod species are considered as major pests of groundnut (Amin and Mohammed, 1980). These include the groundnut aphid, *A. craccivora:* leafloppers, *E. dolichi* and *E. fascialis*; armyworm, *Spodoptera littoralis* Boisduval; the groundnut hopper, *Hilda patruelis* Stali; termite, *Microtermes* sp; millipedes of the genus *Peridontopyge* and the groundnut bruchid, *Caryedon serratus* Oliv.

2.3.2 Pests associated with stored groundnuts

Storage pests infestation of groundnut is mostly by insects although some mites have also been found associated with stored products. Pointel *et al*., (1979) found out that the beetles *Caryedon serratus* were associated with stacked groundnut in Senegal. The red flour beetle, *Tribolium castaneum* Herbst and *Ephestia cautella* Walk have been reported as main pests of groundnut in Malawi (Mercer, 1978). It has been reported that groundnut in Gambia showed 84% pod infestation at peripheral layers by *Elasmolomus sordidus* (Fabricius) (Conway, 1976).

The most serious pest of groundnut in shell are *C. serratus* and *T. granarium* where about 30% infestation of undecorticated groundnut was reported (Magar, 1973). The merchant grain beetle, *Oryzaephilus mercator* (Fauvel), is a pest of stored oilseeds and processed cereal products in Nigeria (Mejule *et*

al., 1990). More than 100 species of insects are capable of infesting stored groundnuts (Redlinger and Davis, 1982).

In developing countries and especially on the African continent, the tropical climate and vulnerable storage conditions are favourable to the proliferation of numerous insect species and therefore induce significant post-harvest losses (Leinard *et al*., 1993). At farmers' level where financial and technical means are limited, post-harvest losses in grain legumes can reach up to 100% in a few months (Labeyrie, 1981). Grains, seeds, fish and animal products are attacked in storage by insect pests belonging mainly to the two orders, Coleoptera and Lepidoptera (Lale, 2001). Stored product pests cause damage by eating portions of products and this leads to losses usually manifested by reduction in weight (Kharnair *et al*., 1996) and also by contaminating produce with frass, exuviae and mummified bodies of dead insects, altering their biochemical constitution or by outright reduction in the amounts of nutrients (Jood *et al*., 1996 a, 1996b; Kumar *et al*., 1996; Lale and Okunade, 2000). Losses are caused by microbial and insect attack, physical fragmentation and by chemical changes, which alter the quality of products (FAO, 1981).

2.4 Biology of Khapra beetle

The Khapra beetle development rates and survival varies depending on the host species, temperature, light, moisture and season (Szito, 2004). Based on these factors there can be one to nine generations of the beetle per year. High

humidity has a slowing down effect on the population build up. Adult longevity is between 12-25 days and females lay between 50-100 eggs (Szito, 2004). Larval development usually takes 4-6 weeks. Larvae moult between 4-15 times. The pupal stage lasts 2-5 days and quiescent adult stage 1-2 days. The larval stage however, can last from a month to a year, if it enters diapause. They are capable of surviving without food for a period of several years (OEPP/EPPO 2004). Khapra beetle exhibits gonochorism (reproduction involving separate male and female individuals).

The Khapra beetle breeds most rapidly under hot, dry conditions and has a potential for spread. It has been reported that *T. granarium* females do not lay a full complement of eggs after one mating but remate soon after the first batch of eggs is oviposited (Karnavar, 1992). Under optimal conditions, the life cycle is completed in about a month. Burges (1963) showed that at 30^0C, in fairly crowded cultures, many last instar *T. granarium* larvae delay pupation and enter a state of dormancy characterised by a low rate of respiration. These larvae are usually much heavier than mature non-diapause larvae and tend to hide in crevices away from food, but emerge from the crevices at irregular intervals and feed; they may then return to the crevices and revert to the dormant condition or less usually pupate.

The adults are short-lived, mated females living 4-7 days, unmated females 20-30 days and males 7-12 days. They do not fly and feed very little, if at all. Mating occurs about five days after emergence. The beetle can lay a full

complement of eggs following a single mating, but a second mating greatly increases the total number of eggs produced. Delay in mating of 15-20 days results in up to 25% reduction in fecundity. The preoviposition period, which is not affected by humidity, is negligible at 40^0C, one day at 35^0C, two days at 30^0C, two to three days at 25^0C, and at 20^0C, no eggs are produced. Under optimum conditions, the female lays an average of about 50-90 eggs loosely in the host material. The eggs hatch in 13-14 days.

Complement development takes place within the range 21 to over 40^0C. The life cycle from egg to adult takes an average of 220 days at 21^0C, 39-45 days at 30^0C and 75% relative humidity and 26 days at 35^0C, the optimum. Development can take place at a relative humidity as low as 2%, at which the life cycle is prolonged.

In the zone where *T. granarium* is indigenous, where mean temperatures are consistently above 25^0C, the larvae develop rapidly into the pupal stage, e.g. in 15 days at 35^0C. If the temperature falls below 25^0C for any period of time and, sometimes, if the larvae are very crowded, they may enter diapause and development ceases. The larvae are cold hardy, surviving temperatures below -8^0C. Diapause often occurs at constant temperature, below 30^0C. In diapause, the larva can moult but is relatively inactive and rarely feeds. It tends to seek out crevices in the fabric of buildings. A larva can remain in this state for several years, but the provision of a new consignment of food,

especially in warm conditions, may stimulate renewed development and pupation.

Young larvae are unable to feed on whole grains and depend on damaged grains or gain products for food (they readily attack softer food such as nuts). Such damaged grains are always present in practice on lots of stored grains. Older larvae can feed on whole grains. The amount and condition of the food present affects the speed of development, but larvae can survive long periods (at least 13 months) without food. These starving larvae pupate within a week on the return of favourable conditions such as high temperature and availability of food. Starvation of dormant larvae for three months, followed by a brief period of feeding, results in the production of 41% of the normal number of eggs. However, this percentage is ample for the survival of the pest.

2.5 Damage caused by Khapra beetle

Khapra beetle, *T. granarium*, is among the most serious and of widest occurrence in stores in tropical and sub-tropical regions of Asia and Africa (Atwal, 1976; Salunkhe *et al*., 1985; Viljoen, 1990). Khapra beetle is a serious pest of wheat grains in storage but it also attacks dried fruits, oil seeds and other grains. The larval stage is primarily responsible for the damage done to products since adults do not feed. The larva commences feeding on the germ of the grains and eats deep into the grain. Infested products are contaminated by the exuviae and frass produced by the beetles. Larval

feeding in sorghum grains has been found to adversely affect quality of minerals (Jood *et al*., 1992), available carbohydrates (Jood *et al*., 1993 a), protein and starch digestibility (Jood and Kapoor, 1992) and bioavailability of proteins (Jood *et al*., 1993 b).

Cornes (1994) in his checklist of stored product insects identified *T. granarium, Lasioderma serricorne* (Fabricius), *T. castaneum* and *E. cautella* as the most serious post-harvest insect pests of cocoa after harvest. The attack of *T. granarium* on groundnut does not result only in weight loss but also in a significant increase in the free fatty acid content thereby making a whole consignment unacceptable in the world market (Nwana, 2000). *T. granarium* is a pest of stored grains, and also groundnuts, and a range of pulses, spices and various cereal products. It is polyphagous, and the boring larvae hollow out grains and pulses. In the tropics, development is rapid and the pest can practice facultative diapause in the absence of food, for a year or longer (Hill and Waller, 1988).

The Khapra beetle has no direct effects on the environment (EPPO 2004). The indirect effects however, are loss of stored grains and the effect of fumigation agents on the environment. If the beetle is left undisturbed in stored grains it can cause significant weight loss and in case of seeds it may lead to significant reduction in seed viability. Weight loss can be between 5-30% and sometimes in extreme cases 70%. Severe infestation may cause unfavourable changes in chemical composition of the infested groundnuts.

Larvae typically attack the embryo point or a weak place in the pericarp of grains or seeds, but will attack other parts during heavy infestations. The Khapra beetle can damage dry commodities of animal origin. Large numbers of larval skins and setae may cause dermatitis and/or allergic reactions. Larvae wander in and out of sacked materials, weakening the sacks, which may ultimately tear (CERIS, 2004).

The Khapra beetle is sufficiently a major pest of stored products to be included on the quarantine lists of many countries, including the United States of America and Australia, outside its main range, which extends from the Sahelian zone in Africa across Asia to Indochina. As a pest, the Khapra beetle is capable of the complete destruction of stored cereals and cereal products (Bell and Wilson, 1995). In addition to direct loss caused by larval feeding, infestation is often followed by colonization by secondary insect pests, fungi and consequently leading to deterioration in grain characteristics (El Nadi *et al.*, 2001).

2.6 Limitations of synthetic pesticides

Protection of stored grains from insect damage is mostly dependent on synthetic pesticides such as fumigation with phosphine or methyl bromide, or dusting with compounds such as primiphos-methyl and permethrin (Singh, 1990; Price and Mills, 1988). Increasing documentation of negative environmental and health impact of synthetic toxic insecticides and increasingly stringent government regulation of pesticides has resulted in

renewed interests in the development and use of botanicals for pest management (Ascher, 1993). High cost, environmental pollution and hazards to human health and livestock involved in the use of synthetic insecticides have resulted in the exploring of plant materials for the control of insect pests in storage (Dike and Mbah, 1992). The high import bills incurred accentuated by devaluation of local currencies, not only pose a serious drain on the economy of third world countries but also make synthetic insecticides unaffordable to the resource-poor farmers (Oparaeke *et al*., 2000). In Nigeria and many developing third world countries, there is also a decline in the use of chemical insecticides due to the withdrawal of subsidies on these pesticides by the government (Lale, 1995; Lale and Yusuf, 2001).

The most commonly used fumigant for control in the regions where *T. granarium* occurs is phosphine. Whereas fumigation practice at recommended doses achieves good control, especially above 25^0C when the egg replaces the resting larva as the most tolerant stage, there is concern that resistance to phosphine may spread among populations of *T. granarium,* as it has in some other insect species, because of malpractice and international trade (Bell and Wilson, 1995). Zettler (1990) reviewed research on the resistance problem in the use of phosphine for stored products protection, and found that resistance to phosphine is increasing, as is the number of insect species that are developing resistance. The development of resistance is one of the biggest problems because one has either to resort to other

agents or to use more pesticides during each application thus aggregating the problem of pollution. In addition, phosphine has been reported to be genotoxic to occupationally exposed fumigators (Garry *et al*., 1989).

Methyl bromide has been defined scientifically as a chemical that depletes the earth's ozone layer (Braga *et al*., 2001). Its ozone-depletion potential (ODP) is 0.4, i.e greater than the admissible threshold of 0.2. All this information has led to a planned phase-out process in developed and developing countries, under the Montreal Protocol on substances that deplete the ozone layer. The complete phase-out of methyl bromide in developed countries was attained in 2005, while in developing countries a reduction should take place during the 2000s with the process completed by the end of 2015 (Braga *et al*., 2001).

Leesch (1995) reported that the use of dichlorvos has been curtailed because of possible carcinogenicity. The United States Environmental Protection Agency has classified DDVP (2-2-dichlorovinyl dimethyl phosphate) as a possible human carcinogen and is proposing to cancel most uses of this pesticide (Mueller, 1995).

Acute toxic symptoms of organophosphate poisoning are generally caused by inhibition of the enzyme acetyl-cholinesterase, which leads to accumulation of acetylcholine (O' Malley, 1977; Solberg and Belkin, 1997). In addition, acute poisoning with organophosphates may lead to a range of neurological sequelae. Several organophosphate compounds, e.g. miprifox,

leptophos and diisopropyl fluorophosphate, cause degeneration of lung axons in the spinal cord and peripheral nerves, a syndrome known as organophosphate-induced delayed neuropathy (Ehrich *et al*., 1994). It has been demonstrated that the neuro-degeneration is associated with a decreased activity or inhibition of the enzyme neuropathy target esterase (Winrow *et al*., 2003). Other organophosphates, e.g. fenitrothion and dimethoate are associated with the intermediate syndrome (Senanayake and Karalliedde, 1987).

The attendant problems of many synthetic insecticides such as high persistence, knowledge of application, cost, availability and health hazard have necessitated the search for humanly safe, ecologically sound and cheap control measures (Sighamony *et al*., 1986, Adedire and Ajayi, 1996; Adedire, 2002). Public awareness of these risks has increased the interest in finding safer insecticides or alternative stored-product protectants to replace dangerous synthetic chemical insecticides (Silver, 1994). One such alternative is the use of natural plant products that have insecticidal activity (Isman, 1994).

2.7 Phytochemical control of stored product insect pests.

The need for new compounds to replace synthetic chemicals has renewed interest in the search for potential natural plant fumigants (Civerolo *et al*., 1993). The interest in insecticides of plant origin has been enhanced by the current public suspicion of any chemical of a persistent nature, whether or

not evidence is available of any adverse effects (Bell, 1992). In recent years, increasing attention has been focussed on evaluating the efficacy and identifying the active components of ethnobotanical materials used in grain protection (Hassanali *et al.*, 1990; Weaver *et al.*, 1991; Regnault – Roger *et al.*, 1993).

The present strategy used by different communities varies from place to place and appears to depend partly on the type and efficacy of suitable plant materials available in different locations (Hassanali *et al.*, 1990). Protection of stored products generally involves mixing grains with protectants made from plant materials (Jembere *et al.*, 1995). Reports are available on the use of plant materials for protection of stored grains (Chander and Ahmed, 1983). In India, the use of deoiled neem (*Azadirachta indica* A. Juss) seed powder mixed into wheat seemed to be an effective and cheap method to control *T. granarium* in stored wheat (Singh and Kataria, 1986).

A large percentage of plants have been studied and screened for insecticidal activity. Plants remain a major untapped resource for potential leads to novel insecticide (van Beek and Breteler, 1993). They reported that plant-derived pesticides are also active pesticides and usually do not persist in the environment for long, since they are rapidly degraded by microorganisms or they are unstable under sunlight. Plant origin products are receiving greater attention as prophylactic measures against stored product pests, mainly because of their safety to non-target organisms (Jood *et al.*, 1993a). A

knowledge of the chemical constituents of plants is desirable not only for the discovery of therapeutic agents, but also because such information may be of value in disclosing new sources of such economic materials as tannins, oils, gums, precursors for the synthesis of complex chemical substances etc. Generally, plants have evolved highly elaborate chemical defenses against insect attack and they have therefore provided rich sources of biologically active chemical compounds, which may be used as crop protecting agents (Adedire and Lajide, 2000). Plant products, mainly in the form of powders or oils, used as protectants of both grains and dried fish, are normally obtained from leaves, roots, flowers, fruits and seeds; and to a lesser extent from bark and stems (Dupriez and Lenner de, 1989). The application rates of powder range from less than 1 g/kg to 20 g/kg of grains, but do not usually exceed 2% of the weight of grain (Ivbijaro and Agbaje, 1986; Ogunwolu and Idowu, 1994). Higher plants especially those in the families Annonaceae, Meliaceae and Rutaceae are known to have vast reservoirs of chemicals, which are toxic to insects or which affect their behaviour, reproductive fitness and development (Jacobson, 1989; Alkofahi *et al*., 1989). Natural phyto-chemicals have gained significant importance as suitable alternatives to synthetic pesticides for management. These chemicals have been generally classified into qualitative substances or toxins and quantitative substances or digestibility reducing substances (Rhoades and Cates, 1976; Feeny, 1976). These chemicals may deter feeding (e.g. Azadirachtin, Limnoids, Coumarin, Gallic acid), inhibit digestive enzymes (e.g. erysodine, erysorine, tannic acid

and a variety of substances present in leguminous seeds (Janzen, 1977) and decrease fecundity and hatchability of eggs.

2.8 Plants controlling storage pests

2.8.1 *Azadirachta indica*

Neem (*A. indica*) products including leaf, kernel and seed powders, seed extracts, and oil have been reported as effective protectants against several stored product pests (Singh and Srivastava, 1980; Ivbijaro, 1983a, Tanzubil, 1986; Saxena, 1989; Schmutterer, 1990). The neem tree, *A. indica* and the chinaberry tree, *Melia azaderach* L., (Meliaceae) produce seeds, which are rich in insect deterrents and insecticidal tetranortri-terpenoids, such as 'azadirachtin' (Keller, 1988). This plant and its constituents have been developed and tested intensively during the last two decades for use as a natural insecticide (Schmutterer *et al*., 1981; Schmutterer and Ascher, 1984; Schmutterer, 1990). Neem products were studied mainly at the laboratory level until 1984, from then on, practical aspects of plant cultivation, seed collection and storage, extraction procedures, and application obtained more attention (Dreyer and Hellpap, 1991). This plant is already widely used in Asian countries and will have a wide impact in other countries of the third world (Schmutterer, 1990) as a cheap and efficient pesticide, especially in the small-scale cultivation of vegetables.

Neem extract contains several active ingredients. *Azadirachtin* is one of the major constituents, exhibiting about 90 per cent of the neem extract activity.

Azadirachtin, structurally similar to the insect-moulting hormone, ecdysone, interacts with the corpus cardiacum, thereby blocking the activity of the moulting hormone. As such, the compound acts as an insect growth regulator, suppressing fecundity, moulting, pupation, and adult formation. Other constituents showing high potency on insects and structurally related to azadirachtin are the salanin, meliantrol, and nimbin (Schmutterer, 1995). Neem extract is a potential insecticide, acting mainly by ingestion and affecting a diversity of insects (Jacobson, 1989; National Research Council, 1992; Ascher, 1993; Schmutterer, 1995). The extract seems to have no harmful effect on beneficials such as spiders, lady bird beetles, and parasitoids, and is considered a potential component in Integrated Pest Management programmes.

Out of 1,800 plant species investigated for pest control properties at the East West Resources Institute; Honolulu, neem was the most promising (Seun, 1975). In India, the leaves have been used as repellants against bugs and lice (Ndumu *et al.*, 1999). Neem trees have many unique compounds that have been identified (Sankaram, 1987). The more common and the most analyzed compounds include nimbin (anti-inflammatory), nimbidin (anti-bacterial, anti-ulcer, analgesic, anti-arrhythmic, anti-fungal), nimbido (anti-tubercular, anti-protozoan, anti-pyretic), gedunin (vasodilator, anti-malaria, anti-fungal), sodium nimbinate (diuretic, spermcide, anti-arthritic), queceretin (anti-protozoal), salannin (repellent), and azadirachtin (repellent, anti-

feedant, anti-hormonal) (Sankaram, 1987). Extracts from seeds and leaves of neem tree were found to inhibit the feeding metamorphosis, fecundity and oviposition and cause diverse behavioural and physiological disorders in many insect species (Chen *et al*., 1996; Ascher, 1993). The mechanism of action of neem especially the antifeedant effect is well-documented, particularly on stored product insects (Schmutterer, 1990). Rembold (1989) reported that azadirachtin is toxic to Mexican bean beetle, *Epilachna varivestis* Mulsan only if administered at concentrations greater than 1000 ppm. Treating insect food material with neem can disrupt the insect feeding by making the treated material unattractive, or unpalatable, and consequently, insect growth, survival and reproduction are adversely affected (Saxena, 1987).

Oparaeke *et al*., (1998) found that neem seed or leaf powder effected high mortality of bruchids, discouraged oviposition, inhibited progeny emergence and protected cowpea seeds from damage by the bruchids. Three main formulations (aqueous extract, seed oil and seed powder) obtained from neem seeds, have been used extensively for the management of insect pests (Stoll, 1988; Okwute, 1992; Lale, 1995). Aqueous solutions are employed more frequently for spraying of growing crops (Olaifa and Akingbohungbe, 1987; Jackai *et al*., 1992; Przybyszewski, 1993). Oil and powder formulations have been used more commonly for the preservation of stored grains (Ivbijaro, 1983 a, 1983b; Jotwani and Scircar, 1965; Makanjuola, 1989; Ogunwolu and Idowu, 1994; Ogunwolu and Odunlami,

1996). Although leaves of neem have been reported as the main sources of the active compounds obtainable from the plant, the fruits and seeds appear to be more important (Stoll, 1988). Neem seed contains 35-45% oil (Ahmed and Grainge, 1985), and this is usually extracted by means of organic solvents, the more commonly used ones being acetone, methanol, ethanol and petroleum ether (Hill and Schoonhoven, 1981; Sighamony *et al.*, 1983; Malik and Naqvi, 1984; Su, 1985; Boughdad *et al*., 1987; Lale, 1992). The oil is also extracted traditionally by kneading and alternate wetting with hot water until the oil in the dough-like material begins to ooze out (Grainge and Ahmed, 1988; Olaifa and Adenuga, 1988; Stoll, 1988). One to 2% of *A. indica* kernel admixture with wheat and pulses gave good protection against *Trogoderma granarium* for 8 months (Jotwani and Sircar, 1965). The kernel powder of *A. indica* at 0.5%, 1.0% and 2.0% gave reasonable protection to wheat against *T. granarium*. In addition, kernel powder admixed at 0.5%, 1.0%, 2.0% and 4.0% and malathion at 10-100 ppm^{+} controlled *T. granarium* on wheat (Saramma and Verma, 1971). The 2% and 4% treatments resulted in *T. granari*um damage levels of 16% and 8% after 8 months (Girish and Jain, 1974). Two percent powdered drupes of *M. azedarach* were ineffective against *T. granarium* larvae compared with *A. indica* (Saramma and Verma, 1971).

2.8.2 *Dennettia tripetala*

Egwunyenga *et al*. (1998) reported that acetone and ethanol extracts of *Dennettia tripetala* Baker fruits were good repellents of *Dermestes maculatus*

De Geer. The repellency activity has been attributed to the presence of β-phenylnitroethane, which is the active component of the extract (Busvine, 1966; Agbakwuru et a*l*., 1978; Osisiogu and Agbakwuru, 1978; Egwunyenga *et al*.,1998). Some workers have reported the effectiveness of the fruits of *D. tripetala* in controlling some storage pests (Agbakwuru *et al*., 1978; Egwunyenga *et al*., 1998; Lale, 1992; 1995; Osisiogu and Agbakwuru, 1978). It has been reported that 0.182 g of *D. tripetala* per 0.5 g maize grains elicited 50 per cent mortality of the maize weevil, *S. zeamais* (Lale, 1992). Okonkwo and Ewete (1998) showed that fruit powder of *D. tripetala* administered at application rate of 3 g per 25 g maize was more effective against *S. zeamais* than 10 ppm of pirimiphos-methyl dust and a tablet of aluminum phosphide. Okonwko and Ewete (1999) stated that *D. tripetala* and *P. guineense* powders treated with cowpea or maize at 0.25 g/25 g achieved 89.4% adult mortality of *C. maculatus* and *S. zeamais.*

2.8.3 *Annona* spp

Aku *et al*. (1998) reported that powders from root bark of *Annona senegalensis* Pers. significantly reduced oviposition and adult emergence in *C. maculatus*, and seed weight loss caused by the pest. They further reported that the extract from the plant root bark was more effective than the powder in the control of *C. maculatus*. *Annona* species is long known for several types of biological activity (e.g cytotoxicity, anti-tumour, anti-malarial, anti-

microbial, anti-feedant, pesticidal). The activity of *A. squamosa* L.was for a long time associated only with anonacine, a benzylisoquinoline alkaloid. However another class of polar compounds with insecticidal activity, the acetoginins, have been isolated from these plants (Lieb *et al*.,1990; Mikolajczak *et al*., 1990; Rupprecht *et al*., 1991; Ohsawa *et al*., 1991).

Stoll (2000) reported that members of the family Annonaceae are more than 90 species of small trees and shrubs. They occur mostly in tropical America, but some are also found in Asia and Africa. He further reported that *A. reticulata* L. (custard apple) and *A. muricata* L. (soursop) are widely distributed in Central America and the Carribean, while *A. squamosa* L. (sweetsop) is commonest in India and Southeast Asia. It has been reported that *Annona* species do not require special conditions of soil or water, but thrive best in places where there is a clear division between the rainy and dry seasons, and generally prefer dry sites. Pandey and Varma (1977) reported that 0.5-2% w/w seed powder of *A. reticulata* gave complete protection against *Callosobruchus maculatus* for three months by repellent effect. However, 2.5% root extract of *A. reticulata* root extract spray had limited effect against *Oryzaephilus surinamensis* L. (Tattersfield and Potter, 1940). Ether extracts of *A. squamosa* were much less effective than DDT against *Tribolium castaneum* (Mukerjea and Govind, 1959). In Niger, studies

have shown that leaves and stems of *A. senegalensis*, used in layers along the sides and within grains in silos can protect stored grain from insect attack (Fuglie, 1998). Of the *Annonas*, custard apple (*A. senegalensis*) is the most effective against insect pests. Care must be taken to avoid getting the seed powder into one's eyes as this is very painful (Stoll, 1988).

2.8.4 *Zanthozylum zanthoxyloides*

Zanthozylum zanthoxyloides (Lam.) Waterm. root bark has been demonstrated to be toxic to adult *C. maculatus* and thereby protects cowpea seeds from depredation by the pest (Ogunwolu and Idowu, 1994; Ogunwolu and Odunlami, 1996). Short duration exposure of adult bruchids to *Z. zanthoxyloides* powder reduces their reproductive fitness (Ogunwolu *et al*., 1998). Constituents from *Zanthoxylum* species have been reported as active in reverting sickle cell anaemia in vitro and they were also active against some microorganisms (Sofowora, 1982). The flora of Nigeria includes 11 *Zanthoxylum* species (Olatunji, 1985). Studies by Marr and Tang (1992) on Hawaiian *Zanthoxylum* species attributed their insecticidal activities to compounds such as isobutyl amides, alphatic ketones, mono-and sesquiterpenes. *Zanthoxylum* root barks are known to contain barberine, chelerythrine, canthine-6-one, e-hydroxyl benzoic acid, 2-hydroxymethyl benzoic acid, anillic acid and other phenolid acid derivatives found useful as antimicrobial and anti-tickling agents (Sofowora, 1982). These useful constituents and other similar constituents possibly occur widespread given

that *Zanthoxylum* spp. occur in Central, North and South America, Africa, and most tropical areas of both hemispheres (von reis Altschul, 1973; Harrison *et al*., 1982; Sofowora, 1982).

2.8.5 *Piper* spp

The active principles of West African black pepper, *Piper guineense* Schum and Thonn has been attributed to the presence of chavicine and piperine (Cobley and Steele, 1976; Su and Sodengam, 1980; Lale, 1995). The insecticidal activity of black pepper on *S. oryzae* and *C. maculatus* has been reported (Su, 1977). He had earlier reported that ground black pepper, *P. nigrum* Linn, was highly toxic to adult *C. maculatus* and attributed this toxicity to piperine, which is contained in the black pepper (Su, 1976). It has been found that black pepper was highly toxic to rice weevil, *S. oryzae,* when used to surface treat wheat subsequently infested with the insect (Helen, 1977). Powders from *P. guineense* (Ivbijaro and Agbaje, 1986; Olaifa and Erhun, 1988), *P. nigrum* and *Dillenia retusa* (L.). Rajapakse, 1990) have been demonstrated to have insecticidal properties against *C. maculatus*. Mejule *et al*. (1987) reported that ethanol extract of *P. guineense* applied topically in maize caused 100% and 95.8% mortality in adult *T. castaneum* and *T. granarium* in 24 hours respectively.

2.8.6 *Citrus* spp.

Citrus peels depressed oviposition and progeny emergence of *C. maculatus* and deterred adults from admixed cowpea (Taylor, 1975; Don Pedro, 1985).

Four major compounds in lemon peel have been identified as insect deterrents (Su and Horvat, 1987). Citrus peels have also been shown to significantly reduce viability of *C. maculatus* eggs (Rajapakse, 1990). It has been reported that the oil of sour orange (*Citrus aurantium* L.) consisting of 98% limonene gave 100% mortality of *C. phaseoli* in 24 hours in airtight plastic or metal containers (Taylor and Vickery, 1974). In Nigeria, orange peel (containing volatile oil) is burnt at night to drive off mosquitoes (Don-Pedro, 1985).

2.8.7 *Eucalyptus* spp.

Members of *Eucalyptus* (Blue gums) species belong to the family Myrtaceae. In Nigeria, it occurs in all the main vegetation (Dike and Mshelia, 1997). They further reported the common species as *E. camaldulensis* Dehn., *E. citriodora* Hook and *E. tereticornis* Sm. There could be 101 species of the tree. These species are drought – resistant and are used for shelterbelt establishment and sand dune stabilization in the Sudan and Sahel savannas of Nigeria (Igboanugo, Personal Communication). The trees reach a height of up to 70 m and are useful as electric and telephone poles. Their woods are used industrially for the manufacture of paper. They also yield gum resin.

Srivastava *et al*., (1988) found that oils of *E. globules* L. at 0.4% concentration controlled *C. chinensis* L. in *Cajanus cajan* (L.), which corroborated the probable insecticidal property of *Eucalyptus* species. The leaves have been shown to contain 67% cineole known to be an active therapeutic agent

(Penfold and Willis, 1961). It has been found that the leaves are efficient in killing bacteria and are used as antiseptic because of the presence of some volatile aldehydes (Dike and Mshelia, 1997). *E. camaldulensis* essential oil (from the leaves) ranges from less than 1 to over 2%. The quantity of 1,8-cineole in the oil ranges from 15-78%. Other compounds in the leaves include betulinic acid, eucalyptic and eucalyptolic acid, oleanolic acid and ursolic acid. Between 0.35 and 1.2% volatile essential oils have been processed from leaves of *E. camaldulensis* (Zainab, 1986). Akinloye and Adegbehin (1984) recorded volatile oil content of 0.6% in *E. camaldulensis*. Extracted oils from Eucalyptus leaves include mainly citronellol, piperitone and phellandrene (Penfold and Willis, 1961). They also observed that young leaves yield higher oil content than the old leaves while Zainab (1986) reported that dry leaves had more oil than fresh leaves. The volatility of these essential oils and aldehydes in Eucalyptus leaves may be acting as fumigants with insecticidal effects (Dike and Mshelia, 1997). Das and Rahamann (1997) reported that *E. globulus* had repellent action on potato tuber moth (*Phthorimoea operculella* (Zeller) after using a 2-3 cm thick layer of dried and crushed leaves or leaf powder. It reduced infestation to about 8-10% and was effective for up to 3-4 months.

2.8.8 *Hyptis spp.*

Hyptis spicigera (Black sesame) Lam. (Poit) has been used by farmers in Burkina Faso to protect cowpeas from attacks of the bean weevil (*Acanthoscelides obtectus*) by adding the leaves or leaf powder (Fuglie, 1998).

Millet in store can be protected from termites by mixing in powder from *Hyptis* leaves (Stoll, 1988). Grain silos should be thoroughly swept and then the interior burned with millet and *Hyptis* stalks. A layer of *Hyptis* leaves are laid on the floor of the silo, then a layer of grain (maize, millet, etc), then *Hyptis*, etc. A layer of *Hyptis* is applied last to cover the grain. In Western Nigeria, leaves of *H. specigera* are mixed with groundnuts to control infestation by the groundnut bruchid, *Caryedon gonagra* (Fuglie, 1998). Nigerian farmers protect cowpeas with the pungent smelling inflorescence (Bungundu, 1970). Lambert *et al*. (1985) reported that beans treated at the rate of 3 g per kg with dried *H. spicigera* leaf powder are much less prone to damage from newly hatched larvae. Millet in store is protected against termites by scattering dried *Hyptis* leaf powder on it (Irvine, 1955).

2.9 Control of Khapra beetle

2.9.1 Use of synthetic chemicals

In some areas, such as northern Nigeria, where *T. granarium* has been a major obstacle to exporting groundnut, intensive programmes of fumigation have succeeded in reducing its importance (Halliday, 1967). Methyl bromide is effective against all the main beetle pests of shelled groundnuts, although the dosage must be increased by 50 percent to be effective against *T. granarium* (FAO, 1985). The dosage rate of phosphine recommended for control of *T. granarium* by the European and Mediterranean Plant Protection Organization (EPPO) (Anonymous, 1984) is 1 g/m^3 for 8 days at 20-30^{0}C, while Winks *et al*., (1980) recommended 1.5 g/m^3 for 10 days at 15-25^{0}C for

control of tolerant species have been well documented. Under expert management, processed commodities can be fumigated with aluminium phosphide (phostoxin) and dichlorvos (Gwinner *et al*., 1990).

2.9.2 Use Of Pheromones

Barak (1989) developed an effective trap against *T. granarium*. Other traps have been used for various stored product beetles such as *Tribolium* spp. and *Trogoderma* spp. These include the PT 6 Allure+ insect trapping system as modified from Nishimir *et al*., (1975) and the Trappit+ developed by Wyatt and Wynn (Barak *et al*., (1990). Pest populations can be monitored using traps such as pitfalls, bait-bag and refuge traps (Haines, 1991). Traps are usually baited with the male produced aggregation pheromone in *T. castaneum*.

Lale (2002) reported that traps in which pheromones are incorporated have been used to detect the presence of insect pests in stores. In species with short-lived adults such as *T. granarium*, the females produce a sex pheromone which attracts males while in species with long-lived adults such as *Tribolium*, the males produce an aggregation pheromone to which both males and females respond. Both types pheromone are used to enhance traps catches.

In many storage situations, the confined space and uniform habitat lend themselves favourably to insect management using pheromones. Control

procedures may be modified once the species of insect and population densities are determined (Lale, 2002).

Levinson and Levinson (1977) reported that the use of pheromones baited traps and food baited traps could help reduce *Trogoderma* population and minimize the frequency of store fumigation. Successful control of the Khapra beetle had been achieved at experimental level by Shapas *et al*. (1977) using a combination of sex pheromone of *T. glabrum* and a protozoan pathogen, *Mattesia trogodermae*.

2.9.3 Non-chemical control

Most storage pests (*Trogoderma* inclusive) have evolved from one country to another along with infested food materials. Well trained personnels should be stationed at borders to prevent the importation of storage pests. *T. granarium* had been successfully excluded from Eastern and Southern Africa through legislative policy (Hill and Waller, 1988). This policy should be backed up by efficient quarantine screening and import restrictions. It is an important pest species against which there are many international quarantine barriers (Wright, 1993). Agricultural produce from countries where Khapra beetle is endemic represent the highest risk for accidental introduction into Australia (Wright, 1993). Host commodities and other goods from Khapra risk countries are subject to fumigation.

Physical control involves such techniques as the modification of the atmosphere around the insect. Lale (2002) reported that this involves the alteration of the proportions of oxygen, carbon dioxide, carbon monoxide and nitrogen such that only a very limited amount of oxygen becomes available to the insects for respiration. The use of carbon dioxide has been reported to the effective in the control of *T. granarium* (Srivastava, 1985). However, Swedish scientists reported the carbon dioxide treatment (in concentrations up to 60% carbon dioxide content) as insufficient to control *T. granarium* (Morner *et al*., 1987). As an alternatives to the fumigation of cereals with methyl bromide or other pesticides, the use of heat treatment has been reported to be very effective against the Khapra beetle (Fleurat-Lessard, 1985). An exposure to 60 ^{0}C for 30 minutes resulted in 100% mortality of all stages of *T. granarium* (Ismail *et al*., 1988).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Insect culture

One hundred grams of edible groundnut kernels were purchased from the open market in Ilorin, northern Nigeria. Adults of Khapra beetle, *Trogoderma. granarium* were collected from the insectary of Nigerian Stored Products Research Institute (NSPRI), Ilorin. These insects were reared on the groundnut kernels in Kilner jars with netted screw caps to allow aeration and prevent entry and exit of insects (Fig 1). Several stocks of the culture were maintained under ambient temperature (25 $\pm$ 5^0C) and relative humidity (65 $\pm$ 5%). The cultures were placed in the Storage Entomology laboratory, Institute for Agricultural Research, Ahmadu Bello Universtiy (IAR/ABU), Zaria, Nigeria. A mass of *T. granarium* larvae was sustained in the culture and the originating larvae were used for this study.

3.2 Groundnut varieties

The groundnut varieties used for the study were six varieties developed at the Institute for Agricultural Research, Zaria: SAMNUT 14, SAMNUT 17, SAMNUT 18, SAMNUT 21, SAMNUT 22 and SAMNUT 23. Table 1 shows IAR recommended groundnut varieties. These varieties are adapted to the Northern Guinea Savanna and Sudan Guinea Savanna zones of Nigeria. The varieties are drought tolerant and high yielding (> 2000 kg/ha) and some, like SAMNUT 21, combine yield or drought



Figure 1: Culture of *Trogoderma granarium* Everts in Kilner jars

Table 1. Institute for Agricultural Research released varieties of groundnut

S/no	Old names	New names	Remarks
1.	MK 374	SAMNUT 1	Rosette Susceptible
2.	SAMARU 38	SAMNUT 2	″ ″
3.	M 25.68	SAMNUT 3	″ .″
4.	69.101	SAMNUT 4	″ ″
5.	M 599.74	SAMNUT 5	″ ″
6.	M 95.71	SAMNUT 6	″ ″
7.	M 104.74	SAMNUT 7	″ ″
8.	M.103.74	SAMNUT 8	″ ″
9.	59.127	SAMNUT 9	″ ″
10.	RMP 12	SAMNUT 10	Rosette Resistant
11.	RMP 91	SAMNUT 11	″ ″
12.	M 318.75	SAMNUT 12	Rosette Susceptible
13.	Spanish 205	SAMNUT 13	″ ″
14.	55-437 (Ex-Dakar)	SAMNUT 14*	″ ″
15.	F 452.4	SAMNUT 15	″ ″
16.	M 554,.76	SAMNUT 16	Rosette Resistant
17.	48 – 115B	SAMNUT 17*	Rosette Susceptible
18.	RRB	SAMNUT 18*	″ ″
19.	K 720.78	SAMNUT 19	″ ″
20.	M 412.801	SAMNUT 20	″ ″
21.	UGA 2	SAMNUT 21*	Rosette Resistant
22.	M 572 – 801	SAMNUT 22*	″ ″
23.	ICGV – IS-96894.	SAMNUT 23*	″ ″

* Indicates groundnut varieties used for susceptibility test.

resistance with rosette resistance. These varieties were chosen on the bases of desirable qualities such as high yield, attractiveness and disease resistance. Three kilograms lots of each groundnut variety were kept in separate air-tight polyethylene bags and disinfested with three tablets of aluminium phosphide (phostoxin) for three days to kill all surviving insects. The groundnut kernels were then aerated for 24 hours by spreading them out on laboratory benches to dissipate fumigant effect.

3.3 Moisture content determination

The moisture content of the groundnut samples was determined on a wet weight basis using a forced ventilation oven at 100^0C for 2 ½ hours to achieve a safe storage level of 7% (Odeyemi and Daramola, 2000). Five grams of each ground groundnut sample were weighed and put in a 9 cm diameter Petri dish. There were five Petri dishes (1 cm deep) per sample, with one Petri-dish per sample not infested served as the control.

3.4 Collection, identification and preparation of plant samples.

Nine indigenous plant materials (Table 2) were screened for their efficacy against *T. granarium.* These include leaves of *Hura crepitans* Linnaeus, *Ricinus communis* Linnaeus and *Hyptis suaveolens* Poit. obtained from an uncultivated land on Kongo Campus, Ahmadu Bello University (ABU), Zaria. Seeds of *Khaya senegalensis* Desr. and fruits of *Xylopia aethiopica* Dunal were obtained from the Savanna Forest Research Station, Zaria and Sabon Gari market, Zaria, respectively. The leaves of *Eucalyptus camaldulensis*

Dehnhardt, *Caesalpinia pulcherima* Linnaeus, *Annona senegalensis* Pers. and *Hibiscus sabdariffa* Linnaeus were similarly procured from the Savanna Forest Research Station, Zaria. All the plant materials were identified at the Herbarium located at the Department of Biological Sciences, A.B.U, Zaria.

These plant parts were oven dried at 60^{o}C for 4 hours and ground to powder in a Thomas –Willey milling machine at the Food Science and Technology Research Programme, IAR, Zaria. This method was employed because of the high humidity of the air. Grains, when dried to the safe moisture content or below can be stored under a wide range of temperatures provided that during storage the moisture level does not rise. The resulting powders were refrigerated in glass jars with lids. The tenth material is the residue of the *E. camaldulensis* obtained after oil extraction of the leaves in a Soxhlet extractor using methanol as the solvent. The preliminary test of these plant powders involved mixing with a commonly consumed groundnut variety (SAMNUT 18) at 5% level (w/w).

3.5 Oil extraction

Two hundred grams each of the ground plant parts (leaves/seeds) were extracted with 400 ml methanol (b.p. 64^{0}C) in a Soxhlet extractor. Following Soxhlet extraction, a filtrate was obtained by using Whatman No. 1 filter paper. The excess solvent was removed by placing the oil extract in a water bath (Grant Instruments (Cambridge) Limited, Barrington, Cambridge, C *-25 QZ England) at 50-60^{0} C. The procedure was repeated until the required

Table 2 Botanicals used against *Trogoderma granarium* Everts larvae

Plant materials	Common name	Family	Plant part Used
Annona senegalensis Pers.	Custard apple	Annonaceae	Leaves
Caesalpinia pulcherima L.	Paradise/peacock plant	Caesalpiniaceae	Leaves
Eucalyptus camaldulensis Dehn.	Gum tree	Myrtaceae	Leaves
E. camaldulensis (deoiled)	Gum tree	Myrtaceae	Leaves
Hibiscus sabdariffa L.	Red calyx roselle	Malvaceae	Leaves
Hura crepitans L.	Sandbox tree	Euphorbiaceae	Leaves
Hyptis suaveolens Poit	African bush tea	Lamiaceae	Leaves
Khaya senegalensis Desr.	African Mahogany	Meliaceae	Seeds
Ricinus communis L.	Castor oil plant	Euphorbiaceae	Leaves
Xylopia aethiopica L.	Aethiopian/ African pepper	Annonaceae	Fruits

quantity of oil extracts was obtained. These concentrates (i.e. crude extracts) were stored in the refrigerator in screwed capped brown bottles.

3.6 Varietal susceptibility of groundnut to Khapra beetle, *T. granarium* larvae.

For each groundnut variety (i.e. SAMNUT 14, SAMNUT 17, SAMNUT 18, SAMNUT 21, SAMNUT 22 and SAMNUT 23), 200 g kernels were placed into a plastic container (16 cm in diameter) into which five newly hatched first instar larvae of *T. granarium* were introduced. The larval stage is primarily responsible for the damage done to products since adults do not feed.The containers were covered with muslin cloth fastened with elastic band to provide ventilation and prevent insect escape or entry of predators. All treatments were arranged in a completely randomized design on a laboratory bench with four replications and left undisturbed for six months. The susceptibility of the groundnut varieties to *T. granarium* larvae was assessed on the basis of kernel damage, mean kernel weight loss; emerged larval population after 6 months storage period and preference of larvae for groundnut varieties. The head capsule and the mean lengths of different larval instars in the successive instars were mearsured.

Damage Assessment by *T. granarium*

The level of damage done to the stored groundnut kernels was evaluated by calculation. The number of kernels with feeding sites was used. The kernels were picked, separated from the frass and counted. The number of

damaged kernels was also counted and then the percentage damage done was estimated thus:

$$\% \text{ Damage} = \frac{\text{No of damaged kernels}}{\text{Total No of kernels counted}} \times \frac{100}{1}$$

Kernel weight loss

The kernel weight loss was determined by the standard weight method. The initial dry weight(200 g) of each groundnut varieties in each replicate was taken and was later compared with the final weight of each variety after six months storage period. This method was used because *T. granarium* larvae developed inside the kernels.

$$\% \text{ Loss} = \frac{\text{Initial weight} - \text{final weight}}{\text{Initial weight}} \times \frac{100}{1}$$

Total larvae population

The number larvae that emerged in each replicate was determined after repeated sieving at the end of the storage period. The mean lengths of different larval instars were calculated as samples of each larval instar were treated with boiling 10% KOH and preserved in glycerine. The lengths of the larvae and the head capsule in the successive instars were measured at the end of each moult with the aid of a microscope fitted with occular micrometer. A total of 30 replications. The lengths of the larvae obtained were means and standard error calculated for each larval instar from the 30 replications.

Assessment of preference

Assessment of the preference of *T. granarium* for groundnut varieties was carried out as follows;

Ten grams kernels from the six groundnut varieties were alternately arranged in a surgical tray of 35 cm diameter and 14 cm in height placed on a laboratory bench. Fifty fourth instar larvae of *T. granarium* were introduced in the centre cavity of the tray for the trials. The tray was covered with a transparent cellophane material and the experimental set up was replicated three times in three trials. The groundnut varieties were arranged in a completely randomized design at a distance of 5 cm from the center cavity of the tray for the *T. granarium* to feed upon. Counts of number of larvae in each variety were recorded after three days.

3.7 Effects of plant powders on mortality of *T. granarium* larvae on stored groundnuts.

One hundred grams of a commonly consumed variety (SAMNUT 18) were weighed into a plastic container (12 cm in diameter) to which a plant powder was added. Names and details of the plant materials used are given in Table 2.The plant parts (leaves/seeds) powders were admixed with groundnut kernels at 5 g per 100 g weight. The containers were thoroughly agitated to allow adequate mixture of the kernels and powders. Five fourth instar larvae of *T. granarium* were introduced into each container. The containers were covered with muslin cloth secured with elastic rubber band to allow aeration and prevent insect escape. The same treatment was carried out for all plant powders in their respective containers except the untreated

control. The experimental set up including the powder free control was replicated three times and arranged in a completely randomized design on a laboratory bench. Counts of daily mortality of the fourth instar larvae were recorded for three days.

3.8 Effects of crude plant extracts on adult mortality and larval survival of *T. granarium*

The effectiveness of crude extracts was further investigated. They include leaf extracts of *H. suaveolens, R. communis, A. senegalensis* and seed extract of *K. senegalensis* and fruit extract of *X. aethiopica.* Fifty grams of the groundnut variety (SAMNUT 18) were weighed into a plastic container (12 cm in diameter) to which three concentrations each of the extracts (1 ml, 2 ml and 3 ml) were pipetted and admixed with the groundnut kernels. The kernels were stirred using a glass rod until all the kernels were adequately coated with the extracts. Three unsexed adults of *T. granarium* were placed on groundnut kernels treated with the crude extracts. Each container was then covered with a muslin cloth fastened with elastic rubber band to allow aeration and prevent insect escape or entry of predators. All treatments and the extract -free control were replicated three times in three trials making a total of nine replicates pooled together. Counts of daily mortality of the adults following crude extracts treatments were recorded for three days. The dead larvae were removed and discarded. The treatments were then allowed to proceed to the end of six months storage period to study the population increase of larvae every two months.

3.9 Phytochemical screening of plant materials used.

Phytochemical screening of the five most promising plant parts was carried out for the presence of active biopesticide components. Leaves of *A. senegalensis, R. communis* and *H. suaveolens* and seeds of *K. senegalensis* and *X. aethiopica* were screened for the presence of bioactive components as described by Sofowora (1982) and Trease and Evans (1989). The bioactive components assayed were tannin, alkaloids, saponin, polyphenols, flavonoids, steroids and glycosides.

3.9.1 Test for tannins:

Dried powdered plant material (0.5 g each) was stirred with 10 ml distilled water in a test –tube using a glass rod. The mixture was filtered with Whatman No. 1 filter paper. Two drops of 1% ferric chloride was added to 1 ml of the filtrate in another test tube. The formation of a blue –black or blue –green colouration was indicative of the presence of tannins.

3.9.2 Test for alkaloids:

Pulverized plant materials (0.5 g each) were stirred with 5 ml of 1% aqueous hydrochloric acid in a test –tube using a glass rod. The test –tubes of the five plant parts were placed in a 500 ml beaker of water and heated in a water bath . The mixture was then filtered using Whatman No 1 filter paper. One milliliter each of the filtrates was treated with three drops of Wagner's reagent. The Wagner's reagent was prepared by dissolving 1.3 g of iodine and 2 g of potassium iodide in water and diluted to 100 ml using distilled

water. The formation of reddish brown precipitate when Wagner's reagent was taken as an index of the presence of alkaloids.

3.9.3 Test for polyphenols:

Dried powdered plant materials (2.0 g each) were put in a test –tube containing 20 ml of water. The test tubes of all the plant parts (leaves or seeds) were placed in a 500 ml beaker of water and then heated in a water bath at 60^0C A mixture of 1% ferric chloride and 1% potassium ferro cyanide was added. The appearance of a green-blue colouration was indicative of the presence of polyphenols.

3.9.4 Test for flavonoids:

Dried powered plant material (0.5 g each) was dissolved in 2 ml methanol in a test –tube. The mixture was placed in a 500 ml beaker of warm water and heated on a hot plate for 2 minutes. The supernatant was then decanted into another test –tube, into which 2 ml of 1N sodium hydroxide solution was added. The moisture was then observed for colour change. A change in colour of the mixture on addition of concentrated hydrochloric acid was indicative of the presence of flavonoids.

3.9.5 Test for saponins:

Dried powdered plant materials (2.0 g each) were boiled with 40 ml of water in a beaker for 5 minutes. This was filtered while hot and the filtrate allowed to cool. To 5 ml of the extract was added 10 ml of dilute sulphuric acid (0.1

N). This was shaken for 2 minutes and drops of olive oil were added. Milky fluid was taken as an index of the presence of saponin.

3.9.6 Test for steroids

One ml of concentrated sulphuric acid was added to 3 ml of the extract. A colourless solution was indicative of the absence of steroids.

3.9.7 Test for glycosides

Ten milliliters of 50% sulphuric acid was added to 1 ml of the extract in a test-tube. The mixture was heated in boiling water for 15 minutes. Ten ml of fehlings solution (5 ml each of solutions A and B) was added and the mixture was boiled. A light green colouration was indicative of the absence of glycosides.

3.10 Preparation of samples and examination in an infrared spectrometer

A Neat sample method was used. A drop of each plant extract was smeared on the potassium bromide (KBr) disc and then placed on the sample holder. The mixture was then inserted in the machine (Nicolet Avatar 330FT-IR). Molecular vibrations were detected and measured in an infrared spectrum.

3.11 Data Analysis

Mortality data were expressed as percentages of the number of larvae/adults introduced and then subjected to analysis of variance

(ANOVA). The laboratory experiments were arranged in completely randomized design.

Treatment means were separated using the Student – Newman – Keuls test at 5% level of probability.

CHAPTER FOUR

RESULTS

4.1 Susceptibility of groundnut varieties to *T. granarium* first instar larvae.

Table 3 shows the larval damage assessment including percentages recorded after six months of infestation. *T. granarium* first instar larvae were responsible for groundnut damage ranging from 43.0% to 81.4% in the least susceptible (SAMNUT 17) and most susceptible (SAMNUT 22) varieties respectively. There was no colonization of the kernels by secondary insect pests during the storage period. The per cent kernel damage in the least susceptible variety was not significantly ($P>0.05$) different from SAMNUT 18 and SAMNUT 23 varieties. The per cent kernel damage in the most susceptible variety was not significantly different from SAMNUT 21 variety. The kernels were severely damaged after the six months storage period and had to be discarded due to mass webbing and excessive frass production.

Table 4 shows mean weight loss of groundnut varieties as a result of infestation by *T. granarium* first instar larvae after six months storage period. SAMNUT 22 variety had significantly highest mean weight loss of 88.3 g, representing 84.1% after damage. SAMNUT 17 had lowest mean weight loss 60.3 g even though it was not significantly different ($P>.0.05$) compared to SAMNUT 14, SAMNUT 21 and SAMNUT 23. There was also no significant difference in the mean weight losses among all the groundnut varieties in the study. Among the six groundnut varieties, SAMNUT 17 was moderately

Table 3 Larvae *T. granarium* damage assessment after six months storage period.

Groundnut variety	No. of kernels damaged/% kernel damage	
SAMNUT 14	877[b]	(64.3)
SAMNUT 17	689[cd]	(43.0)
SAMNUT 18	650[cd]	(66.1)
SAMNUT 21	929[ab]	(58.4)
SAMNUT 22	1013[a]	(81.4)
SAMNUT 23	781[bd]	(64.1)
C.V%	22.0	
SE±	18.2	
SNK	SD	

*All means were statistically separated at P=0.05 level Student- Newman – Keuls. Percentages in parenthesis. r = 12.

Table 4 Mean weight loss of groundnut varieties caused by *T. granarium* larvae after six months storage period.

Groundnut variety	Damage index (g)/% weight loss	
SAMNUT 14	73.0a	(48.2)
SAMNUT 17	60.3a	(34.1)
SAMNUT 18	75.6a	(69.1)
SAMNUT 21	73.5a	(38.6)
SAMNUT 22	88.3a	(84.1)
SAMNUT 23	72.5a	(53.6)
CV (%)		34.2
SE ($\pm$)		25.7
SNK	NS	

*All means were statistically separated at P=0.05 level Student–Newman-Keuls. Percentages in parenthesis. r =12



Plate 1a: Healthy groundnut kernels before *T. granarium* infestation -SAMNUT 14

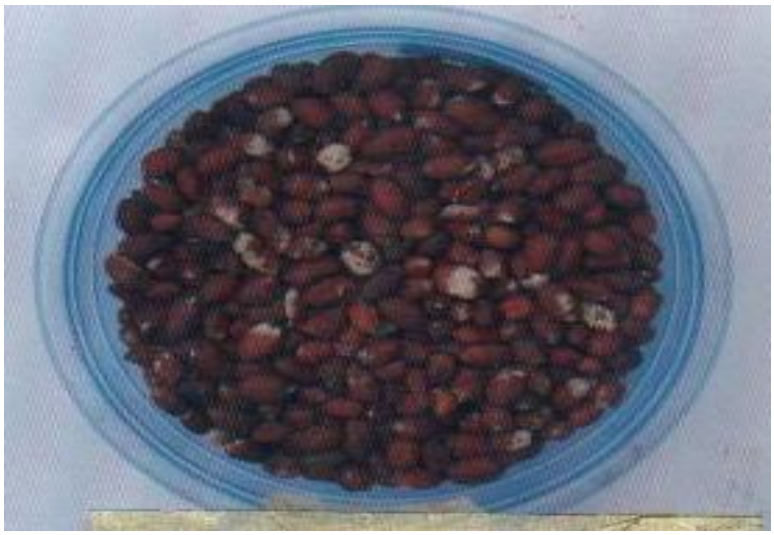


Plate 1b: Visual damage after *T. granarium* infestation – SAMNUT 14



SAMNUT 17

Plate 2a: Healthy groundnut kernels before *T. granarium* infestation –SAMNUT 17



SAMNUT 17

Plate 2b: Visual damage after *T. granarium* infestation –SAMNUT 17



Plate 3a: Healthy groundnut kernels before *T. granarium* infestation – SAMNUT 18



Plate 3b: Visual damage after *T. granarium* infestation – SAMNUT 18



Plate 4a: Healthy groundnut kernels before *T. granarium* infestation – SAMNUT 21



Plate 4b: Visual damage after *T. granarium* infestation – SAMNUT 21



Plate 5a: Healthy groundnut kernels before *T. granarium* infestation – SAMNUT 22

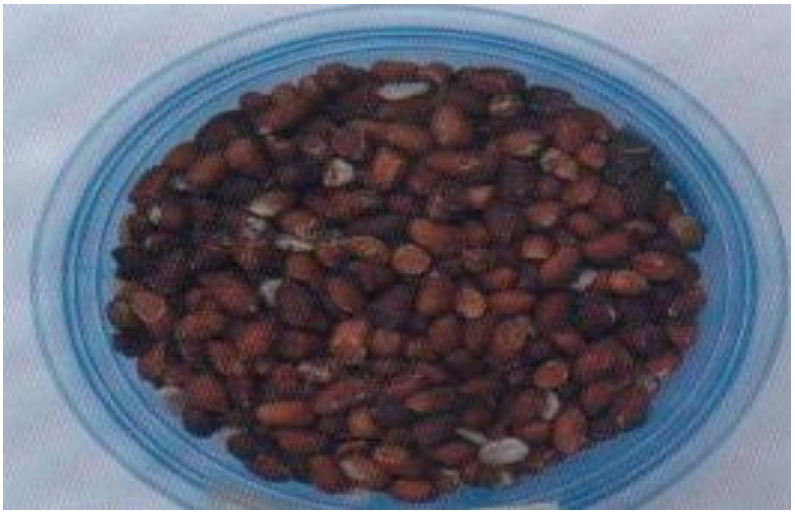


Plate 5b: Visual damage after *T. granarium* infestation – SAMNUT 22



SAMNUT 23

Plate 6a: Healthy groundnut kernels before *T. granarium* infestation –SAMNUT 23



SAMNUT 23

Plate 6b: Visual damage after *T. granarium* infestation –SAMNUT 23

resistant to *T. granarium* first instar larvae compared to other varieties. *T. granarium* larvae were responsible for mean weight damage ranging from 34.1% to 84.1% losses in the least susceptible and the most susceptible groundnut varieties respectively. Plates 1a – 6a show healthy groundnut kernels before infestation. Plates 1b – 6b illustrate visual larva damage six months after infestation. The plates show severe damage and loss of aesthetic value of the kernels after infestation thereby reducing the market value and acceptability by the consumers.

Table 5 shows the total population of *T. granarium* larvae counted in the study after 6 months storage period. Survival of *T. granarium* larvae in SAMNUT 22 was higher than in the other groundnut varieties. SAMNUT 17 had lowest survival of *T. granarium,* which was not significantly different ($P>0.05$) from other varieties. Larval instars were noticed to have free movement to all parts of damaged groundnut kernels. It was found that the medium allowed development of five instar larvae of *T. granarium* as observed in all the varieties (Plate 7). Emosairue (2002) reported that Dyar's Rule can be used to determine the number of actual instars in a species, particularly in a species where the individual moults are not readily observed.

The morphometrics of larval instars of *T. granarium* in stored groundnuts are given in Table 6. The lengths of instars were between 1.59 ± 0.14 mm and 5.34 ± 0.50 mm respectively. These lengths were means of thirty replications. The first instar is creamy white and short, while the second instar bears

Table 5 Total population of *T. granarium* larvae counted after six months storage period.

Groundnut variety	Number of larvae **	
SAMNUT 14	9530[a]	(17.2)
SAMNUT 17	6978[a]	(12.6)
SAMNUT 18	10388[a]	(18.7)
SAMNUT 21	8182[a]	(14.7)
SAMNUT 22	11322[a]	(20.4)
SAMNUT 23	9105[a]	(16.4)
MEAN	770.9	
SNK	NS	

*All figures were not significantly different at P = 0.05 level SNK.
** Percentage in parenthesis. r = 12



Plate 7. Five larval instars of *Trogoderma granarium*

brown head capsule and hairs at the posterior end. The third instar bears hairs at both ends, which are shorter than in the fourth instar. However, third, fourth and fifth instars are reddish brown but the fifth instar is longest and broadest. There was significant difference between the mean body lengths of the five larval instars. However, the mean head capsule width of the larval instars were not significantly different. The first instar had a mean body length of 1.59±0.14 mm and mean head capsule width of 0.08±0.01 mm. The second instar measured 1.73±0.13 mm and 0.25±0.03 mm in body length and head capsule width, respectively. The third instar had mean body length and head capsule width of 2.92±0.40 mm and 0.45±0.20 mm respectively. The body lengths of fourth and fifth larval instars were 4.62±0.33 mm and 5.34±0.50 mm, respectively. The mean head capsule were 0.53±0.05 mm and 0.64±0.04 mm for the fourth and fifth instars respectively. The few adults that infrequently emerged have partly been fed upon by the surviving larvae leaving their wings. The mutilated bodies were indicative of possible cannibalism exhibited by the larvae. The development of *T. granarium* on groundnut kernels was completed in 37±2 days. The life span of the adult is 12 days.

Table 7 shows the preference of *T. granarium* larvae for groundnut varieties. There was no significant difference ($P>0.05$) between the number of larvae found in the groundnut varieties three days after treatment. However, SAMNUT 23 had least mean number of *T. granarium* attracted to it. The

Table 6 Morphometrics of different larval instars of *T. granarium* in stored groundnuts

Stage	Mean length ± SE (mm)	Mean head capsule width ± SE (mm)
First instar	1.6±0.1[d]	0.1±0.0[a]
Second instar	1.7±0.1[d]	0.2±0.0[a]
Third instar	2.9±0.4[c]	0.4±0.0[a]
Fourth instar	4.6±0.3[b]	0.5±0.1[a]
Fifth instar	5.3±0.5[a]	0.6±0.0[a]

*Means followed by the same letter are not significantly different at the P=0.05 SNK. (n=30).

Table 7: Preference of *T. granarium* larvae for groundnuts after six months storage period.

Groundnut Variety	Mean Number of Larvae±SD			
	First Trial	Second Trial	Third Trial	Combined Trials
SAMNUT 14	2.0±0.0	2.0±0.0	3.0±0.0	7.0±0.0
SAMNUT 17	3.3±0.8	3.3±0.8	2.7±0.4	9.7±0.8
SAMNUT 18	2.3±0.4	3.0±0.0	2.7±0.4	8.0±0.0
SAMNUT 21	3.0±0.0	2.0±0.0	2.3±0.4	7.3±0.2
SAMNUT 22	4.3±0.4	4.7±0.4	3.3±0.8	12.3±0.2
SAMNUT 23	1.7±0.4	1.7±0.4	2.7±0.4	6.0±0.0
C.V (%)	52.4	61.1	66.9	37.9
SNK	NS	NS	NS	NS

*Means were statistically separated at P = 0.05 level Student-Newman-Keuls.

investigation produed no significant differences suggesting a similarity in response of the beetles to the groundnut varieties. SAMNUT 22 consistently had highest number of *T. granarium* larvae attracted to it throughout the study while SAMNUT 23 variety had lowest number of the larvae at three days after infestation in the first and second trials. In the third trial, SAMNUT 21 variety had lowest number of *T. granarium* larvae.

4.2 Effect of plant powders on mortality of larvae of *T. granarium*

Effects of plant powders on percent larval mortality of *T. granarium* are shown in Table 8. The leaf powders of *H.suaveolens, R. communis, A. senegalensis*, the fruit powder of *X. aethiopica*, the seed powder of *K.senegalensis* and the leaf powder of *H.crepitans* gave 53.3%, 46.7%, 40.0%, 40.0%, 33.3% and 26.7% larval mortality of *T.granarium* respectively at one day after treatment (DAT). The analysis of variance showed significant difference ($P<0.05$) between the plant powders compared with the control.

The leaf powder of *H.suaveolens*, seed powder of *K.senegalensis*, leaf powder of *R. communis*, fruit powder of *X. aethiopica*, leaf powders of *A. senegalensis, H. crepitans* and *E.camaldulensis* gave 86.7%, 86.7%, 73.4%, 73.4%, 53.3%, 46.7% and 40.0% larval mortality of *T.granarium* respectively at two DAT. All treatments showed significant difference compared with the control.

The leaf powders of *A. senegalensis, H. crepitans R. commumis,* and *H. suaveolens* gave higher larval mortality of 73.4%, 53.4%, 86.6% and 100.0 %. The fruit powder of *X. aethiopica* and seed powder of *K. senegalensis* gave 86.6% and 100.0% mortality three DAT. There was no significant difference in larval mortality between *E. camaldulensis* and the control at one DAT. The leaf powders of *A. senegalensis, H. crepitans, R. communis, H. suavolens* and the fruit powder of *X. aethiopica* and seed powder of *K. senegalensis* recorded higher mortality than the leaf powders of *E. camaldulensis, H. sabdariffa* and *C. pulcherima* which gave 46.7%, 20.0% and 13.4% larval mortality respectively three DAT. The leaf powders of *A. senegalanesis, R. communis, H. suaveolens, H. cepitans* and the fruit powder of *X. aethiopica* and seed powder of *K. senegalensis* were significantly more effective in causing larval mortality. All the plant powders were more effective at the higher dosage than the lower dosage in controlling the number of *T. granarium* fourth instar larvae infesting groundnut kernels.

In all plant powders screened, the mortality rates of *T. granarium* larvae were not significantly different ($P > 0.05$) among powdered leaves of *C. pulcherima, H. sabdariffa* and *E. camaldulensis* (deoiled) and the control at one, two and three DAT. However, a highly significant difference ($P<0.05$) was obtained between *A. senegalensis, H. crepitans, R. communis, K. senegalensis, X. aethiopica,* and *H. suaveolens*. The powders showed toxicity on the fourth instar larvae of *T.*

granarium and control suggesting their effectiveness in evoking mortality of *T. granarium* larvae.

4.3 Effects of crude plant extracts on adult mortality of *T. granarium* on stored groundnuts.

Table 9 shows that all rates of plant extracts have significant effect ($P<0.05$) on adult mortality of *T. granarium*. The mortality effect increased with the concentration. The table shows mortality effects in relation to concentration and exposure time. Analysis of variance showed that there were significant difference among the plant extracts at one, two and three days after treatment (DAT). Groundunt kernels treated with 1ml and

2 ml/50 g kernels of *R. communis, H. suaveolens* and *K. senegalensis* gave no significant difference when compared at one, two and three DAT but were significantly different

Table 8 Effects of dust formulation of different plant specieis on larval mortality of *T. granarium*.

	Percent Larval Mortality		
	Days after treatment		
Treatment	1	2	3
Annona sengalensis	40.0^{abc}	53.3^{abc}	73.4^{ab}
Hura crepitans	26.7^{bc}	46.7^{bc}	53.4^{b}
Ricinus communis	46.7^{abc}	73.4^{ab}	86.6^{a}
Eucalyptus camaldulensis	20.0^{bcd}	40.0^{cd}	46.7^{bc}
E. camaldulensis (deoiled)	0.0^{d}	13.3^{e}	20.0^{cd}
Hibiscus sabdariffa	13.3^{cd}	20.0^{de}	20.0^{cd}
Khaya senegalensis	33.3^{a}	86.7^{a}	100.0^{a}
Xylopia aethiopica	40.0^{abc}	73.4^{ab}	86.6^{a}
Caesalpinia pulcherima	0.0^{d}	6.7^{e}	13.4^{d}
Hyptis suaveolens	53.3^{ab}	86.7^{a}	100.0^{a}
Control	0.0^{d}	0.0^{e}	0.0^{d}
CV (%)	53.1	26.6	24.2

*Means in the same column with the same superscript (s) are not significantly different at P = 0.05 Student-Newman-Keuls test.

with 3 ml/50 g kernels of these plant extracts. The analysis showed that the plant extract treatments at 3 ml/50 g groundnut kernels significantly caused mortality compared with the control. However, leaf extract of *A. senegalensis* and fruit extract of *X. aethiopica* significantly caused adult mortality of *T. granarium* at 2 ml and 3 ml/50 g kernels compared to the control at one, two and three DAT with the latter being more effective.

At one DAT, there was no significant difference between 1 ml and 2 ml/50 g of *R. communis, H. suaveolens, K.senegalensis* and the untreated control. There was no significant difference between 1 ml of *X. aethiopica, A. senegalensis* and the control. The analysis of variance shows no significant difference between 2 ml and 3 ml/50 g of *R. communis*, 3 ml of *H. suaveolens*, 1 ml, 2 ml and 3 ml of *A.senegalensis*, 1 ml and 2 ml/50 g *K. senegalensis.*

At two DAT, there was no significant difference between 3 ml /50 g kernels of leaf extracts of *R. communis, A. senegalensis*, fruit extract of *X. aethiopica* and seed extract of *K. senegalensis*. The analysis of variance shows no significant difference between 2 ml and 3 ml of *R. communis* and *H. suaveolens*, 2 ml/50 g kernels of *X. aethiopica, A. senegalensis* and 1 ml, 2 ml and 3 ml/50 g kernels of *K. senegalensis*.

At three DAT, there was no significant difference between 3 ml/50 g kernels of extracts of *R.communis, H. suaveolens, A. senegalensis, K. senegalensis* and 2 ml and 3 ml/50 g kernels of *X. aethiopica*. All these rates of plant extracts were significantly different from the control ($P<0.05$). This implied that 1 ml/50 g kernel of seed extract of *K. senegalensis* applied at one DAT, 2 ml/50 g of fruit extract of *X aethiopica* and leaf extract of *A. senegalensis* had impact on the mortality of *T. granarium* adults.

At one DAT, adult mortality ranged from 7.4% (for 1 ml leaf extract of *R. communis, H. suaveolens* and fruit extract of *X. aethiopica*) to 74.1% (for 3 ml fruit extract of *X. aethiopica*). The effect of extract concentrations was significant. At two DAT, adult mortality range from 18.5% (for 1 ml leaf extract of *H.suaveolens*) to 88.9% (for 3 ml fruit extract of *X. aethiopica*). At three DAT, adult mortality ranged from 22.2% (for 1 ml leaf extract of *H.suaveolen*) to 92.3% (for 3 ml fruit extract of *X. aethiopica*.)

At the end of one, two, and three DAT, 3 ml/50 g kernels of fruit extract of *X. aethiopica* gave the highest adult mortality of 74.1%, 88.9% and 92.3% respectively while *R. communis, H. suaveolens and H. suaveolens* gave the lowest adult mortality of 29.6%, 59.3% and 66.7% respectively. Only 3.7% adult mortality of *T. granarium* was recoded in the control. The fruit extract of *X. aethiopica* was most efficient showing 92.3% dead insects. This was closely

followed by groundnut kernels to which leaf extract of *R.communis* at the rate of 3 ml/50 g kernels was administered, recording 88.9% of dead insects. Among the experimental treatments, kernels treated with fruit extract of *X. aethiopica*, leaf extracts of *R.communis* and *H.suaveolens* at 1 ml/50 g kernels recorded the least percentage of dead insects (7.4%) at one DAT. There were significant differences between treatment rates for different plant extracts ($P<0.05$).

The combined contributions of the plant extracts during the storage period are shown in Table 9. The percent contribution of fruit extract of *X. aethiopica* (85.2%) at 3 ml/50 g kernels was the highest. This was followed by leaf extracts of *A.senegalensis* (61.7%), *R. communis* (60.5%), seed extract of *K.senegalensis* (59.3%) and leaf extract of *H.suaveolens* (53.1%). The least percent combined contribution to adult *T. granarium* mortality was from *H. suaveolens* in 1 ml (16.0%) and 2 ml (34.6%) per 50g kernels.

The yields of oil extracted from 200g of the plant powders with 400 ml methanol were *R. communis* 4.2 ml (1.05%), *X. aethiopica* 5.6 ml (1.4%), *H. suaveolens* 2.8 ml (0.08%), *A. senegalensis* 3.5 ml (0.88%) and *K. senegalensis* 4.8 ml (1.20%).

4.4 Effects of plant extracts on the survival of *T. granarium* larvae on stored groundnuts.

Table 10 shows the mean numbers of larvae that survived after application of three rates of plant extracts to *T. granariun* on stored groundnut in the first trial. At two months after treatment (MAT), the mean number of larvae ranged from 0.3±0.6 to 7.0±6.2 at 1 ml/50 g kernels of leaf extracts of *R. communis* to fruit extract of *X. aethiopica* respectively; 0.0±0.0 to 4.7±1.2 at 2 ml/50 g kernels of leaf extract of *R. communis* and seed extract of *K. senegalensis* and 0.0±0.0 and 2.7±1.5 at 3 ml/50 g of leaf extract of *R. communis* and seed extract *K. senegalensis*.

At four MAT, the mean number of larvae ranged from 15.3±3.0 to 18.3±7.0 at 1 ml/50 g kernels of leaf extracts of *H. suaveolens* and *R. communis*; 8.7±3.0 and 12.0±3.0 at 2 ml/50 g kernels of *R. communis* and *K. senegalensis* respectively; 5.7±1.5 and 7.7±3.0 at 3 ml/50 g kernels of *X. aethiopica* and *A senegalensis* respectively.

At six MAT, the mean numbers of larvae ranged from 23.0±7.2 to 42.3±3.2 at 1 ml/50 g kernels of *A. senegalensis* and *X. aethiopica*; 13.3±6.8 to 26.7±16.3 at 2 ml/50g kernels of *R. communis* and *H. suaveolens* and 8.3±3.0 and 16.0±1.0 at 3 ml/50 g kernels of *A. senegalensis* and *H. suaveolens*.

Table 9 Effects of three rate rates of plant extracts on adult mortality of *T. granarium* on stored groundnut kernels.

Plant extract	Rates of application (ml)	Percent adult mortality ⟷ Days after treatment 1	2	3	Combined
R. communis	1	7.4^{de}	22.2^{efg}	29.6^{efg}	19.8^{ef}
	2	18.5^{cde}	37.0^{cdef}	51.8^{cde}	35.8^{bcde}
	3	29.6^{bcd}	63.0^{abc}	88.9^{a}	60.5^{a}
H. suaveolens	1	7.4^{de}	18.5^{fg}	22.2^{fg}	16.0^{ef}
	2	18.5^{de}	37.0^{cdef}	48.1^{cdef}	34.6^{cde}
	3	33.3^{bc}	59.3^{bc}	66.7^{abcd}	53.1^{abc}
X. aethiopica	1	7.4^{de}	14.8^{fg}	29.6^{efg}	17.3^{ef}
	2	44.4^{b}	59.3^{bc}	70.4^{abc}	58.0^{ab}
	3	74.1^{a}	88.9^{a}	92.3^{a}	85.2^{a}
A. senegalensis	1	14.8^{cde}	29.6^{defg}	40.7^{def}	28.4^{de}
	2	29.6^{bcd}	48.1^{bcde}	59.3^{bcd}	45.7^{abcd}
	3	33.3^{bc}	70.4^{ab}	81.5^{ab}	61.7^{a}
K. senegalensis	1	18.5^{cde}	40.7^{cdef}	44.4^{cdef}	34.6^{cde}
	2	18.5^{cde}	51.8^{bcd}	59.3^{bcd}	43.2^{abcd}
	3	44.4^{b}	63.0^{abc}	70.4^{abc}	59.3^{a}
Control	0	3.7^{e}	3.7^{g}	3.7^{g}	3.7^{f}
SD $\pm$		0.8	1.0	1.1	2.8

***Means of three replications. Means in the same column with the same superscript(s) are not significantly different at P = 0.05 level SNK**

At two and four MAT the mean numbers of larvae, *T. granarium*, of plant extracts were significantly ($P<0.05$) compared with the control. However, the leaf extract of *R. communis* suppressed survival of larvae of *T. granarium* at 2 ml and 3 ml/50 g kernels two MAT. The effectiveness of the leaf extract *R. communis* was consistently lower compared to other plant extracts at 2 ml/50 g kernels through two, four and six MAT. There was no significant difference between the mean numbers of larvae of leaf extract of *R. communis* at 3 ml/50 g kernels and the mean number of larvae of fruit extract of *X. aethiopica* at 1ml/50 g kernels. However, the mean number of larvae of the leaf extract of *R. communis* at 3 ml/50 g kernels and fruit extract of *X. aethiopica* at 1 ml/50 g kernels were not significantly different from other plant extracts. All treatments were significantly different from the control. Survival of larvae did not differ statistically between different rates of application. However, the different rates of application showed significant difference ($P<0.05$) compared with the control.

Table 11 shows the mean numbers of larvae that survived after application of three rates of plant extracts to *T. granarium* on stored groundnuts in the second trial. The number of larvael decreased with increase in concentration of plant extracts. At two

Table 10: Effects of period of exposure, plant extracts and their rates of application on survival of larvae of *T. granarium* (First Trial)

Plant extract	Rates of application (ml)	Mean number of larvae ± SD		
		Months after treatment		
		2	4	6
R. communis	1	0.3 ± 0.6^{b}	18.3 ± 7.0^{b}	26.3 ± 10.5^{bc}
	2	0.0 ± 0.0^{b}	8.7 ± 3.0^{b}	13.3 ± 4.9^{bc}
	3	0.0 ± 0.0^{b}	6.0 ± 3.0^{b}	12.7 ± 4.0^{b}
H. suaveolens	1	4.7 ± 1.2^{b}	15.3 ± 3.0^{b}	31.7 ± 3.8^{bc}
	2	4.7 ± 1.2^{b}	9.7 ± 1.5^{b}	26.7 ± 16.3^{bc}
	3	0.3 ± 0.6^{b}	6.7 ± 2.1^{b}	16.0 ± 1.0^{bc}
X. aethiopica	1	7.0 ± 6.2^{b}	19.3 ± 9.1^{b}	42.3 ± 3.2^{b}
	2	1.3 ± 2.3^{b}	11.7 ± 3.8^{b}	22.0 ± 3.6^{bc}
	3	0.3 ± 0.6^{b}	5.7 ± 1.5^{b}	13.3 ± 2.5^{bc}
A. senegalensis	1	0.7 ± 1.2^{b}	16.7 ± 8.0^{b}	23.0 ± 7.2^{bc}
	2	0.3 ± 0.6^{b}	10.3 ± 6.1^{b}	22.7 ± 11.6^{bc}
	3	0.3 ± 0.6^{b}	7.7 ± 3.8^{b}	8.3 ± 3.0^{c}
K. senegalensis	1	5.3 ± 5.8^{b}	17.7 ± 3.0^{b}	37.3 ± 9.1^{bc}
	2	4.7 ± 4.7^{b}	12.0 ± 3.0^{b}	14.3 ± 1.5^{bc}
	3	2.7 ± 1.5^{b}	7.7 ± 1.5b	13.3 ± 6.8b^{c}
Control	0	39.0±12.6^{a}	108.7±12.2^{a}	130.0 ±29.6^{a}
SD ±		9.9	24.6	29.4

***Means of three replications. Means in the same column with the same superscript(s) are not significantly different at P = 0.05 level SNK**

months after treatment (MAT), the mean number of larvae ranged from 3.7±4.0 to 19.0±14.2 at 1 ml/50 g kernels of leaf extract of *R. communis* and fruit extract of *X. aethiopica* respectively; 2.3±1.1 to 4.3±4.5 at 2 ml/50 g kernels of seed extract of *K. senegalensis* and leaf extract of *H. suaveolens* and 1.7±1.5 to 4.0±4.0 at 3 ml/50 g kernels of seed extract of *K. senegalensis* and leaf extract of *H. suaveolens.* All treatments were significantly different from the control.

At four MAT, the mean number of larvae ranged from 11.7±3.0 to 31.7±15.8 at 1 ml/50 g kernels of *R. communis* and *X. aethiopica;* 4.7±3.5 to 7.3±6.7 at 2 ml/50 g kernels of *K. senegalensis* and *H. suaveolens* respectively and 3.3±3.2 to 6.3±4.0 at 3 ml/50 g kernels of *K. senegalensis* and *H. suaveolens*. The fruit extract of *X. aethiopica* was not significantly different from the leaf extract of *A. senegalensis* and *H. suaveolens* at 1 ml/50 g kernels. All treatments were significantly different from the control.

At six MAT, the mean number of larvae ranged from 14.3±4.2 to 33.0±13.1 at 1 ml/50 g kernels of *R. communis* and *A. senegalensis*; 8.3±4.9 and 14.0±2.0 at 2 ml/50 g kernels of *X. aethiopica* and *H. suaveolens* and 6.7±2.3 and 9.3±2.3 at 3 ml/50 g *H. suaveolens* and *K. senegalensis* respectively. The leaf extract of *R. communis* gave a mean number of larvae (14.3±4.2) which was not significantly different from the fruit extract of *X. aethiopica* with a mean number of larvae (51.0±15.1) and leaf extract of *A. senegalensis* mean number of larvae (33.0±13.1) at 1 ml/50 g groundnut kernels. There was no significant

Table 11: Effects of period of exposure, plant extracts and their rates of application on survival of larvae of *T. granarium* (Second Trial)

Plant extract	Rates of application (ml)	Mean number of larvae ± SD		
		Months after treatment		
		2	4	6
R. communis	1	3.7 ± 4.0^{b}	11.7 ± 3.0^{c}	14.3 ± 4.2^{b}
	2	3.0 ± 2.6^{b}	6.7 ± 2.8^{c}	12.0 ± 3.0^{d}
	3	2.7 ± 3.8^{b}	5.0 ± 2.6^{c}	8.0 ± 1.0^{d}
H. suaveolens	1	9.3 ± 0.6^{b}	17.0 ± 9.2^{bc}	24.3 ± 5.6^{cd}
	2	4.3 ± 4.5^{b}	7.3 ± 6.7^{c}	14.0 ± 2.0^{d}
	3	4.0 ± 4.0^{b}	6.3 ± 5.8^{c}	6.7 ± 2.3^{d}
X. aethiopica	1	19.0 ± 14.2^{b}	31.7 ± 15.8^{b}	51.0 ± 15.1^{b}
	2	3.7 ± 0.6^{b}	6.3 ± 4.0^{c}	8.3 ± 4.9^{d}
	3	3.0 ± 2.6^{b}	4.0 ± 3.4^{c}	9.3 ± 2.3^{d}
A. senegalensis	1	7.7 ± 6.4^{b}	18.3 ± 7.5^{bc}	53.0 ± 1.9^{b}
	2	2.7 ± 3.8^{b}	6.7 ± 2.0^{c}	9.3 ± 6.6^{d}
	3	2.7 ± 3.0^{b}	4.3 ± 1.5^{c}	8.7 ± 8.3d
K. senegalensis	1	8.3 ± 4.2^{b}	12.0 ± 6.9^{c}	28.3 ± 9.5^{cd}
	2	2.3 ± 1.1^{b}	4.7 ± 3.5^{c}	12.0 ± 4.0^{d}
	3	1.7 ± 1.5^{b}	3.3 ± 3.2^{c}	9.3 ± 2.5^{d}
Control	0	55.0 ± 36.5^{a}	77.7 ± 20.6^{a}	123.0±12.1^{a}
SD ±		15.4	19.3	29.2

***Means of three replications. Means in the same column with the same superscript(s) are not significantly different at P = 0.05 level SNK**

difference (P<0.05) between the mean number of larvae of the leaf extract of *H. suaveolens* (24.3±5.6) and seed extract of *K. senegalensis* (28.3±9.5). All treatments were significantly different from the untreated control.

Table 12 shows the mean numbers of larvae that survived following application of three rates of plant extracts to *T. granarium* on stored groundnuts in the third trial. At two months after treatment (MAT), the mean number of larvae ranged from 11.3±7.0 to 23.7±14.5 at 1 ml/50 g kernels of leaf extracts of *R. communis* and *A. senegalensis* respectively; 7.3±4.7 to 21.0±17.6 at 2 ml/50 g kernels of *R. communis* and *A. senegalensis* and 3.0±2.6 to 6.3±2.5 at 3 ml/50 g kernels of *R. communis* and *K. senegalensis* respectively.

At four MAT, the mean number of larvae ranged from 20.7±7.4 to 40.0±29.5 at 1 ml/50 g kernels of *H. suaveolens* and *A. senegalensis* respectively; 14.0±5.3 and 20.0±5.5 at 2 ml/50 g kernels of *K. senegalensis* and *A. senegalensis* respectively and 6.7±2.3 to 16.3±4.5 at 3 ml/50 g kernels of *R. communis* and *K. senegalensis* respectively. All treatments were significantly (P<0.05) different from the control.

At six MAT, the mean number of larvae ranged from 26.3±9.5 to 49.0±42.8 at 1 ml/50 g kernels of *H. suaveolens* and *A. senegalensis*; 9.0±5.3 and 27.7±3.0 at 2 ml/50 g kernels of *K. senegalensis* and *R. communis* respectively while the mean

Table 12: Effects of period of exposure, plant extracts and their rates of application on survival of larvae of *T. granarium* (Third Trial)

Plant extract	Rates of application (ml)	Mean number of larvae ± SD		
		Months after treatment		
		1	2	3
R. communis	1	11.3 ± 7.0^{ab}	24.3 ± 6.0^{b}	28.7 ± 12.7^{b}
	2	7.3 ± 4.7^{ab}	16.7 ± 3.8^{b}	27.7 ± 3.0^{b}
	3	3.0 ± 2.6^{b}	6.7 ± 2.3^{b}	16.3 ± 4.5^{b}
H. suaveolens	1	12.7 ± 0.6^{ab}	20.7 ± 7.4^{b}	26.3 ± 9.5^{b}
	2	8.0 ± 1.7^{b}	16.3 ± 5.5^{b}	24.3 ± 14.6^{b}
	3	5.3 ± 3.0^{b}	12.7 ± 6.1^{b}	21.0 ± 8.9^{b}
X. aethiopica	1	14.3 ± 14.4^{ab}	25.0 ± 19.3^{b}	30.7 ±20.0^{b}
	2	13.0 ± 10.5^{ab}	16.0 ± 6.2^{b}	27.0 ± 8.5^{b}
	3	4.3 ± 1.5^{b}	12.0 ± 3.6^{b}	9.3 ± 4.2^{b}
A. senegalensis	1	23.7 ± 14.5^{ab}	40.0 ± 29.5^{b}	49.0±42.8^{b}
	2	21.0 ± 17.6^{ab}	20.0 ± 5.5^{b}	17.3 ± 3.5^{b}
	3	5.7 ± 2.0^{b}	11.0 ± 6.7^{b}	12.7 ± 5.9^{b}
K. senegalensis	1	19.7 ± 18.7^{ab}	28.0 ± 18.1^{b}	41.3 ± 14.9^{b}
	2	9.7 ± 1.2^{b}	14.0 ± 5.3^{b}	9.0 ± 5.3^{b}
	3	6.3 ± 2.5^{b}	16.3 ± 4.5^{b}	13.7 ± 6.7^{b}
Control	0	33.7 ± 14.2^{a}	59.0 ±14.8^{a}	85.0 ± 5.2^{a}
SD ±		11.4	15.8	21.9

***Means of three replications. Means in the same column with the same superscript(s) are not significantly different at P = 0.05 level SNK**

number of larvae ranged from 9.3±4.2 and 21.0±8.9 at 3 ml/50 g kernels of *X. aethiopica* and *H. suaveolens*. All plant extract treatments were significantly different from the control at three rates. However, at two MAT, 1 ml and 2 ml of *R. communis* were not significantly different (P> 0.05) from 1 ml of *H. suaveolens*, 1 ml and 2 ml of *X. aethiopica*, *A. senegalensis*, 1 ml of *K. senegalensis* and the extract-free control.

4.5 Combined effects of the plant extracts on the survival of *T. granarium*

Table 13 shows the combined effects of plants extracts on the survival of *T. granarium* on stored groundnuts. Leaf extracts of *R. communis*, *H. suaveolens* and *A. senegalensis* and seed extract of *K. senegalensis* and fruit extract of *X. aethiopica* are significantly (P<0.05) different from the control. Leaf extract of *R. communis* gave lowest number of larvae (3.5±11.2) while fruit extract of *X. aethiopica* had highest mean number of larvae (7.3±19.7). However, all plant extracts were not significantly different from one another at two months after treatment (MAT).

At four MAT, leaf extract of *R. communis* gave lowest mean number of larvae (12.4±15.6) while the leaf extract of *A. senegalensis* gave highest mean number of larvae (15.0±32.5). All treatments were significantly different from the control. At six MAT, leaf extract of *R. communis* had lowest mean number of larvae (17.7±23.2) while *X. aethiopica* had highest mean numbr of larvae (23.7±46.4). All treatment were significantly different from the control. Leaf extract of *R. com*

Table 13 Combined effects of crude extracts on emergence of *T.granarium* larvae on stored groundnuts.

	Mean number of larvae ± SE Months after treatment		
Plant extract	2	4	6
R. communis	3.5±11.2[b]	11.6±20.3[b]	17.7±23.2[b]
H. suaveolens	5.9±10.7[b]	12.4±15.6[b]	21.2±23.1[b]
X. aethiopica	7.3±19.7[b]	14.6±28.1[b]	23.7±46.4[b]
A. senegalensis	7.2±26.9[b]	15.0±32.5[b]	20.4±40.6[b]
K. senegalensis	6.7±16.6[b]	12.9±22.6[b]	19.8±37.4[b]
Control	42.7±33.2[a]	81.8±75.3[a]	112.7±72.6[a]
SE±	32.5	57.4	75.2

- All plant extract treatments were significantly different from the control at P = 0.05. Means followed by a common letter are not significantly different at 5% probability level (S N K) .

munis consistently had lowest mean number of *T. granarium* larvae through the six months storage period.

4.6 Correlation coefficient of time of exposure of *T. granarium* larvae to plant extracts

The correlations among different periods of exposure in all cases were positive and highly significant (Table 14). The table shows the relationship between different periods of infestion when the data on the first, second, and third trials were combined. This indicated that the more the period of exposure to crude extracts, the less the tendency of the *T. granarium* larvae to develop to maturity and subsequent generations. The strength of this relationship between the four and six months infestation appeared to be stronger (r= 0.669**).

The survival of larvae *T. granarium* two and four months after treatments were positively correlated with crude plant extract treatments, the correlations being positively significant at 5% probability level. There was strong suggestion of close association between survival of larvae and crude extracts. This implied that increase in period of exposure of larvae to the plant extracts affected the development of the insects.

4.7 Active organic chemical ingredients in the test plant

Table 15 shows the presence or absence by chemical analysis of flavonoid, saponins, tannins, polyphenols, steroids, glycosides and alkaloid contents in the

Table 14 Matrix of correlation coefficients between different months of exposure of *T. granarium* larvae to crude extracts.

Means across three trials

	V1	V2	V3
V1	1.000		
V2	0.927**	1.000	
V3	0.759**	0.669**	1.000

V1 = second month; V2 = fourth month; V3 = sixth month.

Values are correlation coefficients at P = 0.05

various plant materials. The results showed that *X. aethiopica* contained flavonoids, saponins, tannins, polyphenols, steroids, glycosides and alkaloids to different content. However, only flavonoids and polyphenols were detected in *A. senegalensis* and *R. communis. K. senegalensis* contained saponins and polyphenols while *H. suaveolens* contained flavonoids, polyphenols and alkaloids. The resultant effects of flavonoids and other components have been reported in the literature. The distribution of flavonoids is widespread in higher plants (Harborne, 1988), their occurrence in plant tissue can deter insect feeding and inhibit pathogen attack of crops. The isoflavones coumestrol, phaseollin and afrormosin which occur abundantly in soyabean foliage, often serve as an effective antifeedant against phytophagous insects.When fed at low concentrations to insects, several flavonoids also repelled feeding by the larvae of *Pectinophora gossypiella* (Schoonhoven, 1972).

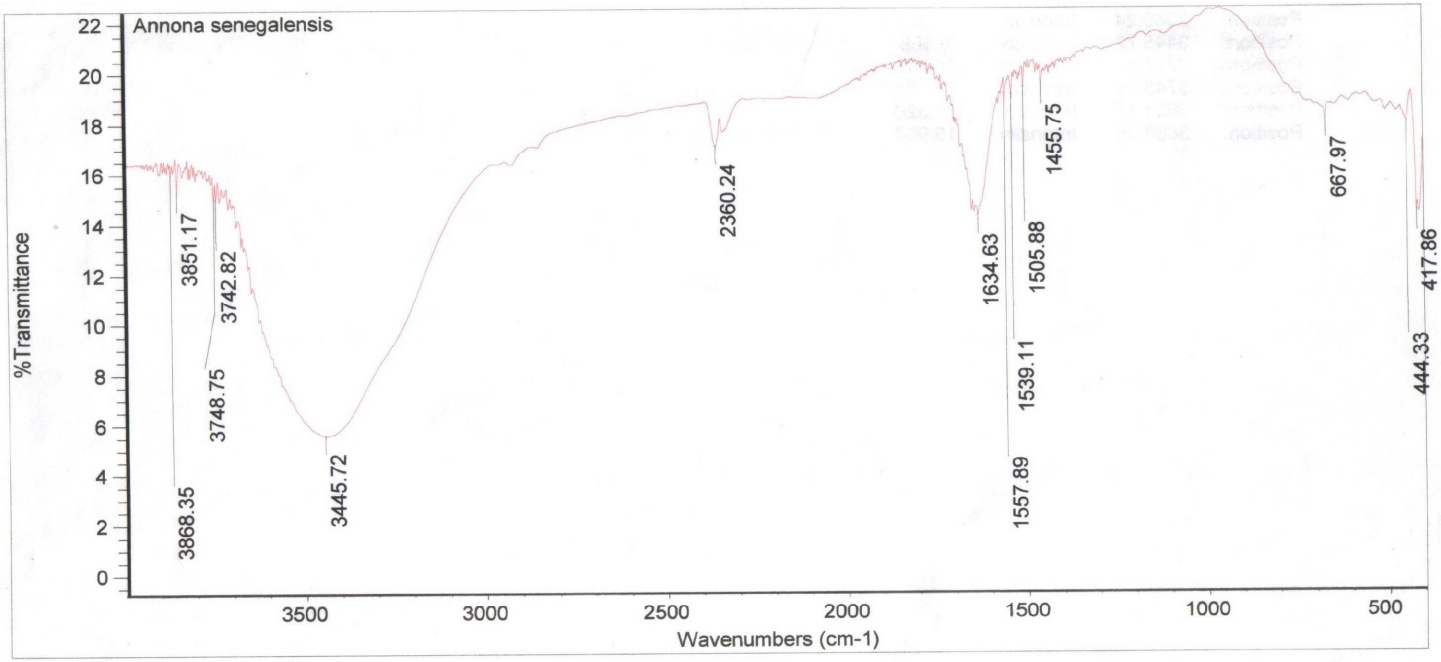
4.8 **Spectroscopic analysis of the test plants**

Infrared spectroscopic analysis of the organic compounds of the test plants was investigated. Figure 2 shows the appearance and relative intensities of the absorption peaks of *A. senegalensis* due to a number of functional groups of organic compounds present in the test plant. The wide variety of fingerprints shows the usefulness of this region for identification of various components. The organic compounds of the test plant were absorbed in the regions 3445.72

Table 15 Qualitative analysis of the active biopesticide components of the test plants.

Plant material	*Flavonoids*	*Saponins*	*Tannins*	*Polyphenols*	*Steroids*	*Glycosides*	*Alkaloids*
A. senegalensis	+	-	-	+	-	-	-
H. suaveolens	+	-	-	+	-	-	+
X. aethiopica	+	+	+	+	+	+	+
R. communis	+	-	-	+	-	-	-
K. senegalensis	-	+	-	+	-	-	-

Key
+ = chemical ingredient detected (present)
- = chemical ingredient not detected (absent)



Fri Jul 21 10:46:07 2006 (GMT+02:00)
FIND PEAKS:
Spectrum: Annona senegalensis
Region: 3999.84 400.00
Absolute threshold: 22.205
Sensitivity: 49
Peak list:

Position:	417.86	Intensity:	14.227
Position:	444.33	Intensity:	17.964
Position:	667.97	Intensity:	18.040
Position:	1455.75	Intensity:	19.476
Position:	1505.88	Intensity:	19.363
Position:	1539.11	Intensity:	19.039
Position:	1557.89	Intensity:	18.492
Position:	1634.63	Intensity:	14.256

Fig. 2. Absorbance peak of *Annona senegalensis* leaf extract

cm^{-1} and 667.97 cm^{-1} wave lengths at the high frequency and low frequency respectively.

Table 16 indicates the features of functional groups found in the organic compounds of the leaf extract of *A. senegalensis.* It shows the narrower ranges within which each of the functional groups absorbs. The spectrum shows a series of absorbance peak with varying wavelengths. Amine and amide absorbed in the regions 3445.2 cm^{-1} and 1634.63 cm^{-1} wavelengths while alkene absorbed in the region 667.97 cm^{-1} wavelength..

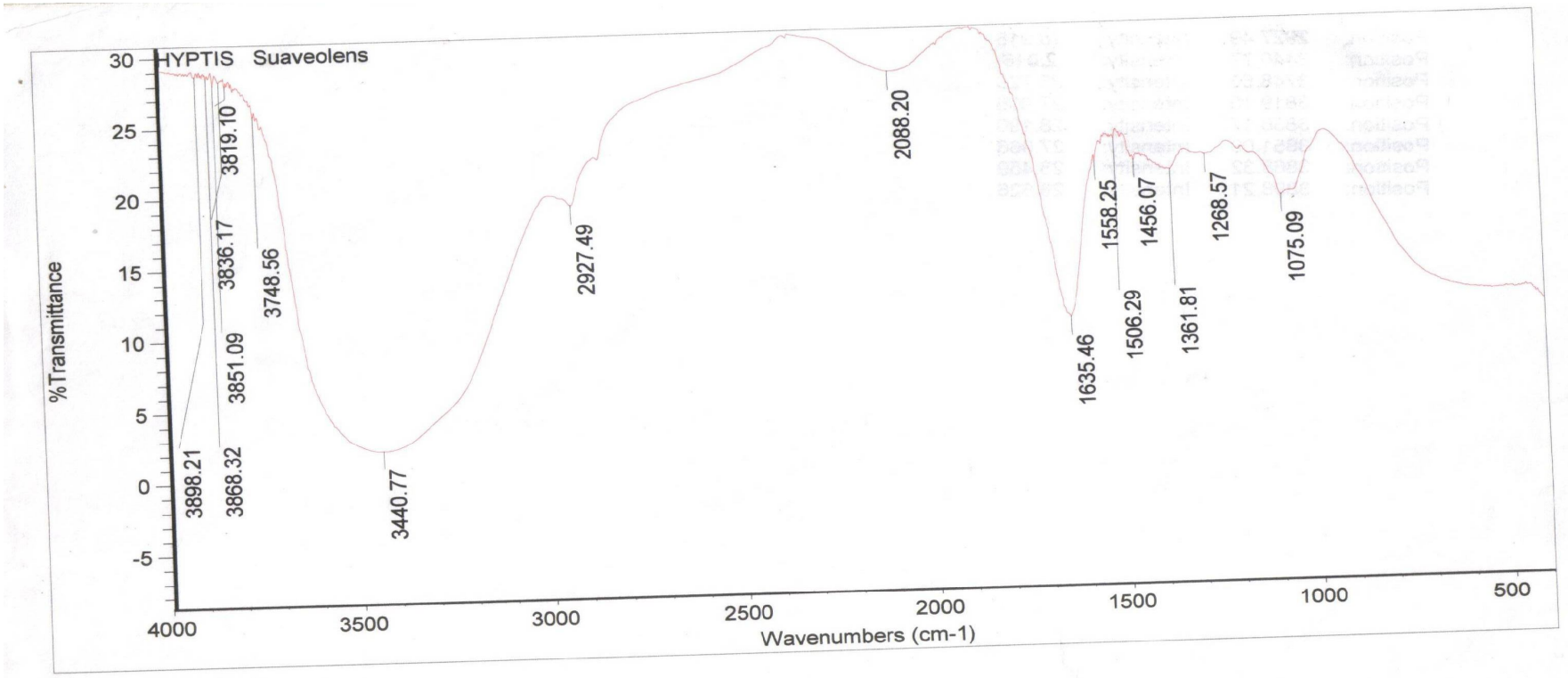
Figure 3 shows the appearance and relative intensities of the absorption peaks of *H. suaveolens* due to a large number of functional groups of organic compounds in the test plant. The functional groups were absorbed between 3440.77 cm^{-1} at the high frequency end and 1075.09 cm^{-1} at the low frequency end.

Table 17 shows the features of functional groups present in the organic compounds of the leaf extract of *H. suaveolens.* Amine, imine and aldehydes were observed at different absorption wavelengths of 3440.77 cm^{-1} , 2927.49 cm^{-1} and 1075.09 cm^{-1} respectively.

Figure 4 shows the appearance and relative intensities of the absorption peaks of *K. senegalensis* due to a number of functional groups in the test plant.

Table 16 **Suspected functional groups of organic compounds in *A. senegalensis***

Peaks (cm^{-1})	Intensities	Structural unit
3445.72	5.586	$-NH_2$,$=NH^+$
2360.24	17.078	$\rangle NH_2^+$, $\rangle NH^+$, $=NH^+$
1634.63	14.256	$-NH_2$, or $\rangle C=C\langle$
1557.89	18.492	NH_2
1539.11	19.039	$\rangle NH$
1505.88	19.363	$\rangle NH$ } conjugated
1455.75	19.476	$\rangle C\text{-}H$ } nitro-NO_2
667.97	18.040	$^{H_R}\rangle C = C\langle^{H_R}$



Wed Jul 26 10:11:09 2006 (GMT+02:00)
FIND PEAKS:

Spectrum:	HYPTIS	Suaveolens
Region:	4000.00	400.00
Absolute threshold:	30.376	
Sensitivity:	69	

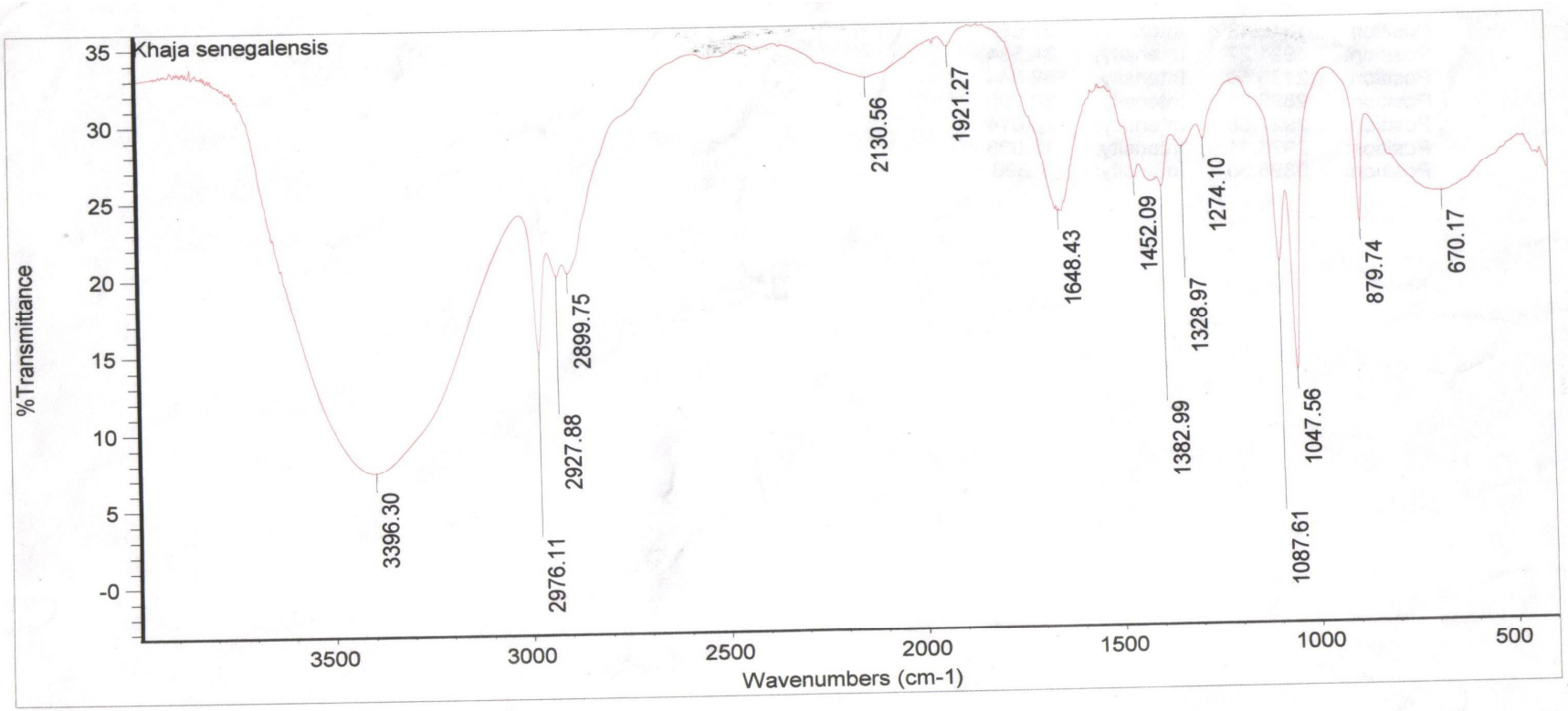
Peak list:

Position:	1075.09	Intensity:	18.274
Position:	1268.57	Intensity:	21.272
Position:	1361.81	Intensity:	20.251
Position:	1456.07	Intensity:	20.947
Position:	1506.29	Intensity:	22.573
Position:	1558.25	Intensity:	20.946
Position:	1635.46	Intensity:	10.066
Position:	2088.20	Intensity:	27.752

Fig. 3. Absorbance peak of *Hyptis suaveolens* leaf extract

Table 17 **Suspected functional groups of organic compounds in *H. suaveolens***

Peaks (cm^{-1})	Intensities	Structural unit
3440.77	2.016	$-NH_2$,$=NH_2$ or –O-H
2927.49	18.918	$\rangle CH_2$ $-CH_3$
2088.20	27.752	-C=O=N-
1635.46	10.066	$-NH_2$ or $\rangle C=C\langle$
1506.29	22.573	$\rangle NH$
1456.07	20.947	$\rangle$C-H
1268.57	21.272	-O-N bonding
1075.09	18.274	$\rangle$ C-OH,C-O stretching



Fri Jul 21 11:08:10 2006 (GMT+02:00)
FIND PEAKS:

Spectrum:	Khaja senegalensis		
Region:	3999.84	400.00	
Absolute threshold:	35.972		
Sensitivity:	60		
Peak list:			
Position:	670.17	Intensity:	24.530
Position:	879.74	Intensity:	22.591
Position:	1047.56	Intensity:	13.089
Position:	1087.61	Intensity:	20.210
Position:	1274.10	Intensity:	28.273
Position:	1328.97	Intensity:	27.797
Position:	1382.99	Intensity:	25.181
Position:	1452.09	Intensity:	25.789

Fig. 4. Absorbance peak of *Khaya senegalensis* seed extract

The functional groups of *K. senegalensis* were absorbed between 3396.30 cm^{-1} at the high frequency end and 670.17 cm^{-1} at the low frequency end.

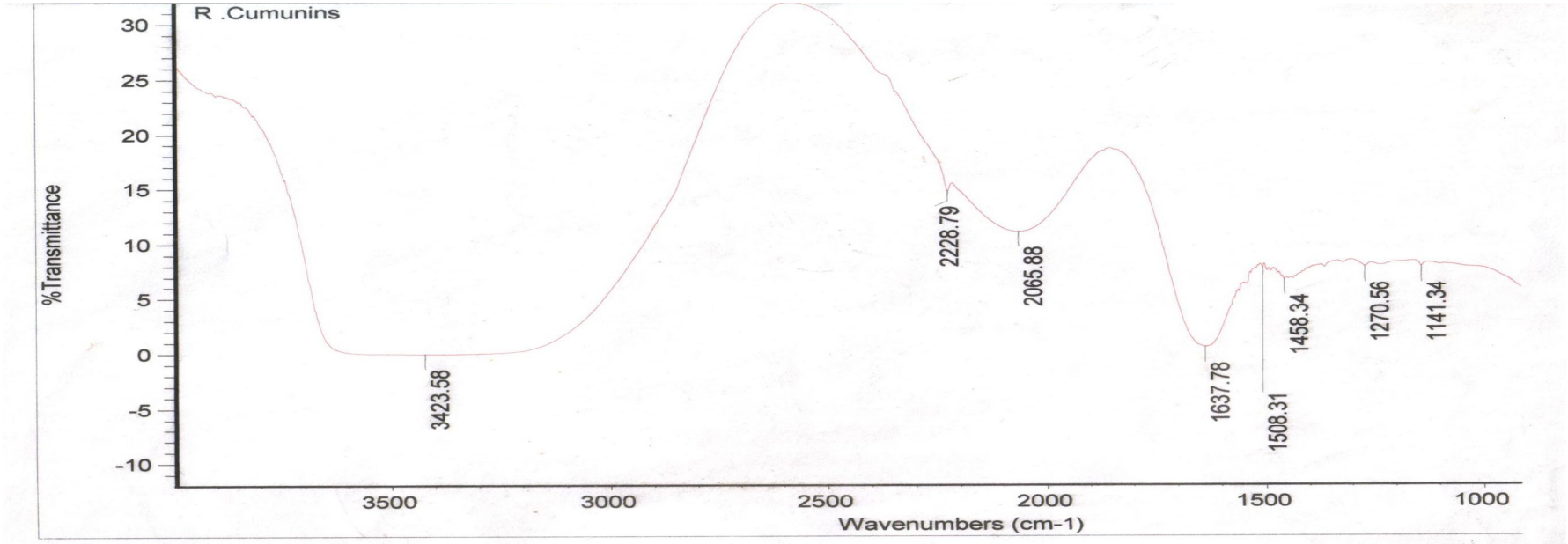
Table 18 shows the features of functional groups present in the organic compounds of the seed extract of *K. senegalensis*. Alkenes and quinines were absorbed at 3396.30 cm^{-1} wavelengths and 1648.43 cm^{-1} wavelengths respectively. Carboxylic acids were absorbed between 2899.75 cm^{-1} and 2976.11 cm^{-1} respectively.

Figure 5 shows the appearance and relative intensities of the absorption peaks of *R. communis* due to a number of functional groups in the leaf extract of the plant. The functional groups of the organic compounds were absorbed between 3423.58 cm^{-1} wavelengths at the high frequency end and 1141.34 cm^{-1} wavelengths at the low frequency end.

Table 19 shows the features of functional groups present in the organic compounds of the leaf extract of *R. communis*. H– bonded –0H in the range 3600 cm^{-1} and 3200 cm^{-1} at the high and low frequency, which was broad. There were organic compounds, which include imines and oximes at 2228.79 cm^{-1} wavelengths. There was presence of alkyl sulphide at 2065.88 cm^{-1}. The isothicyanates were absorbed at the absorbance peak of 2065.88 cm^{-1}. The region was broad and very intense. Other functional groups suspectetd were secondary amides and nitramines at 1508.31cm^{-1} and 1270.56 cm^{-1} respectively.

Table 18 Suspected functional groups of organic compounds in *K. senegalensis*

Peaks (cm^{-1})	**Intensities**	**Structural unit**
3396.30	7.398	–O–H –C ≡ C–H
2976.11	15.038	⟩CH_2,– CH_3
2927.88	20.014	
2899.75	20.200	⟩CH
1452.09	25.789	⟩CH ⟩CH_3
1382.99	25.181	– CH_3 –$C(CH_3)_3$
1328.97	27.797	⟩C=C⟨
1274.10	28.273	–O–H = C–O–C⟨
1087.61	20.210	⟩ C–OH,C–O stretching
1047.56	13.089	–⟩ C–O–C⟨–
879.74	22.591	R_2C=C⟨$^{H}_{R}$
670.17	24.530	$^{H}_{R}$⟩C=C⟨$^{H}_{R}$



Fri Jul 21 10:49:49 2006 (GMT+02:00)
FIND PEAKS:

Spectrum:	R .Cumunins		
Region:	3999.84	400.00	
Absolute threshold:	31.582		
Sensitivity:	74		
Peak list:			
Position:	1141.34	Intensity:	7.953
Position:	1270.56	Intensity:	7.945
Position:	1458.34	Intensity:	6.700
Position:	1508.31	Intensity:	7.802
Position:	1637.78	Intensity:	0.595
Position:	2065.88	Intensity:	11.123
Position:	2228.79	Intensity:	14.781
Position:	3423.58	Intensity:	0.0037

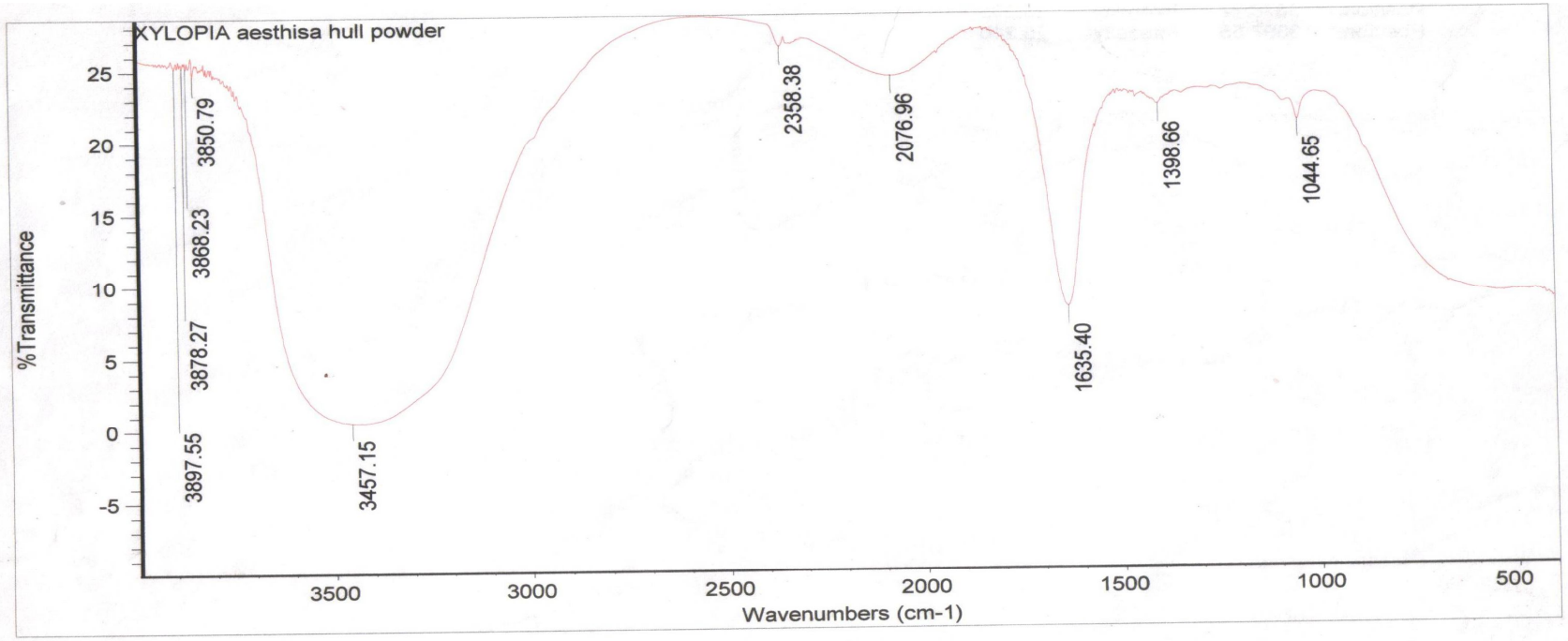
Fig. 5. Absorbance peak of *Ricinus communis* leaf extract

Table 19 **Suspected functional groups of organic compounds in *R. communis***

Peaks (cm^{-1})	Intensities	Structural unit
3423.58	0.0037	–O–H $–NH_2$ $=NH_2$
2228.79	14.781	–C≡C– –C≡N
2065.88	11.123	–C=C=N– ––N=C=S
1637.78	0.595	$–NH_2$
1508.31	7.802	⟩NH –CS–NH–
1458.34	6.700	⟩C-H
1270.56	7.945	–O–H $–N–NO_2$ $O–NO_2$
1141.34	7.953	–O–H

Figure 6 shows the appearance and relative intensities of the absorption peak of fruit extract of *X. aethiopica* due to a number of functional groups in the test plant. The functional groups of the organic compounds were absorbed between 3897.65 cm^{-1} at the high frequency end and 1044.65 cm^{-1} at the low frequency end.

Table 20 shows the features of functional groups in the organic coumpounds of the fruit extract of *X. aethiopica*. Amides, amines, alkyl and carboxyl groups were organic groups absorbed at varying wavelength of the spectrum.



Fri Jul 21 10:41:55 2006 (GMT+02:00)
FIND PEAKS:

Spectrum:	XYLOPIA aesthisa hull powder		
Region:	3999.84	400.00	
Absolute threshold:	28.464		
Sensitivity:	63		
Peak list:			
Position:	1044.65	Intensity:	21.031
Position:	1398.66	Intensity:	22.202
Position:	1635.40	Intensity:	8.171
Position:	2076.96	Intensity:	24.362
Position:	2358.38	Intensity:	26.466
Position:	3457.15	Intensity:	0.543
Position:	3850.79	Intensity:	24.598
Position:	3868.23	Intensity:	25.168

Fig. 6. Absorbance peak of *Xylopia aethiopica* fruit extract

Table 20 **Suspected functional groups of organic compounds in *X.aethiopica.***

Peaks (cm^{-1})	Intensities	Structural unit
345.15	0.543	–O–H $–NH_2$ $=NH_2$
2358.38	26.466	$\rangle NH_2^+$, $–\rangle NH^+$ $=NH^+$ –C≡N
2065.88	11.123	–C=C=N– ––N=C=S
1637.78	0.595	$–NH_2$
1508.31	7.802	⟩NH –CS–NH–
1458.34	6.700	⟩C-H
1270.56	7.945	–O–H $–N–NO_2$ $O–NO_2$

CHAPTER FIVE

DISCUSSION

5.1 Susceptibility of groundnut varieties to *T. granarium* larvae.

Results showed that the different groundnut varieties had varying degrees of susceptibility to first instar larval infestation in terms of mean kernel weight loss, kernel damage assessment, total larvae population and preference for groundnuts by *T. granarium* larvae. The improved groundnut varieties had varying degrees of susceptibility to *T. granarium* in storage. The damaged kernels were characterized by high presence of frass and exuviate as a result of larval feeding and development. The first instar larvae fed on the kernels but the level of damage could have been more if higher instars were initially used to infest the kernels.

The changes in the insect population that took place over the six months storage period were associated with heating, which was probably the result of the combined effects of insect metabolism and the oxidation of oil in the insect damaged groundnut (Smith, 1968). A considerable number of *T. granarium* larvae appeared in the varieties after 6 months storage period. This was probably due to suitability of the varieties for multiplication of the insect and damaged condition of the groundnuts. The least susceptible variety had percent weight loss of 34.1. Comparatively SAMNUT – 22 variety had significantly higher level of infestation (84.1%) than other varieties. The susceptibility of the

stored groundnut kernels to *T. granarium* depended on variety of crop, hardness of kernel coat, kernel colour, kernel length, smoothness, roughness and coarseness. Singh *et al*. (1980 a,b) had earlier associated the susceptibility of stored food commodity to the variety of crop, seed size, insect species and environment. Hopkins (1955) summarized that *Trogoderma* larvae generally preferred cracked grains and grain dusts to clean, wholesome sound grains and they developed faster on processed and milled products than unprocessed materials.

The larvae of *T. granarium* were the predominant insect pest stage on the stored groundnuts. Five larval instars of the pest were found after six months storage period. Odeyemi and Hassan (1993) reported that *T. granarium* has 4-6 instars. The separate instars encountered could be attributed to the observation of Odeyemi (1997), who reported that larvae became bigger in crowded conditions than those reared under isolated conditions.

The free moving larvae were active on the surface of the kernels after agitation and there were no other insects found in the containers after the storage period. The occurrence of pupae and adults was occasional, low and irregular. The possible use of breeding to introduce characters of interest among different groundnut varieties hold future promise. Development and incorporation of effective trap (Barak, 1989; Barak *et al., 1990)* have also been found useful against *T. granarium.* The number of larval instars in this study and in the study

reported by Odeyemi and Hassan (1993) differed. They reported that the larval instars can vary from 4 to 6 depending on prevailing condition. In this study, the five larval instars may be explained by availability of nutritive diet and the optimum environmental conditions. Odeyemi (1997) observed that there was significant difference in the values of body length, body width and head capsule width of *T. granarium* at late and early days of hatching.

5.2 Mean mortality of *T. granarium* as influenced by plant powders

Results obtained suggested that the plant powders caused mortality of *T. granarium* larvae. The poor performance of *C. pulcherima* was in agreement with the findings of Rao (1957), which reported that extracts of flowers of *C. pulcherima* tested against *S. oryzae* on filter paper were ineffective. Another member of the family Caesalpiniaceae, *Cassia occidentalis* L. seed oil did not reduce oviposition of *C. maculatus* at 10 ml/kg seed (Lienard *et al.*, 1993).

The ineffectiveness of deoiled *E. camaldulensis* leaf powder was probably due to extraction of bioactive components along with oily extract before use leaving the residue. It has been reported that between 0.35 and 1.2% volatile essential oils have been processed from leaves of *E. camaldulensis* (Zainab, 1986). In Nigeria, *Eucalyptus* occurs in all the main vegetation and the leaves are efficient in killing bacteria and are used as antiseptic because of the presence of some volatile aldehydes (Dike and Mshelia, 1997). In this study, the undefatted *E.*

camaldulensis was, however, able to suppress the survival of the larvae compared to deoiled powder. The effectiveness could increase if the concentration is increased or more time allowed for exposure of larvae.

The promising biopesticides among the nine indigenous plants screened in this study were *H. suaveolens, R. communis, A. senegalensis* leaf powders and *X. aethiopica, K. senegalensis* fruit/seed powders. It has been known in history that *A. senegalensis* has insecticidal effects against several insects as a result of contact action, stomach poison, repellence or ovicidal action (Harper *et al*., 1947). *A. senegalensis* leaves are very fragrant and has been used as food/drink and for medical purposes by humans and repellant to control stored grain pests (Dalziel, 1937; Giles, 1964).

The efficacy of *R. communis* on *Trogoderma* in this study agreed with the findings of Okonkwo and Okoye (1992). The leaf powder admixed with 100 g groundnut kernels gave mortality of 86.6% in 3 days. Similarly, 1-5 g of dry ground castor leaves, *R. communis* mixed with 300 g cowpea seeds, achieved 100% mortality in 7 days (Okonkwo and Okoye, 1992). In a corroborated experiment, aqueous leaf extract of *R. communis* showed excellent insecticidal activity against *C. chinensis* L. (Upasani *et al*., 2003). They isolated and tested flavonoids as insecticidal and antimicrobial agents of the plant. Care must be taken in the use of castor oil plant due to presence of toxic substance, ricin, which causes pains and death. The toxic substance can be removed by

dissolving the castor oil plant in sodium carbonate solution. (Personal communication)

In this study, *H. sabdariffa* leaves were ineffective in the control of *T granarium* larvae. This may be due to absence of potential biopesticides in the leaves. Hopkins and Chisholm (1960) reported that seed oil of *H. sabdariffa* contains epoxy and cylopropene acids. Reports further indicate that the seeds of *H. sabdariffa* has high oil and protein contents (Mohiuddin and Zaidi, 1975). In Nigeria, it is only the swollen calyces and bracts of the roselle fruits that are eaten (Daramola, 1984).

In this investigation, 5 g of *H. suaveolens* leaf powder mixed with 100 g kernels achieved 100% mortality in 3 days. *H. suaveolens* is a rich source of compounds with anti-insect activity, which is believed to act as a defence mechanism in the plant (Cole, 1992). It is a common weed that is found growing in most wastelands (Akobundu and Agyakwa, 1998) as such could be easily obtained by farmers and used for pest management (Keita *et al*., 2006). The use of these plant parts in the control of *T.granarium* will serve as alternative to the use of methyl bromide, which has been banned because of its detrimental effect on the environment. There could be the need to fine other compatible alternatives in order to enhance and integrated control approach against *T. granarium*.

5.3 Mean mortality of *T. granarium* adults as influenced by crude plant extracts

Results obtained showed that the use of plant extracts (leaf, fruit / seed) in protecting groundnut against *T. granarium* was effective in causing mortality as the number of surviving adults was significantly different from to the untreated control. The highest rate of 3 ml / 50 g kernel treatment gave appreciable reduction in the number of surviving adults. This could be attributed to the acute contact action of the extracts on the insect body, blockages of spiracles (asphyxiation), volatile components, etc. The surviving adults were still active when disturbed and laid eggs before they died. Treatment of kernels with doses of plant extracts ranging from 1.0 – 3.0 ml / 50 g kernel was effective in causing mortality of adult *T granarium.* All the plant extracts were more effective at the higher dosages than lower dosages. However, there was increased mortality of adult *T. granarium* with increase in rates of treatment. This shows that crude plant extracts were effective in protecting from *Trogoderma* infestation and damage.

Leaf extract of *R. communis* taint the colour of the groundnut kernels, which also appeared wrinkled and discoloured. However, the appearance of kernels treated with *K. senegalensis* seed extract was most acceptable. The leaves of *A. senegalensis* serve as livestock feed. The seeds have been reported to cause pain in the eyes and care must be taken in its use. Mclaughlin *et al*.(1996) have

attributed insecticidal action of *A. senegalensis* to acetoginins, which powerfully inhibit ATP production in respiratory process. The effectiveness could also be ascribed to identified components such as squamon, asimicin, desacetyluvaricin especially in *A. glabra* L. (Ohsawa *et al.*, 1991). When castor oil (*R. communis*) was added to the diet of *T. granarium* at levels of 7 – 30% by weight, the oil retarded the growth of *T. granarium* and increased mortality (Punj *et al.*, 1970). This could be attributed to the presence of ricin and organic compound (flavonoids) in *R. communis*. The effectiveness of *H. suaveolens* could be due to the presence of hypatadienic acid, certain alkaloids, and phenols (Rao *et al.*, 1990); hydrobenzoic and hydrocinnamic acids (Schulz and Karl, 1980). These crude extracts have been shown to be effective in the control of *T. granarium* since the insect has been reported to have developed resistance to other chemical insecticides including phosphine (Bell and Wilson, 1995). All the treatments caused adult *T. granarium* mortality with increasing efficacy as the quantity of the extracts increased. Fruit extract of *X. aethiopica* applied at 2 ml/50 g kernels gave the highest mortality of 44.4%, 59.3% and 70.4% at one, two and three DAT. At 3 ml/50 g kernels, fruit extract of *X. aethiopica* gave 74.1%, 88.9% and 92.3% at one. Two and three DAT respectively. Excellent performance of fruit extract of *X. aethiopca* was therefore, observed from one to three DAT at 3 ml/50 g kernels. Thus fruit extract of *X. aethiopica* is effective alternative to synthetic fumigants in the control of *T. granarium.*

5.4 Mean survival of *T. granarium* larvae as influenced by crude extracts

Results obtained showed that applications of crude extracts of *A. senegalensis, R. communis, H. suaveolens* leaves and *K. senegalensis* seeds and *X. aethiopica* fruits in storing groundnut reduced surviving *T. granarium* larvae. The level of treatment was significantly different ($P<0.05$) compared to no application at all. These results indicated that decrease in larval survival was accounted for by the concentrations of the crude extracts and period of exposure. The efficacy of the crude extracts could further be enhanced by exposing the insect to higher concentrations than the concentrations used in this study. However, the potency of these extracts depends largely on their volatile bioactive components.

During emergence of the larvae of *T. granarium*, the untreated control showed mutilated cannibalized adults with no signs of parasitoids/parasites or predators in the containers. The numerous larvae were probably responsible for the cannibalism. The larvae settled in holes or were moving freely on the kernels while few adults were seen moving freely whether disturbed or not.

The bioactive agent, phenol, was found in all the test plants. The organic components recorded in the test plants were effective in reducing *T. granarium* population, although they could occur at varying proportions with other active ingredients. The results of the bioactive chemical components of the test plants

revealed that *A. senegalensis, H. suaveolens, X. aethiopica and R. communis* also contained flavonoids. Saponins were present in *X. aethiopica* and *K. senegalensis* while tannins, steroids and glycosides were contained in *X. aethiopica* only. *H. suaveolens* and *X. aethiopica* contained alkaloid. The major bioactive chemical components of the test plants were flavonoids, polyphenols, saponins, tannins, alkaloids, glycosides and steroids. The most important of these bioactive constituents of plants are alkaloids, tannins, flavonoids and phenolic compounds (Hill, 1952). Alkaloids, flavonoids, saponins and tannins are principal bioactive agents present in most medicinal plants (Sofowora, 1982). Similarly, flavonoid has been reported to be a component of *R. communis* (Upasani *et al.,* 2003) while *H suaveolens* contains certain alkaloids, acids and phenols (Dukes, 1980; Rao *et al.,* 1990).

5.5 Organic components of the test plants

Synthetic chemicals consist of a single compound only and so it is easier for an insect to develop resistance to them, compared to plant products which are a complex mixture of defence chemicals. Fruit extract of *X. aethiopica* contains all the chemical components tested and these include flavonoids, saponins, tannins, polyphenols, steroids, glycosides and alkaloids. These components were possibly responsible for attacking different targets in groundnuts treated and the *Trogoderma*. Polyphenols are phytochemical chameleons (Haslam, 1993). All high and low tannin trees were in a large forest light gap subjected to

naturally occurring herbivores. After ten days the losses of leaf surfaces eaten by insects were 80% higher in low tannin plants than in high-tannin plants (Coley, 1986). Exploiting biological molecules like tannins, alkaloids, etc. will promote agricultural production and especially food security. Phytochemicals are the molecules of the future.

Williams and Fleming (1987) reported that the usual range of an infrared spectrum is between 4,000 cm^{-1} at the high frequency end and 625 cm^{-1} at the low frequency end. They also reported that the use of potassium bromide tends to give better spectra, except that a band at 3450 cm^{-1}, from the OH group of traces of water, almost always appears. The fact that many functional groups can be identified by their characteristic vibration frequencies make the infrared spectrum the simplest, most rapid, and often more reliable means for assigning a compound to it class (Williams and Fleming, 1987).

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary of Findings

- A review of literature has been undertaken on the bionomics of groundnut and the use of plant materials for the control of *T. granarium.*
- *T. granarium* larvae were found to be the predominant stage of the life cycle infesting groundnut kernels throughout the period of investigation..
- *T. granarium* larvae were found to prefer SAMNUT 22 variety for feeding and development and the highest population of the larvae occurred on the variety.
- At six months storage period, lowest population of the larvae was found in SAMNUT 17. At the end of storage period, no goundnut variety was free from larvae population increase.
- The fruit extract of *X. aethiopica* gave 90-100% adult mortality of *T. granarium* in the three trials while *R. communis* gave 90% adult mortality.
- The seed extract of *K. senegalensis* gave 67-78% adult mortality throughout the three trials. They were effective at reducing larval population at different rates of treatment. The fruit extract of *X. aethiopica* was found to exert the greatest mortality effect on *T. granarium* with up to 100% kill of the adults.

- It was observed that the higher the concentration of the test plants extracts and the longer the exposure time, the more toxic they were on the adults and larvae of *T. granarium*.
- The preference of *T. granarium* for groundnut shows that the distribution of the larvae among the groundnut varieties was not significantly different. It was found that the non-diapause *T. granarium* have five larval instars and not four or six as shown in some literature.
- It was found that the larvae cannibalized the adults.
- Larvae moved away from source of light.

6.2 Conclusion

The study has revealed that *T. granarium* is a major insect pest of groundnut A complete control of the pest could not be sustained but a substantial reduction in the insect pest survival was recorded with the plant products. The effectiveness of biopesticide treatment was also manifested compared to untreated. From the present study, seed extracts of *X. aethiopica* and *K. senegalensis* appear to hold promise as available and effective biopesticides for *T. granarium* while the effectiveness of *R. communis* was associated with distorted and discoloured kernels which may not be acceptable by consumers.

It is expedient to make use of these naturally abundant plant materials as dependable alternative to the use of synthetic fumigants in the control of *T.*

granarium. The insect pest produced five larval instars at the ambient temperature and relative humidity.

The presence of phenols in all the test plant extracts and flavonoids in other plant extracts may be responsible for the effectiveness of these plants in reducing *T. granarium* infestation on stored groundnuts. These biopesticides contain astringent qualities against *T. granarium*.

The least susceptible groundnut variety (SAMNUT 17) could be compatible with *X. aethiopica* in order to enhance an integrated control approach against *T. granarium*.

6.3 Recommendations

Groundnut is an important leguminous crop with its nutritional value in the diet of man and his livestock. Efforts should be made to protect the crop from post harvest damage by storage pests particularly *Trogoderma*. The use of proven biopesticides, which allows the product to retain its quality, is therefore recommended. Attention should be focused at encouraging farmers to use plant materials to replace the use of synthetic and imported fumigants, which are environmentally unsafe, costly and hazardous to the user and non-target organisms.

Government should locate research institute that will exploit and explore available insecticidal botanicals to formulate biopesticide for the control of *T. granarium*. The increasing awareness of the inherent potential of botanicals should be sustained by government readiness to finance research. It is the duty of the extension agents to furnish information on the already discovered botanicals.

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APPENDICES

Effects of plant dusts on larval mortality of *T. granarium*

One day after treatment (DAT)

Source	DF	SS	MS	F-values	Pr >F
Model	12	39.12	3.26	6.22	0.0002
Error	20	10.48	0.52		
Corrected Total	32	49.63			

Two DAT

Source	DF	SS	MS	F-values	Pr >F
Model	12	79.45	6.62	17.62	<.0001
Error	20	7.52	0.38		
Corrected Total	32	86.97			

Three DAT

Source	DF	SS	MS	F-values	Pr >F
Model	12	103.82	8.65	19.83	<.0001
Error	20	8.73	0.43		
Corrected Total	32	112.55			

Effects of plant extracts on adult mortality of T. graurium

FIRST TRIAL (One DAT)

Source	DF	SS	MS	F-values	Pr >F
Model	17	26.12	1.54	3.34	0.0019
Error	30	13.79	0.46		
Corrected Total	47	39.19			

Two DAT

Source	DF	SS	MS	F-values	Pr >F
Model	17	28.54	1.68	3.28	0.0022
Error	30	15.37	0.51		
Corrected Total	47	43.91			

Three DAT

Source	DF	SS	MS	F-values	Pr >F
Model	17	26.60	1.56	2.15	0.0328
Error	30	21.87	0.73		
Corrected Total	47	48.47			

SECOND TRIAL (one DAT)

Source	DF	SS	MS	F-values	Pr >F
Model	17	15.29	0.90	2.14	0.0335
Error	30	12.62	0.42		
Corrected Total	47	27.91			

Two DAT

Source	DF	SS	MS	F-values	Pr >F
Model	17	26.46	1.56	2.05	0.0418
Error	30	20.20	0.97	0.76	
Corrected Total	47	55.47			

Three DAT

Source	DF	SS	MS	F-values	Pr >F
Model	17	35.27	2.07	3.08	0.0035
Error	30	20.20	0.67		
Corrected Total	47	55.47			

THIRD TRIAL
One DAT

Source	DF	SS	MS	F-values	Pr >F
Model	17	18.31	1.08	2.28	0.0235
Error	30	14.16	0.47		
Corrected Total	47	32.47			

Three DAT

Source	DF	SS	MS	F-values	Pr >F
Model	17	40.52	2.38	2.83	0.0062
Error	30	25.29	0.84		
Corrected Total	47	65.81			

(First trial)
Effects of plant extract on survival of larvae
(Two months after treatment)

Source	DF	SS	MS	F-values	Pr >F
Model	7	4003.72.	571.96	34.75	< .0001
Error	40	658.28	16.46		
Corrected Total	47	4662.00			

(**Four months after treatment**)

Source	DF	SS	MS	F-values	Pr >F
Model	7	26552.49	3793.21	18.98	< .0001
Error	40	1850.76	46.26		
Corrected Total	47	28403.25			

(Six months after treatment)

Source	DF	SS	MS	F-values	Pr >F
Model	7	33719.29	4817.04	28.30	< .0001
Error	40	6807.38	170.18		
Corrected Total	47	40526.67			

SECOND TRIAL
Effects of plant extract on survival of larvae
(Two months after treatment)

Source	DF	SS	MS	F-values	Pr >F
Model	7	7367.80	1052.54	10.93	< .0001
Error	40	3850.51	96.26		
Corrected Total	47	11218.31			

(Four months after treatment)

Source	DF	SS	MS	F-values	Pr >F
Model	7	13334.85	1904.98	18.32	< .0001
Error	40	4159.96	103.99		
Corrected Total	47	17494.81			

Six months after treatment

Source	DF	SS	MS	F-values	Pr >F
Model	7	32507.18	4643.88	24.47	< .0001
Error	40	7591.29	189.78		
Corrected Total	47	40098.47			

THIRD TRIAL

Two months after treatment

Source	DF	SS	MS	F-values	Pr >F
Model	7	2448.80	349.83	3.79	0.0030
Error	40	3693.01	92.32		
Corrected Total	47	6141.81			

Four months after treatment

Source	DF	SS	MS	F-values	Pr >F
Model	7	5343.87	763.41	4.80	0.0005
Error	40	6356.79	158.91		
Corrected Total	47	11700.66			

Six months after treatment

Source	DF	SS	MS	F-values	Pr >F
Model	7	11528.76	1646.97	5.98	< 0.0001
Error	40	11015.15	275.38		
Corrected Total	47	22543.91			