NEEM (*AZADIRACHTA INDICA* A. JUSS.) SEED POWDER AND EXTRACTS FOR THE CONTROL OF THE SPOTTED STEM BORER, *CHILO PARTELLUS* (SWINHOE), ON MAIZE AND ITS POTENTIAL IN PEST MANAGEMENT

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A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES, ADDIS ABABA UNIVERSITY, IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN INSECT SCIENCE

ADDIS ABABA
ETHIOPIA
DECEMBER, 1999

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ACKNOWLEDGEMENT

I express my sincere gratitude to Dr. R. C. Saxena (ICIPE), for his invaluable guidance, enthusiastic advice and supervision at all stages of the research work. I had the privilege of enjoying his generous support and encouragement throughout this study. I am very grateful to Mr. Francis Onyango (ICIPE) for his unreserved assistance and sharing experience pertaining to insect rearing techniques. Mr. Christopher Olando (ICIPE) was very helpful in statistical analysis of field and laboratory data.

I would like to extend my thanks to my University Supervisor Dr. Emiru Seyoum for his constructive comments and advice in the preparation of this thesis. My thanks go to Dr. Masresha Fetene, Head, Department of Biology, who constantly assisted and encouraged me towards the completion of this endeavor. I am indebted to Dr. Mekuria Lakew for his constructive comments on the draft thesis. My sincere acknowledgement goes to Dr. Teferi Gemetchu for his advice and inspiration to pursue my studies in the areas of Agricultural Entomology. I sincerely appreciate Dr. Assefa Gebre-Amlak for his useful comments and contributions as my former University Supervisor. I also wish to express my sincere gratitude to Dr. Beyene Petros, Dr. Yalemtsehay Mekonnen, and Dr. Seyoum Mengistou for their unfailing advice and support during their tenure of office as Heads of the Department. My colleagues at the Department of Biology deserve my thanks for their consistent encouragement and assistance.

This work was supported by a grant received from The International Centre of Insect Physiology and Ecology (ICIPE) through The African Regional Postgraduate Programme in Insect Science (ARPPIS). I would like to express my gratitude to The Research and Publication Office (AAU) for the kind support of the research in Ethiopia through a research grant RPO/GF/87/51. Acknowledgement also goes to the Department of Biology and the School of Graduate Studies (AAU) for facilitating my studies as a postgraduate scholar.

ABBREVIATIONS

AGI	Adult growth index
A.T.E.	Average time of emergence (duration of the pupal stage)
DPTX	Dipterex
LGI	Larval growth index
NBC	Neem bitter concentrate
NSE	Neem seed extract
NSP	Neem seed powder
NSP*SD	Neem seed powder and sawdust mixture
RCBD	Randomized complete block design
Rep	Replication
TRT	Treatment
UC	Untreated control
WAE	Weeks after crop emergence

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ABSTRACT

The efficacy of neem (*A. indica* A. Juss.) seed products for the control of the spotted stem borer, *Chilo partellus* (Swinhoe) on H511, ICZ3, ACV3, and Katumani maize cultivars was investigated in two geographical locations. Maize plants were either artificially infested with blackhead stage egg batches of *C. partellus*,.or were initially left unprotected for natural infestation to take place before application of treatments. Neem seed powder (NSP) (3 g/plant), neem seed powder-sawdust mixture (NSP*SD) (6 g/plant), or 10% aqueous neem seed extract (NSE) (500l/ha) were applied at four weeks after crop emergence (WAE) with untreated controls. Dipterex (DPTX) (1 g/plant), or Sevin (500l/ha) were also used for comparison. Maize plants treated with neem seed products or chemical insecticides sustained much less borer holes, reduced leaf damage and stem tunneling than those in the controls in all the test cultivars ($P<0.001$). NSP provided comparable and effective protection *in par* with Dipterex or Sevin. NSP*SD and 10% NSE also showed more or less similar and appreciable effects in reducing leaf damage and stem tunneling by *C. partellus* larvae. Foliar applications of neem seed products and chemical insecticides effectively suppressed the densities of *C. partellus* and subsequently improved the yield in all the test cultivars ($P<0.05$). Foliar applications of neem seed products level to chemical insecticides in markedly reducing primary crop damages, in effectively suppressing the level of infestation by *C. partellus,* and in improving yield in all the test cultivars. The findings unequivocally demonstrated that applications of neem seed products effectively control *C. partellus* and avert serious crop damages and yield loss in field situations.

In the laboratory, neonate *C. partellus* larvae were reared on artificial diet containing minute quantities of NSP (25, 50 or 100 ppm), 10% NSE (25, 50, or 100 ppm), or neem bitter concentrate (NBC) (5, 10, or 25 ppm). Artificial diet without neem seed products served as controls. Larvae were introduced singly into the culture vials containing 10 ml of artificial diet incorporating the treatment types and were either maintained on the same diet or transferred to standard diet two weeks after inoculation. Per cent larval survival, pupal weight, per cent pupation and emergence as an adult were examined and recorded. The duration of the developmental stages and total development periods were studied. Larval growth index (LGI) and Adult growth index (AGI) values were also determined. NSP (100 ppm) significantly reduced survival of larvae to the pupal stage and to adult emergence as compared to the other treatment types ($P<0.005$). NSP (50 ppm) and NBC (5, 10, 25 ppm) appreciably reduced the percentages of larvae that survived to pupation and adult emergence.

NSP (50 and 100 ppm) markedly extended the larval period of *C. partellus* as compared to the other treatment types and the controls ($P<0.001$). Both NBC and 10% NSE showed less appreciable effects on the duration of the larval period at the concentrations tested in this study. The pupal weights of male *C. partellus* were markedly affected in a concentration dependent manner. Diet with neem seed products appeared to produce

male pupae with inferior pupal weights as compared to the controls (P<0.05). Diet with NSP (50 and 100 ppm), 10% NSE (100 ppm), and NBC produced pupae with reduced body weight in varying degrees. The total developmental periods in both male and female *C. partellus* were significantly prolonged on artificial diet containing NSP at 25, 50 or 100 ppm as compared with the other treatment types and the controls (P<0.001). Artificial diet with NSP showed markedly extended developmental periods in female and male moths. Insects reared on diet with NSP (50 and 100 ppm) also had much lower LGI and AGI values (P<0.05). Diet with NBC also produced insects with appreciably reduced LGI values as compared to diet with 10% NSE or the control. Insects reared on diet with NSP and NBC had more or less comparable and markedly reduced AGI values. Reduced LGI and lowered AGI values obtained indicated that the survival and development *of C. partellus* was markedly affected by neem seed products. The relatively prolonged development period and the very low percentages of insects that developed to adults indicates that NSP (50 or 100 ppm) renders the diet most unsuitable and was effective in reducing the survival, growth and development of *C. partellus*. Consequently, insects reared on artificial diet incorporating NSP at these concentrations had much lower LGI and AGI values which indicates the potential of neem seed products to effectively curtail or impair growth and development. Low survival rates and impeded growth and development were more pronounced with an increase in the concentration of the treatment types.

This study confirmed the efficacy of neem seed products to control *C. partellus* on maize and offers potential prospects for a biorational management of this pest to reduce yield losses below economic injury levels. It is recommended that further research geared towards the development of appropriate formulations, convenient methods of application, evaluation of the bioactive components in the seeds and other parts of the neem tree, selection of improved ecotypes need to be undertaken. The use of neem seed products for pest control is compatible with traditional farming practices and can easily be adopted by resource-poor farmers in Ethiopia. It requires inexpensive and simple pest management techniques for practical use. The development of relatively simple procedures for processing pest control materials from *A. indica* and other plant species, at the household or rural community level, is crucial and of paramount importance. Further studies on the utility of neem seed products for use in crop protection against by insect pests. It is therefore recommended to undertake research to determine appropriate and optimal formulations and develop more refined methods of application that would promote easy adoption for use by resource-limited farmers in rural areas. The behavioural, histopathological, and physiological effects of the blend of bioactive compounds in neem seed products need also be studied in order to elucidate their biological effects and modes of action.

CHAPTER 1
GENERAL INTRODUCTION

The most serious problem that countries of sub-Saharan Africa face today is the need to increase and sustain food production for their growing populations. A great majority of the population in the region live in rural areas and depend on agriculture for their living. In the African scenario over 90% of food production is obtained from subsistence polycultural farming owned by indigenous small scale peasant farmers (Abasa, 1983). The population increases at an average rate of 3% annually while food production rises only by 2.3%, and total agricultural production by 2.4% (ABN, 1989; Saxena *et al.*, 1989; Mensah, 1989). Consequently, the production level could hardly support the growing human population in the region.

In Ethiopia, the population at present is estimated to be over 60 million and the need to increase food production is one of the most serious challenges facing the country (CSA, 1998). In order to attain food self-sufficiency as well as food-security for this growing population,it has adopted several strategies among which increasing crop production in a sustainable way is one of the top priorities of economic development plans. To this effect broad-based extension programmes in farmers' fields in different parts of the country are geared towards alleviating this problem. Improvement of agricultural productivity and increase of food production at a level keeps pace with the rapidly growing population is therefore, the prime concern of the country.

Although sorghum and millets are also popular traditional staple cereals, maize (*Zea mays* L.) seems to be now one of the most widely used agricultural crops in Ethiopia and other East African countries. It is a cereal food crop of Central American origin and was introduced to Africa some 60 years ago (Tivy, 1990; Mengech *et al.*, 1995). Its contribution to the local and regional economic development is quite remarkable. In the context of the rapidly expanding human population and the serious periodical food shortages in the region, increased production of crops in general and maize in particular is not only desirable but is a mandatory step towards a self-sustained economy.

Efforts to increase the productivity of maize and other cereal crops through improved agronomic practices are however thwarted by a number of factors. One of such factors limiting the production of maize and other agricultural produces in many parts of Africa is the damage caused by a wide range of insect pests. In this respect, lepidopterous stem borers of maize and other cereal crops come to be the first in line as the major pest problems. The most important stem borers of cereals and graminaceous grasses belong to the family Pyralidae which includes the genera *Chilo*, *Ostrinia*, *Eldana*, and *Diatraea;* and Noctuidae which includes the two genera *Busseola* and *Sesamia* (Harris, 1990; Minja, 1990).

In the control of these stem borers, the most popular strategy is the use of synthetic chemical insecticides. It rapidly suppresses pest populations in the field. However, its repeated and wide application produces a number of undesirable ecological and economical repercussions. These include the development of resistance to insecticides by pest species, pest resurgence, secondary pest outbreaks, destruction of non-target organisms, water pollution, and build-up of residues in soil, food and stored products. The relatively high cost of pesticides and inaccessibility in local markets are also additional factors limiting its use by small-scale farm holders in many places. Thus, for the subsistence farmer in developing countries, the use of these chemicals for the control of cereal stem borers is neither ecologically sound nor economically and technically feasible. (Rice, 1993a).

As an alternative to chemical control of stem borers, efforts are now being directed towards pest control measures that are specific for the target pest and least damaging to the environment. The development of integrated pest management (IPM) strategies try to exploit options on biointensive approaches. That is optimization of the dynamic and harmonious use of biological control agents, resistant crop varieties, insect growth regulators (IGRs), botanicals, and adoption of sound cultural practices in the control of maize stem borers. In this endeavour, the use of natural products derived from plants is considered to be an environmentally sound and economically justifiable approach. They are biodegradable in their nature and generally safe to the environment, and thus are considered to be promising and potentially useful in integrated pest management.

To this effect, numerous plants have been studied in recent years. One such plant is the neem tree (*Azadirachta indica* A. Juss.). It is well recognized as a source for natural products with pest control properties. Crude extracts from different parts of the tree have been found to be effective against a wide range of insect pests of food crops in different climatic zones. These products are believed to be non-toxic to natural enemies of pests and other non-target organisms as compared to conventional synthetic insecticides. Although efforts and interests to learn, develop and introduce natural products from neem (*A. indica*) as biorational pest control materials in many parts of the tropics (Schmutterer, 1987, 1990; Saxena, 1989, 1993) are enormous, the efficacy of neem seed powder and extracts in pest control and its potential in the management of pests of food crops has not yet been fully exploited. Its inherent pest control properties and the possibility of its practical uses in the management of *Chilo partellus* (Swinhoe) has been sought as an open and promising field of research for long. To fill these gaps of knowledge, the present work aimed to undertake basic and applied research to determine the effect of crude neem seed powder and aqueous extracts on the growth and development of *C. partellus*. This study also aimed at investigating the potential of foliar applications of crude extracts from the neem tree in the management of this stem borer on different cultivars of maize.

Hereafter, attempt is made to survey relevant information on the spotted stem borer, *Chilo partellus* (Swinhoe) as a major pest on maize crops. The most commonly used control methods and the literature on the use of natural products and crude extracts from the neem tree (*A. indica* A. Juss.) for the management of *C. partellus* and other insect pests, are also considered. The following topics have been given special attention in this review.

1.1. Background

1.1.1. Maize (*Zea mays* L.): Economic importance and production constraints in East Africa

Maize (*Z. mays*) is one of the most important agricultural produce used primarily as staple food for millions of people in East Africa. It is also used as a cash crop, animal feed, and source for other by-products. With sorghum, it constitutes the major cereal crop and is extensively grown in many places, especially in fertile and high rainfall areas (Minja, 1990). In Kenya alone, it is grown on over 1.2 million hectare of arable land every year (Warui *et al.*, 1986). Likewise, the production of maize in Ethiopia has increased progressively over the last three decades and is estimated to be over 1,357,680 metric tons annually (Gebre-Amlak, 1988). Compared to other cereal crops, it ranks first in yield per hectare, fourth in total grain yield, and fifth in total hectares of cultivated land (Negasi and Tadesse, 1985).

Under the peasant system of production where the bulk of agricultural crops are grown, the maximum yield of maize can hardly be attained. One of the major constraints in many parts of Africa is the damage caused by stem borers. The most important stem borer species on maize in Ethiopia and Kenya include *Chilo partellus* (Swinhoe), *C. orichalcociliellus* Strand, *Sesamia calamistis* Humps, *Eldana saccharina* Walker, and *Busseola fusca* (Fuller) (Negasi and Tadesse, 1985; Warui *et al.*, 1986; Gebre-Amlak, 1988; Unnithan and Seshu Reddy, 1989). Yield losses due to these stem borers in many places exceed 50% of the total production (Unnithan and Seshu Reddy, 1989).

1.1.2. Bionomics and ecology of *Chilo partellus* (Swinhoe)

1.1.2.1. Distribution, life history, and host range

Chilo partellus (Swinhoe) (Synonym: *Chilo zonellus*) is an economically important pest of maize and sorghum in many parts of Africa (Bleszynsk, 1970). It is believed to be indigenous to the Asian continent and was introduced to East Africa in the early 1950s'. Now, it is a serious threat to the production of maize and other cereal crops in eastern and southern Africa (Sithole, 1990; Harris, 1990). Recent reports on the distribution and relative abundance of *C. partellus* indicate that it is spreading to west Africa as well (Harris, 1990). This stem borer is widely distributed in Kenya (Ogwaro, 1983; Seshu Reddy, 1983; Warui and Kuria, 1983). Studies on the geographic distribution of stem borer species in Ethiopia indicate that *C. partellus* is the dominant species specially at altitudes below 1500m (Negasi and Tadesse, 1985; Gebre-Amlak, 1988). The distributions and degree of infestation by this pest are largely influenced by climatic conditions; and hence vary from place to place, and from season to season.

Chilo partellus moths are nocturnal in their habits. Depending on prevailing environmental conditions, adults have an average life span of two to five days. The female in her life time oviposits masses of 200-600 eggs in batches or clusters in her lifetime (Khan, 1983; Harris, 1990).The eggs are laid on the under surface of leaf blades of young host plants. Under favourable conditions, the eggs hatch in four to eight days and migrate from the oviposition sites to the whorls of young plants where they feed gregariously prior to dispersion (Sithole, 1990). The first instar larvae spin silken threads on to which they hang and disperse by means of wind to colonize neighbouring host plants. They feed on the tender developing leaves in the whorls for a few days and may cause deadheart at the growing points. In older plants, the larvae enter into the leaf sheath or the cobs and cause considerable damage by feeding on them. The second and third instar larvae bore into the stem and cause tunneling as they feed on the central part of the stems. Fully mature larvae pupate inside the tunnels after boring exit holes on the stems through which the adults emerge.

The egg, larva, pupa and adult stages of *C. partellus* in southern Africa last on the average 5-8, 15-29, 6-8 and 2-4 days, respectively, depending on the prevailing temperature and relative humidity (Rensburg *et al.*, 1988). Under field conditions, *C. partellus* displays two population peaks; one between six to eight weeks, and the other between 11-14 weeks after crop emergence (Warui and Kuria, 1983; Seshu Reddy *et al.*, 1990). In the short rains, these peaks appear between two to five weeks, and 10-12 weeks after crop emergence. Khan (1983) reported that *C. partellus* overwinters in the larval stage and is carried over to the following season in maize and sorghum stubble. It has also been reported that survival of *Chilo* spp. in the dry season depend on the availability of alternate hosts and the maize/sorghum leftover in the field (Wheatley, 1961). The maize stubble, cobs and stalks have been found to harbour the borers during the dry season. Many workers have confirmed the ability of *Chilo* spp. and *B. fusca* to diapause during the dry season (Warui *et al.*, 1986; Gebre-Amlak, 1988; Unnithan and Seshu Reddy, 1989). In most cases, infestation of maize plants by the stalk borers is perpetuated from season to season by diapausing larvae.

Maize and sorghum are the major host plants of *C. partellus*, but it may also attack pearl-millet, rice, wheat, finger millet and sugar cane in the field. It has been reported that *Chilo* spp. survive the dry season on different species of alternate hosts in the field. In eastern and southern Africa, wild host plants of *C. partellus* include various grasses of the family Graminacae such as *Andropogon* spp., *Sorghum halpense*, *S. verticilliflorum*, *Panicum maximum*, and *Pennisetum purpureum* (Harris, 1990; Sithole, 1990).

1.1.2.2. Crop damage and yield loss due to *C. partellus*

In eastern and southern Africa, *C. partellus* is known to be the most injurious pest causing direct crop loss to maize and sorghum. Infestations of maize plants during the first month of crop growth often cause deadheart and result in serious crop losses (Taneja and Nwanze, 1989; Harris, 1990). The magnitude of yield losses largely depends on the stage of the crops attacked and the density of borer populations at the time of attack.

Larvae of *C. partellus* cause damages by feeding on the leaves, stems, and maturing grains in the cobs. Newly hatched larvae migrate upward into the whorl and feed on leaves in the funnel for a few days. They cause a characteristic pattern of small holes and lesions on the leaves of maize plants. When the attack occurs during the early stages of crop growth, they destroy the growing points and cause deadheart which is characterized by dead central leaves in young maize plants (Sithole, 1990). After a few days, the larvae bore into the stem and cause extensive tunneling by feeding on the pith and vascular bundles in both young and older plants. Stem tunneling results in stunted growth, retards plant vigor, and prevents cob formation. It also affects the grain filling process and causes yield loss.

Plants thus affected are prone to wind damage, lodging, and secondary infections (Minja, 1990; Sithole, 1990). The level of infestation of maize crops by *C. partellus* in the field depends on prevailing environmental factors such as rainfall, temperature, relative humidity, and altitude. The time of the onset of the rainy seasons, the amount of precipitation an area receives, and the distribution of rainfall in the season all influence the intensity of infestation and damage by *C. partellus* larvae (Sharma and Sharma, 1987). This pest can inflict severe damages and serious yield losses of maize if not managed properly from the early growth stages of the crop.

Infestations of maize crops by *C. partellus* are mostly localized and sporadic in nature, but outbreaks in widespread areas are not uncommon. Sharma (1976) reported that ten days old maize plants are more susceptible to damages caused by *C. partellus*. Densities as low as five eggs/plant could cause appreciable yield losses. Maize crops become more tolerant to infestation at older plant ages, and control measures may not even be compulsory after five weeks after crop emergence. When susceptible and resistant varieties were artificially infested at different ages with newly emerged larvae of *C. partellus* at various densities, yield losses were highest for infestation at twelve days after crop emergence (Sharma and Sharma, 1987). These authors reported economic injury levels of 1.2, 1.4, 2.6 and 3.4 larvae per plant when maize plants were infested at 12, 17, 22, or 27 days old, respectively, in the susceptible variety as compared with 1.2, 1.3, 8.9, and 14.1 larvae per plant for infestation at the four plant ages, respectively, for the resistant variety.

In a field test in Pakistan, two groups of maize plants were compared for the effect of borer infestations on yield. A natural population of *C. partellus* was allowed to build up in one while the eggs were removed daily in the control. The difference in yield was 2121 kg/ha when 25.2% of the plants were infested, and 2860 kg/ha when 33% were infested (Mohyuddin and Attique, 1978). Yield reductions in some maize cultivars were close to 60%, whereas stem infestation levels as high as 98% have been recorded (Neupane *et al.*, 1985). Yield losses ranging between 4% and 45% have been reported in maize in India due to attack by larvae of *C. partellus* (Singh and Sharma, 1984). The extent of stem tunneling caused by *C. partellus* larvae at different levels of artificial infestation on the growth and yields of maize cultivars were studied in the field in Kenya (Kumar, 1988). The author reported that there was greater tunneling in the susceptible Inbred-A maize than in ICZ1-CM, ICZ2-CM and Katumani Composite B cultivars. This tunneling significantly reduced plant growth in all the test cultivars. There was a significant negative correlation between tunneling and the resultant grain yield for Inbred A and Katumani Composite B. However, this was not evident in ICZ1-CM and ICZ2-CM maize which were more tolerant to attack by *C. partellus* larvae.

1.1.3. Control strategies in the management of *C. partellus*

The fact that several factors influence the onset, spread, and intensity of infestation give a chance for an integrated approach for the control of maize stem borers. A collective biorational strategy where several parameters would be considered is expedient for effective management of *C. partellus* and other stem borers of cereal crops. The use of chemical insecticides, adoption of cultural practices, host plant resistance, and biological control are the most common methods employed to control *C. partellus* infestations and to avert serious crop losses due to this stem borer.

1.1.3.1. Application of chemical insecticides

Undoubtedly, the use of insecticides is the most common method of control of cereal stem borers in many places. Several insecticides are in use for the control of maize stem borers. The major groups of chemical insecticides used in pest control in different parts of the world are organochlorine, organophosphorus, carbamate, and pyrethroid compounds. These pesticides act on insects basically as nerve poisons. Insecticides widely recommended in the control of stem borers include endosulfan, carbaryl, phentoate, BHC, quinalphos, carbofuran (furadan), dipterex (trichlorophon, 5% granular), thiodan, malathion, disulfoton and diazinon. These pesticides are mostly used as sprays, dusts, granular formulations, or as systemic compounds (Jotwani, 1983; Khan, 1983; Warui and Kuria, 1983). Some of these insecticides reduce infestation by 30% to 40%. The use of insecticides against stem borers is estimated to avert an overall loss of over 20% grain yield.

In one experiment conducted in Kenya, application of insecticides reduced infestation of maize by stem borers to as low as to 7% as compared to as high as 22% in untreated plots (Warui and Kuria, 1983). The yield from untreated plots was about 20% less than otherwise, thereby indicating the benefits of insecticide application. In another experiment, control of stem borers with DDT resulted in 44% increase in yield. (Unnithan and Seshu Reddy, 1989). Granular formulations of carbofuran, disulfoton, diazinon and fenthion at different concentrations reduced larval damage on maize due to *C. partellus* and increased grain yields (Khan, 1983). Marwaha *et al.* (1986) recommended granular applications of furathiocarb and carbofuran over some other insecticide formulations as most effective in the control of *C. partellus*. Dust or granular formulations are mostly applied by placing the insecticide in the leaf whorls of maize plants. This allows the control of *C. partellus* and related species where neonate larvae gregariously migrate to the funnel of young plants. The larvae remain inside the whorls for a few days feeding on tender leaves and hence are vulnerable to insecticide applications at this stage of their life cycle. The effectiveness of stem borer control with insecticides essentially depends on direct deposition of the insecticide inside the funnel or axils of loose leaves before the larvae bore into the stems. Once the larvae bore into the stems they are no more exposed to foliar applications of insecticides (Minja, 1990). The period between oviposition, migration to the whorel of the host plant and duration of feeding in the funnel before larvae bore into the stem is short and timing is critical.

Chemical control of *C. partellus* is a slow and labour demanding procedure which calls for careful timing and requires precise placement of the insecticide in the whorls and leaf sheaths of plants. Application of granular, dust, or spray formulations generally proves to be inadequate as the borers are protected inside the plant tissues once they bore into the stems (Jotwani, 1983). The difficulties in determining the proper time of application, the cost of repeated applications, the choice of suitable insecticides, and the method of application makes adoption of chemical control of stem borers difficult and uneconomical for farmers (Lawani, 1982; Ingram, 1983). Thus, the control of *C. partellus* using chemical insecticides is mostly ineffectual and not economically justifiable. In addition, chemical insecticides are not selective in their action and may aggravate borer pest problems as a result of their indiscriminate effects on the natural enemies that substantially contribute to maintain pest densities below economic injury levels. The occurrence of resistance to insecticides in many pest species further undermines the use of chemical insecticides. The repeated and wide use of chemical insecticides entails a number of undesirable ecological side effects and economical drawbacks. The hazards posed by these chemicals on the environment, human beings and animals are of great concern to all. Moreover, the average peasant farmer in developing countries is unable to afford the steadily increasing cost of the synthetic pesticides. It is not an appropriate strategy for resource-limited farmers (Unnithan and Seshu Reddy, 1989). Thus, the use of chemical control alone is not an advisable long-term strategy for the management of stem borers and should by no means be used exclusively. Therefore, the need to gear research efforts into the development of inexpensive, nontoxic, environmentally safe and biodegradable pest control products derived from plants cannot be underestimated.

1.1.3.2. Use of resistant maize varieties

Resistance is the inherent ability of the host plant to prevent, restrict, retard or overcome pest infestations. The expression and stability of resistance in a plant to an insect species depends on the interaction between the genotype of the plant and the insect pest under different environmental conditions (Pathak and Olela, 1983). Traditional farmers in subsistence agriculture have long used resistant varieties in food crops. It offers an economical and relatively durable strategy in the control of stem borers in maize and sorghum growing regions of the tropics. It avoids environmental pollution. It is compatible with chemical, biological and cultural methods of control, and incurs no additional cost to the resource-limited farmer (Smith, 1983; Saxena *et al.*, 1989; Agrawal *et al.*, 1990;

Pathak, 1990, 1991). Studies on inheritance of resistance showed that resistance to *C. partellus* in maize and sorghum is polygenically inherited. It is governed by additive, nonadditive, or both types of gene action (Pathak and Olela, 1983; Pathak, 1985, 1990; Agrawal *et al.*, 1990). It is controlled by additive and dominant major gene effects under natural infestation, whereas pronounced epistatic gene effect is observed under artificial borer infestation. The level of resistance to damage by the target pest is governed by additive, nonadditive, or both types of gene action (Pathak, 1990). For example, both additive and non-additive gene effects are important in the inheritance of resistance to deadheart formation. The gene effects for leaf feeding and stem tunneling are predominantly additive (Pathak, 1990, 1991). The factors responsible for the different levels of resistance are categorized as biophysical, morphological, chemical, physiological and mechanical (Chaudhary and Khush, 1990). On the other hand, mechanisms of resistance in maize to *C. partellus* are usually classified as nonpreference, antibiosis, and tolerance (Dabrowski and Nyangiri, 1983; Pathak and Olela, 1983; Pathak, 1985). Agrawal *et al.* (1990) reported that ovipositional nonpreference, reduced leaf feeding, low deadheart formation, low stem tunneling, and tolerance to leaf and stem feeding contribute to resistance to *C. partellus*. Marked differences in establishment of first instar larvae have also been observed among resistant and susceptible varieties. The resistance/susceptibility of maize cultivars to *C. partellus* is measured by the level of colonization of maize plants by the insect, oviposition, larval establishment and development. The primary damages caused by larval feeding are expressed in foliar lesions and stem tunneling. Secondary damages are reflected in stalk- and tassel-breakage, and ear dropping.

Significantly higher oviposition preference and greater stem tunneling in susceptible (Inbred-A and ICZ1-CM) than resistant (Inbred-D, Inbred-G, and ICZ2-CM) maize lines were observed in field and screenhouse studies (Dabrowski and Nyangiri, 1983; and Ampofo, 1986). Inbred-A was found to be the most preferred genotype for oviposition and the authors surmised that some contact-chemo-and/or mechanoreceptors on the tip of the ovipositor or on the tarsus of front legs of *Chilo* females may play an important role in the plant acceptance for oviposition. Extensive larval feeding in Inbred-A and low damage on the resistant lines suggested that biophysical factors such as dense trichomes, pigmentation on leaf surface, lack of positive gustatory stimuli, and chemicals acting as feeding deterrents (physiological inhibitors) might affect feeding activities and larval survival that lead to resistance to *C. partellus*. In addition, Woodhead (1983) reported that surface waxes on the leaves and stems probably affect the movement of first instar larvae, and some components act as feeding deterrents. In addition, low sugar content, amino acids, total sugars, tannins, total phenols, lignins, and high silica content have been reported to be associated with *C. partellus* resistance in sorghum (Agrawal *et al.*, 1990).

1.1.3.3. Adoption of cultural practices

Cultural control methods using agronomic practices include manipulation of crop residues and alternate hosts, soil tillage, adjustment of planting dates, simultaneous planting, crop spacing, crop rotation, crop sanitation, and intercropping. These measures are widely used crop management practices in polycultural farming systems (Lawani, 1982; Gebre-Amlak, 1988). Destruction of crop residues and alternate hosts, use of maize varieties less susceptible to attack, adjusting time of planting, optimum use of fertilizers and irrigation have some potential in reducing pest populations with little adverse effect on the beneficial ones (Lawani, 1982; Sharma, 1976). Traditional farming practices in subsistence agriculture ensure the survival of most diapausing larvae until the early part of the rainy season. Crop residues, fresh grass, and various alternate host plants ensure oviposition, survival and diapause of *C. partellus* during the dry season, and sustain carry-over infestations to the next planting season (Seshu Reddy, 1983). Periodic removal of infested plants is effective in reducing infestation by second-generation larvae of stem borers (Saxena *et al.*, 1989). The practice of destroying crop residues or removing both wild host plants and crop residues during the dry season considerably reduces borer populations which would otherwise be available to colonize young plants at the beginning of the next cropping season (Warui and Kuria, 1983; Kfir *et al.*, 1989). However, the practice of burning the stalks completely after grain harvest is very unpopular since farmers use the stalks for a variety of purposes. The destruction of alternate hosts is equally a problem and has little appeal to the peasant farmers. This aggravates the situation in that emerging adults from wild hosts immigrate into maize crop fields and thus infestation with stem borers becomes inevitable (Adesiyun and Ajayi, 1980).

Vercambre *et al.* (1985) recommended early sowing of maize, use of tolerant and rapidly maturing maize varieties, and destruction of all stubble remaining in the field for effective control of *C. partellus*. Tillage during the dry season causes insect mortality by mechanical damage, exposure to weather factors or natural enemies. Plowing also destroys volunteer plants, stubble and weeds and thereby reduces borer populations by denying them food and breeding sites (Lawani, 1982). Plant spacing regulates the density of the host plant and therefore affects the activities of the pest population and natural enemies. It also influences the behavior of the pest in searching for food, oviposition site, or migration and dispersal of larvae to neighbouring plants (Ampofo, 1986). For example, neonate larvae of *C. partellus* move from oviposition sites to the tips of leaves and spin silk threads to disperse to other plants within the vicinity, a critical stage which exposes larvae to mortality factors (Ampofo and Nyangiri, 1986). Increasing the spacing between adjacent plants would decrease the chance of the migrating larvae from infesting neighbouring plants. Close spacing may increase effectiveness of natural enemies and reduce damage by stem borer. However, it may aggravate the damage by creating microclimate favourable to some pests (Lawani, 1982).

Cultural practices based on time of planting ensure growing the crop at a time when the pest density is very low such that the most susceptible stage of crop development coincides with the time when the pest is least abundant. Warui and Kuria (1983) found that early planted maize will have passed the susceptible growth stage by the time *C. partellus* and *C. orichalcociliellus* reach high populations in the field. Planting early and simultaneously at the onset of the rainy season avoids damaging populations of stem borers and reduces infestation levels in a region. However, adjusting the sowing dates is difficult in that rainfall is unreliable and unpredictable in most areas, thus making area-wide synchronization of sowing dates by farmers is impossible (Saxena *et al.*, 1989). On the other hand, continuous planting and later planting of maize as practiced by local farmers in some regions provide food for the borers and thus increase the total borer infestation (Unnithan and Seshu Reddy, 1989).

Intercropping is an inherent component of crop management system in most African farming communities. However, the impact of intercropping on the densities of pest populations and on the activities of natural enemies is not well understood and scientifically rationalized to become a standard agronomic practice of the resource-limited farmers. The most common combinations of crops grown in East Africa are maize-sorghum-groundnuts, maize-cassava-beans, maize-sorghum-beans, maize-millet-beans or cowpea and maize-pigeon peas-beans (Abasa, 1983; Dissemond and Weltzien, 1986). Ampong-Nyarko *et al.* (1994) also studied the ovipositional behaviour of *C. partellus* in maize-sorghum-cowpea, sorghum-cowpea and maize-cassava intercropping systems and found that *C. partellus* gravid moths oviposit about a third of the total eggs on non-host crop cowpea or cassava. There is a consensus that *C. partellus* oviposition on non-host crops is one mechanism for its reduced abundance in intercropping. Increase of yields of maize and beans or sorghum and beans by at least 38% above what was harvested from pure stands of either crop has also been reported (Abasa, 1983). These results suggest that intercropping can be adopted as a justifiable component of IPM programmes for the management of *C. partellus* on maize crop.

1.1.3.4. Biological control agents

Biological control is the use of living organisms as pest control agents. It involves the use of pathogens, parasitoids, and predators to maintain pest populations at densities within economically acceptable limits. Parasitoids and predators contribute to the mortality of *C. partellus* at different stages of its life cycle. Ants, spiders, mites and reduviid bugs are commonly observed predating on the eggs, larvae, and pupae of *C. partellus*. The natural enemy complex of stem borers in East Africa includes *Trichogramma* spp. parasitizing the eggs, *Apanteles sesamiae* Cameron (Braconidae) on larvae, as well as *Pediobius furvus* Gahan (Eulophidae), *Dentichasmias busseolae* Heinrich (Ichneumonidae), and *Lepidoscelio* spp. on the pupae (Mohyuddin, 1972, 1990; Ingram, 1983; Seshu Reddy, 1983, 1989).

Egg parasitoids in the families Trichogrammatidae and Scelionidae cause considerable mortality in most areas. Neupane *et al.* (1985) reported that of seven hymenopterous parasites reared, *Trichogramma chilonis* causes 70% egg parasitism. In Kenya, egg parasitoids belonging to these families cause up to 92% mortality in *Chilo* spp. Parasitism on larvae and pupae is usually bellow 10%. Older larvae are usually attacked by a wide range of hymenopterous and tachinid parasitoids (Seshu Reddy, 1989; Mohyuddin, 1990). *A. sesamiae* is a small wasp that deposits its eggs inside the larvae of stem borers and destroys up to 95% of the larvae in maize and sorghum stubble thereby reducing the carryover larval population. It parasitizes the larvae of *C. partellus*, *B. fusca*, *S. calamistis*, and *E. saccharina* in East Africa (Mohyuddin, 1972, 1990; Seshu Reddy, 1989).

Apanteles flavipes (Cameron) (Braconidae) is the parasite of choice in the biological control of lepidopterous borers on graminaceous crops. Results obtained *with A. flavipes* were variable and differed according to the country where the parasites were used, the insect host species and the plant species infested by the host (Beg and Inayatullah, 1980). It causes up to 30% larval parasitism (Neupane *et al.*, 1985).

Mohyuddin (1990) reported the success of introducing *A. flavipes* against *C. partellus* in Pakistan. This parasitoid was also introduced into South Africa against *C. partellus* and *B. fusca* on sorghum and maize but could not be recovered after winter. It displays preference to the frass of particular borer species feeding in particular crop plants. However, this behavioural preference could be modified under new environmental pressures. *A. flavipes* is considered to be the most suitable candidate for biological control of *C. partellus* in Africa.

The eulophid *P. furvus* is a gregarious pupal parasitoid which readily attacks pupae of stem borers inside the tunnel in stems provided the pupae are not protected by cocoons (Mohyuddin, 1972). This parasitoid was introduced into Madagascar from Uganda and has effectively controlled the pink stem borer, *S. calamistis,* in the island.

Dentichasmias busseolae is a solitary pupal endoparasitoid of *C. partellus*. It is a widely distributed endemic species in Africa. It causes up to 58% mortality in pupal populations of *C. partellus* (Mohyuddin, 1972). Seshu Reddy (1989) reported that parasitism of *C. partellus* by *D. busseolae* in sorghum appeared at 11 weeks after plant emergence and reached a maximum of 60% to 70% thereafter. *D. busseolae* could only be reared on *Chilo* spp., but *E. saccharina*, *B. fusca* and *S. calamistis* pupae are accepted as hosts and favour development when offered in *C. partellus* tunnels (Mohyuddin, 1972). Pupation behaviour of these stem borers, dimension of the moth exit, the width of the tunnel and other physical barriers do not seem to prevent parasitization, and the host range of this parasitoid is limited by an olfactory cue associated with the frass of *Chilo* spp.

However, most of the attempts to release and establish parasitic Hymenoptera in many countries of the temperate regions were not successful as the parasites could not survive the winter (Breniere *et al.*, 1985). Skoroszewski and Hamburg (1987) reported the release of *A. flavipes* to control *C. partellus* and *B. fusca* in South Africa. It temporarily established on both species, but could not be recovered after the winter. The factors for failure to establish durably include the low density of *C. partellus* during the cold season and absence of alternate food plants after the maize harvest. Use of repeated inundative releases may be needed to bring down the pest population below economic injury levels.

1.1.4. Neem (*A. indica*): Biological activity and uses in pest control

Botanicals have been used in traditional farming systems in many parts of the world. Materials such as nicotine, rotenone, and pyrethrum have long been used in pest control (Ahmed *et al.*, 1984). Nicotine as a crude extract of tobacco, *Nicotiana tabacum* and *N. rustica* was used for pest control purposes since 1763. Rotenone from *Derris malaccensis* and *D. elliptica*, and other leguminous plants is an other celebrated example used for pest control purposes. Pyrethrum derived from the dried flowers of *Chrysanthemum cinerariaefolium* is also widely used in modern agriculture (Warui *et al.*, 1986; Olaifa *et al.*, 1987). It breaks down rapidly and does not pose the danger of persistence in the environment. Most of these materials have relatively low mammalian toxicity, a short period of activity, and a fairly broad spectrum of control compared with many chemical pesticides.

Research on botanicals for pest control suffered a decline following the introduction of DDT, parathion, and other synthetic insecticides in the late 1940's and early 1950's. Interest on pesticides of plant origin has enjoyed a renaissance during the past two decades. It has now opened an array of new materials for experimentation and use in pest control. The Indian neem tree, *Azadirachta indica* A. Juss., has evoked the propensity of renewed interest and credibility of research in the development and use of botanical insecticides (Isman *et al.*, 1996).

In the search for alternative methods of pest control, in recent years, considerable effort has been expended in the isolation and identification of naturally occurring compounds of plant origin. Approximately 2000 plant species worldwide are reported to have pest control properties. Ahmed *et al.* (1984) listed some 26 plant species in 16 different families that are claimed to have potential for use as pest control materials against insects under traditional farming systems. Among these plants, the neem tree (*A. indica*) stands to be the most promising source of botanicals for pest control. It is found to be effective against well over 25 plant pests.

The neem tree, *A. indica* (syn. *Antelaea azadirachta*, *Melia azadirach*), belongs to Meliaceae (Mahogany) family. Neem is native to Burma and the arid regions of the Indian subcontinent (Vietmeyer, 1992; Saxena, 1993). It is a hardy evergreen perennial tree species commonly found in South Asia and in tropical and subtropical areas of Africa, America, and Australia (Ahmed *et al.*, 1984; Jacobson, 1987; Schmutterer, 1990). It is drought resistant and thrives under humid and semi-arid conditions. The tree grows well on poor, marginal soils with low fertility, and improves soil conditions. Roots grow deep and over a wide area, and are able to extract available nutrients from the deep layers of severely leached sandy soils and subsequently enrich surface soils with leaf litter to the benefit of agricultural crops. It tolerates high temperatures, low rainfall, long spells of drought, and salinity.

In Ethiopia, neem (*A. indica*) is widely planted in the dry and moist Kolla and Weyna Dega agroclimatic zones of Illubabor, Kefa, Wolega, Harerge, Shoa and other regions. It grows between 400 to 2000 m above sea level (Bekele *et al.*, 1993). The tree is grown mainly on degraded land as shelterbelts and as a shade tree. It is a fast-growing medium sized tree which may reach a height of over 20-25 m, with a dense, leafy, oval-shaped canopy (Bekele *et al.*, 1993; Saxena, 1993). The leaves are glossy green in appearance and grow crowded at the ends of branches. They are compound and up to 40 cm long. Each leaflet is curved and, pointed, with roughly saw-toothed edges and have a smaller leaflet at the leaf tip. The flowers are small, fragrant, cream-white, and hanging in long graceful sprays. The fruits are produced in drooping panicles and are oval yellow berries when ripe, 2 cm long, thin skinned with oily pulp, usually one or two seeds.

In addition to the use of stumps and stem cuttings, *A. indica* is propagated by seeds. The seeds are viable only for a few weeks and the rate of germination decreases when they are stored longer after harvesting (Bekele *et al.*, 1993; Saxena, 1993). Seed viability generally ranges from six to eight weeks. However, thoroughly cleaned and properly dried seeds stored in a cool place remain viable up to 6 months (Saxena, 1993). Under natural conditions, neem grows in the wild and seed dispersal usually takes place by birds and bats that feed on the pulp of ripe fruits on the trees. Seedlings could be raised in nurseries on a large scale and planted as shade trees or used in forestry programmes. Seedlings that are nine to twelve months can be successfully transplanted on sandy or loam soils (Plates I-IV). They are fast growing after the first year and are normally weeded during establishment. The young trees do not require extra attentions except fencing to protect them from damage by cattle, goats and other domestic animals. The trees begin fruiting in three to five years and become fully productive in about 10 years. A single tree produces 30 to 100 kg of neem fruit annually depending on climatic conditions, edaphic factors, the ecotype or the genotype of the plant. Thirty kg of neem seeds yield 6 kg of neem oil and 24 kg of neem cake (Saxena *et al.*, 1984; Saxena, 1993).

Neem has been found to be a source of insecticides and a good example is Margosan-O registered for marketing as a commercial neem pesticide by EPA in the US (Vietmeyer, 1992). Depulped and dried neem seeds can be processed with an expeller oil-press to obtain the oil and neem cake (Plate VII). In addition to its use in pest control, the oil can be effectively used as a raw material in the soap industry. Neem cake is commonly used as a fertilizer in many places where neem trees are widely grown. The leaves are traditionally used to protect grains in storage against insect pests. The tree possesses complementary economic uses such as firewood, charcoal, and timber. The wood is tough and resistant to decay and termites. It is highly valued for its uses as medicinal (leaves, bark and roots), fodder (leaves, neem cake), bee-forage, in soil conservation, and as a windbreak. It is also used as an ornamental and shade tree in urban areas. These and other multi-purpose benefits make planting neem trees appealing as well as economically rewarding to the rural communities.

Neem has been found effective against a wide range of insect pests in various agro-ecological zones. Different parts of the neem tree are commonly used for medicinal and pest control purposes (Plate V). Extracts from different parts of the tree contain bioactive constituents that show selective pest control properties through a variety of biological activities such as antifeedant, growth regulatory and some toxicity. The leaves and seeds are particularly rich in biologically active compounds. A great deal of effort has been expended in the isolation and purification of limonoids from seeds and other parts of *A. indica* and other species of Meliaceae. So far, over 100 different limonoids have been isolated and characterized from the seeds of the neem tree many of which have variable degree of biological activity against insect pests (Isman *et al.*, 1996). These compounds are a group of modified triterpenes with a 4,4,8-trimethyl-17-furanyl-steroid precursor and its derivatives. However, commercial extraction and processing of these materials require expensive and sophisticated techniques which put them out of the reach of the farmers in developing countries (Ahmed *et al.*, 1984). The high structural complexity of limonoids also has limited the effort to develop synthetic compounds with the entire limonoid skeleton. On the other hand, the natural blends of these compounds found in crude plant extracts are more bioactive and effective than most of the isolated and purified single compounds (Isman *et al.*, 1996).

The neem seed kernel contains a considerable number of bioactive compounds including azadirachtin, salannin, salanol, salanol acetate, 3-deacetylsalanin, azadiradion, 14-epoxyazadiradion, gedunin, nimbin and deacetylnimbin (Jones *et al.*, 1989; Champagne *et al.*, 1992). The most important active principle is the C-*seco* limonoid, azadirachtin (Butterworth and Morgan, 1971; Jones *et al.*, 1989; Schmutterer, 1990; Champagne *et al.*, 1992; Isman *et al.*, 1996). The molecular structure of azadirachtin is so complex and difficult to synthesize in the laboratory (Plate VI). Structure and activity studies indicate that the complete carbon skeleton of the molecule is required for growth inhibition and antifeedant activity (Isman *et al.*, 1996). The oil contains many other bioactive compounds, most of which are derivatives of vilasinin (Kraus *et al.*, 1987; Henderson *et al.*, 1964). These include sedanin, 1-tigloyl-3-acetylvilasinin, nimbin, ochinolide B and salannin. Bioassay with the Mexican bean beetle, *Epilachna varivestis,* showed these compounds to have antifeedant activities comparable to azadirachtins (EC_{50} =13 ppm) (Isman *et al.*, 1996).

Azadirachtins ($C_{35}H_{44}O_{16}$) are secondary metabolites mainly found in the seeds of the neem tree. The seed kernels of *A. indica* and related species contain an array of azadirachtins of which seven isomers labelled as A to G are so far identified. They are potent growth inhibitors (Rembold, 1989; Champagne *et al.*, 1992; Rice, 1993b). Azadirachtin A is the main bioactive constituent in neem extracts. It makes up about 70%, and together with azadirachtin B (=3-tigloylazadirachtol, or deacetylazadirachtinol), accounts for 99% of the azadirachtins of the neem seed kernel extracts. Among the limonoids, the insect growth regulatory effects of neem are exclusive to the azadirachtins. These compounds have basic tetranotriterpenoid molecular structures with MW 721. Azadirachtins account for 85-90% of the growth inhibiting and moult disrupting activity, and 72% of antifeedant activity of neem extracts (Butterworth and Morgan, 1971; Isman *et al.*, 1996; Rice, 1993b). Azadirachtin molecules have two main active sites. The left-hand side possesses growth regulatory effects and severely disrupts the endocrine system of insects (Plate VI). The right hand side is antifeedant and oviposition deterrent (Rice, 1993a, 1993b).

Several hypotheses exist on the mode of action of these bioactive compounds. Interference with the neuroendocrine system controlling ecdysone and juvenile hormone synthesis, and inhibition of ecdysone release from the hormone-releasing gland has been suggested. In addition, azadirachtin is a chitin synthesis inhibitor (Schmutterer, 1988). Insects treated with azadirachtins may live for many days since their neural membranes and synaptic enzymes are not affected. These compounds have two main sites of action: insect gustatory receptors and neuroendocrine cells. Ultrastructural studies indicated that cells of the corpora cardiaca and corpora allata are disrupted by low doses of azadirachtins (Rice, 1993b).

The effectiveness of neem seed powder and extracts in the control of stem borers of maize can be evaluated by the extent to which these products reduce the level of infestations and crop damages, and provide improved crop production. Studies on the use of neem (*A. indica*) revealed that crude extracts of the seeds and the oil possess important pest control properties against a number of pest species on vegetables and field crops (Dreyer, 1987; Schmutterer *et al.*, 1993). Neem seed contains a considerable number of bioactive ingredients that show substantial levels of insecticidal activities against a number of pests. Neem extracts have a wide range of effects on feeding, metamorphosis, fecundity, sterility, egg hatchability, and on the overall fitness of insects (Schmutterer, 1990). These effects upon insect development are most important from the viewpoint of practical insect pest control.

Neem has been effective in controlling many pests of stored grain (Akou-Edi, 1984; Saxena *et al.*, 1984; Zehrer, 1984; Ivbijaro, 1990). Although extracts of *A. indica* in laboratory tests have been shown to affect more than fifty species of phytophagous insects, field trails with convincing results were not available (Bernays, 1983). However, azadirachtin containing neem seed extracts produce good results in pest control in the field. Aqueous, alcoholic and enriched (azadirachtin-rich) extracts are mostly used. The residual effect lasts about four to eight days, depending on the environmental conditions and the plant species treated. Aqueous neem seed extract seems to protect plants to a certain extent for not longer than four to five weeks. Systemic effects last somewhat longer. Ultraviolet light, rainfall, and perhaps the acidity on treated surfaces of plants cause a fast degradation of the active material. Consequently, much higher concentrations of azadirachtin have to be used in the field to obtain results comparable to those in laboratory tests. Several problems, mainly related to purification of these complex bioactive compounds, have to be overcome to develop reliable pesticides from neem seed extracts (Schmutterer, 1988).

Neem seed extracts have been found effective against armyworms (Redfern *et al.*, 1984), the rice leaf folder *Chaphalocrocis medinalis* (Guenee) (Saxena *et al.*, 1981), green leafhopper and brown planthopper of rice (Saxena *et al.*, 1983; Saxena *et al.*, 1984), *Bemisia tabaci* (Genn.) (Dreyer, 1984), and *Spodoptera* spp.(Jacobson, 1987). Crude extracts of neem are reported to have noticeable juvenilizing effects on fifth instar nymphs of the cotton stainer *Dysdercus koenigii*, in which metamorphosis was inhibited to a certain degree (Jaipal *et al.*, 1983).

In spite of the sensitivity of insects in many orders to azadirachtin, neem products are selective as they do not harm important natural enemies of crop pests. They are also nontoxic to warm-blooded animals. Neem seed extracts have, therefore, a considerable potential for use in integrated pest management, provided certain strategies are considered for their formulation and application (Schmutterer, 1988).

The potential of neem for pest control in developing countries, however remains largely untapped due to the advent of broad-spectrum insecticides with a distinctive toxicity. The presence of a mixture of bioactive limonoids with different structures in crude extracts of neem provides a diverse arsenal of phytochemicals that possibly act synergestically against many insect pests. The blend of bioactive constituents improves the efficacy of crude extracts of neem as compared to that of any single compound. As neem contains numerous ingredients with different structures and biological activity, the development of resistance to neem in insect pests is slow and less probable. This condition increases the durability of neem as a pest control material and favours it's use as a crude botanical preparation. However, it is imperative to test the efficacy of neem extracts against a variety of insect pests before it can be adopted for wide usage.

Knowledge on the use of neem as a source of pest control material is either based upon folklore or upon diverse findings by several workers. The diversity of these findings is reflected in the mode of actions attributed to neem and parts of the plant used as sources of the bioactive substances. Reports on the methods and procedures of preparation and extraction, and the duration of the pest control activity are also varied. This again reflects differences in the procedures adopted and agro-climatic conditions where the studies were conducted. In addition, the biology and behaviour of the target pest and the genotype and age of the neem tree presumably contribute to the diversity in the findings (Ahmed *et al.*, 1984).

Information on the use of neem extracts in the control of stem borers, specifically that of *C. partellus* on maize crop, is scarce. Some work has been reported so far on the use of neem kernel powder in controlling *C. partellus* in the field and screenhouse (Jotwani and Srivastava, 1984; Dreyer, 1987). However, very little information is available regarding to the control *C. partellus* and other cereal stem borers using crude extracts from *A. indica*. Systematic studies on their effects on growth and development of *C. partellus* and other cereal stem borers are much needed to formulate an effective pest management.

The potential of such abundant, easily available, and inexpensive natural products from *A. indica* are not yet fully exploited for pest management. This is particularly true when it comes to the possible advantages of neem seed extracts in the control of maize and sorghum stem borers. Therefore, this study aims at elucidating the effects of neem seed powder and crude extracts on the growth and development of *Chilo partellus* (Swinhoe), one of the key pests of maize in East Africa including Ethiopia and Kenya. The study also attempts to evaluate the potential of neem seed powder and aqueous suspension in the management of *C. partellus* populations on maize cultivars with different levels of resistance under field situations.

Plate I. *Azadirachta indica* (A. Juss.): Young neem trees beginning to bear fruits at Mbita Point Field Station (ICIPE).

Plate II. Neem seedlings raised in nursery and ready for distribution to the community.

Plate III. A young neem tree thriving well after transplanted.

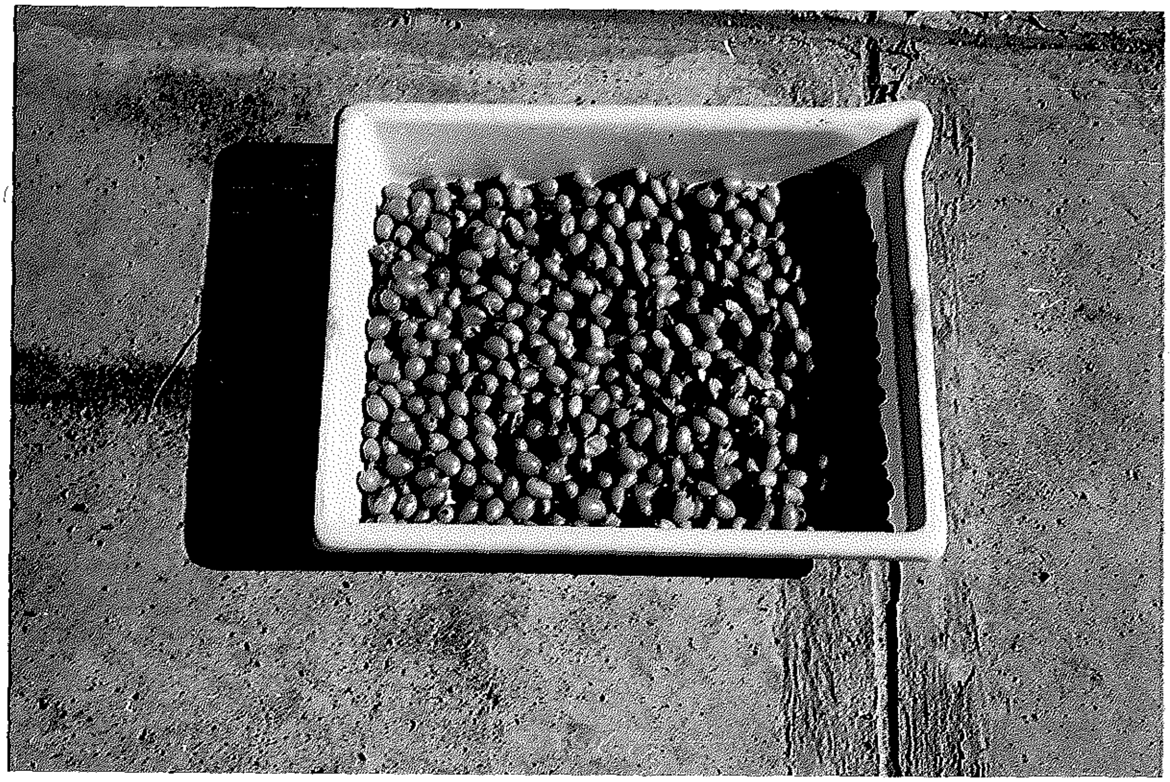

Plate IV. Neem fruits about to ripe collected from five years old trees.

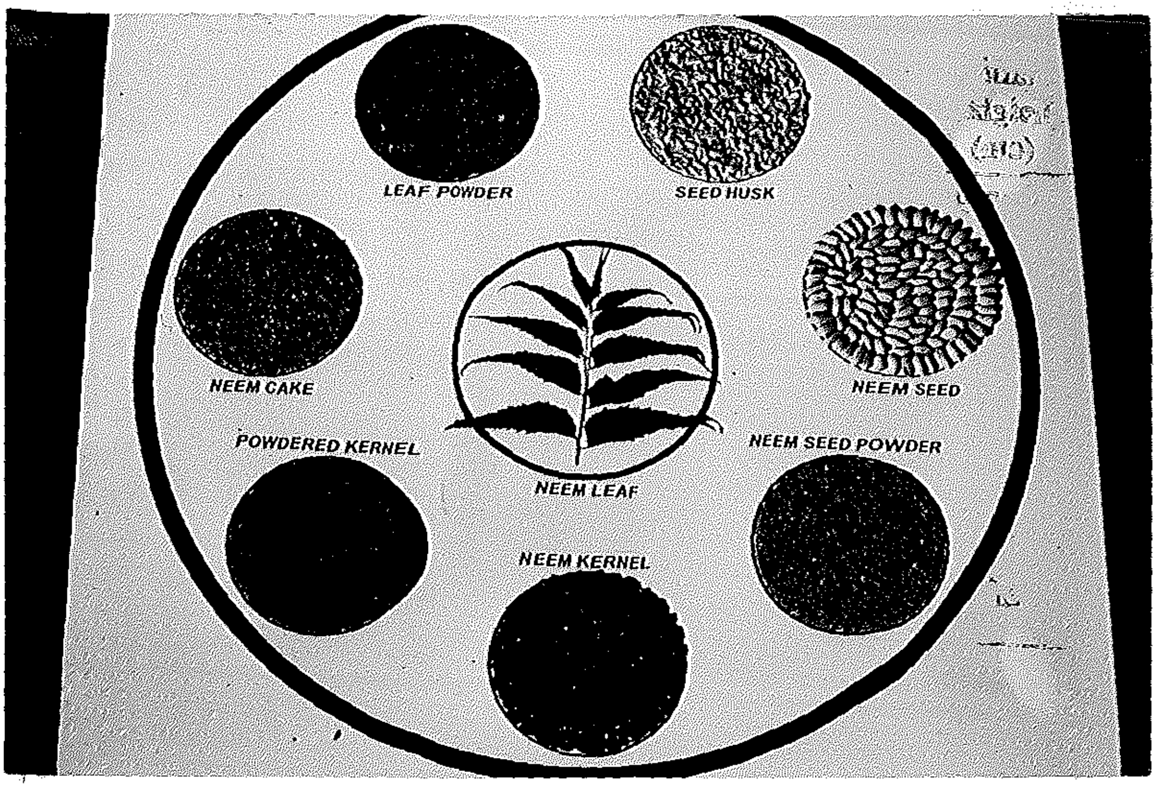

Plate V. Different parts of the neem tree (*A. indica*) commonly used for medicinal and pest control purposes.

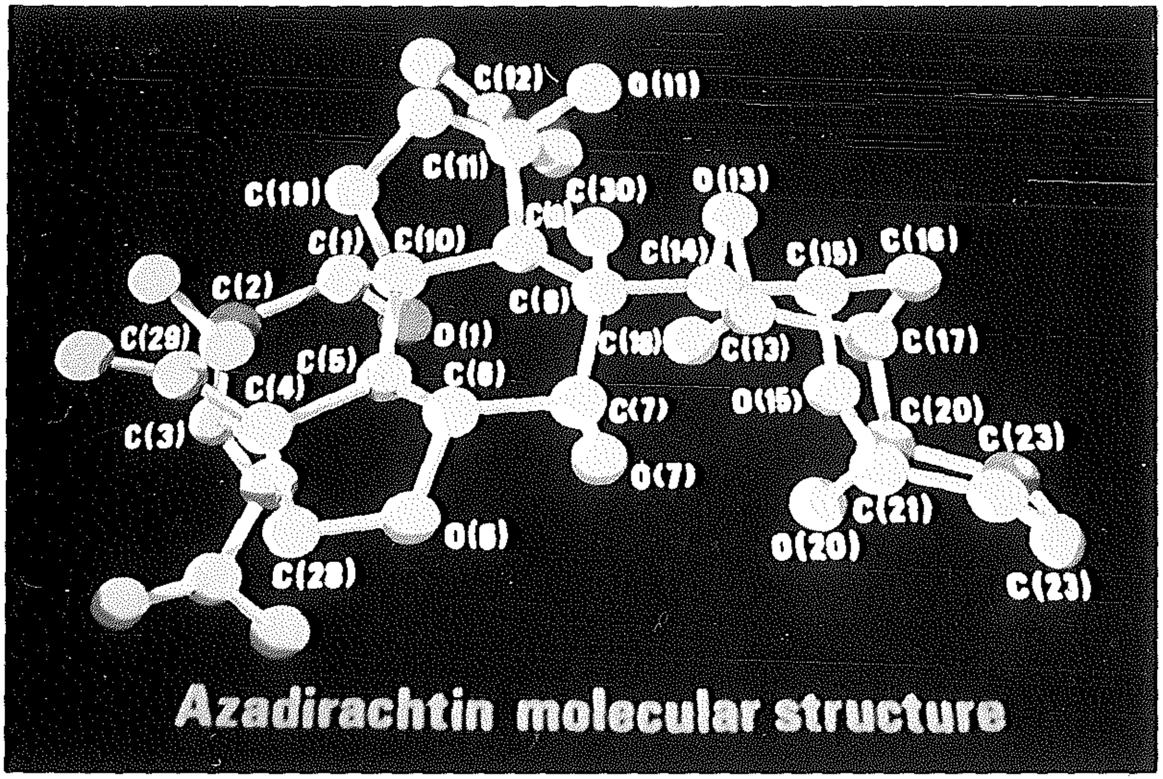

Plate VI. Molecular structure of azadirachtin from neem (*A. indica*). Courtesy: Dr. R.C. Saxena.

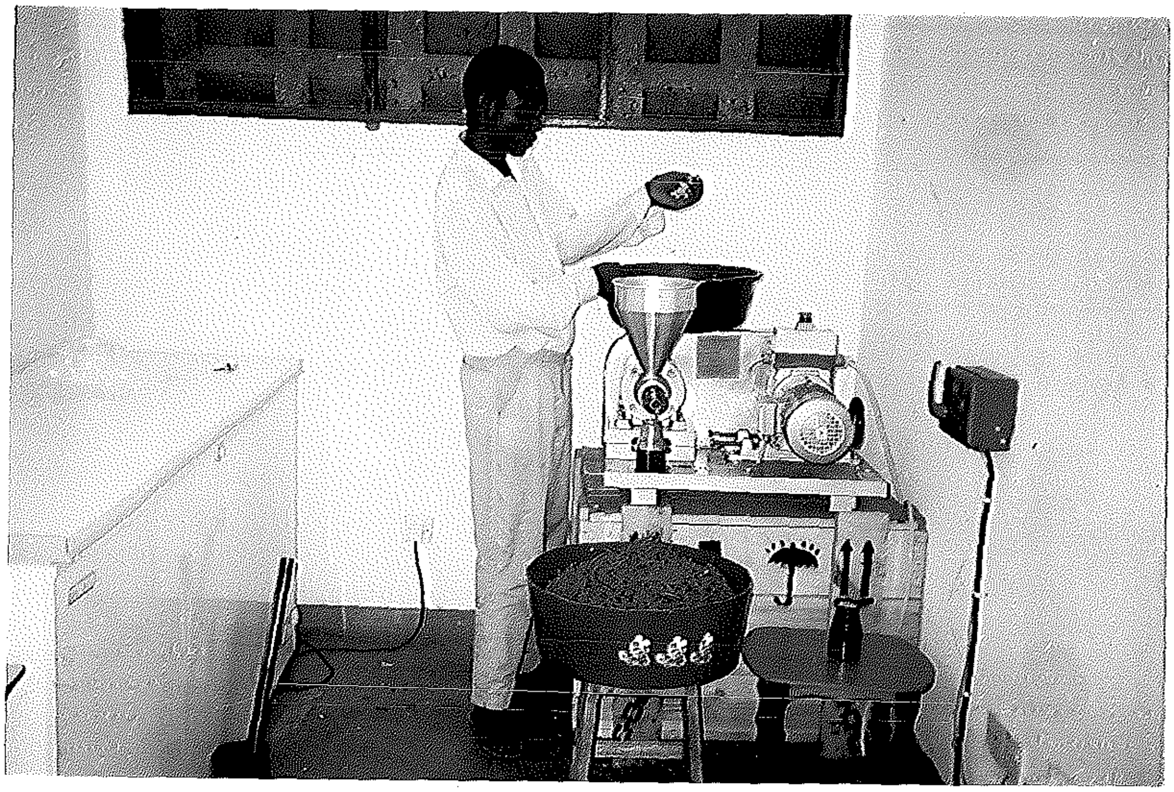

Plate VII. Depulped and dried neem seeds processed with a press to produce neem oil and neem cake.

Plate VIII. Neem cake which is used as a fertilizer in many places where neem trees are widely grown.

CHAPTER 2

EFFECT OF NEEM (*A. INDICA* A. JUSS.) SEED POWDER AND ITS AQUEOUS EXTRACT ON *C. PARTELLUS* (SWINHOE) ON ARTIFICIALLY INFESTED MAIZE CULTIVARS UNDER FIELD CONDITIONS

2.1. OBJECTIVES

The study was initiated with an overall objective of generating base-line data which will be used for developing environmentally safe, economically feasible, biointensive botanical pest control strategies and methods for the management of the spotted stem borer, *Chilo partellus* (Swinhoe). The specific aims of the field experiments were to investigate and determine the effectiveness of foliar applications of powder and aqueous suspension of dried seeds of neem (*A. indica*) against *C. partellus*, and subsequently to determine their effect on the yield of maize cultivars subjected to artificial infestations at field conditions in western Kenya.

2.2. MATERIALS AND METHODS

2.2.1. The Study Area

The study was conducted at Mbita Point Field Station (MPFS) of The International Centre of Insect Physiology and Ecology (ICIPE) in western Kenya located at $0^{0}25'$ S-$0^{0}30'$ S latitude; $34^{0}10'$E-$34^{0}15'$E longitude; and an elevation of 1,170m above sea level (Kumar *et al.*, 1993). The field studies included two experiments conducted in different seasons: the first experiment was conducted during the long rains of 1993 and the second during the short rains of 1993-1994. The field station is provided with irrigation facilities which were used during field experiments as required. The annual rainfall at Mbita Point Field Station located at the Kenyan shores of Lake Victoria averages 880 mm. The area receives about 650 mm rainfall during the long rains season which extends from the end of March to July. The short rains at the end of the year start in November and account for about 150 mm of precipitation. The temperatures of the region are warm with a mean temperature of 22^{0}C, and fluctuate between a maximum of 30^{0}C-32^{0}C and a minimum of 14^{0}C-16^{0}C (Sombroek *et al.*, 1982).

2.2.2. Maize varieties and planting procedures used

Susceptible (Hybrid 511) and moderately resistant (ICZ3) cultivars of maize (*Zea mays* L.) were obtained from Kenya Seed Corporation and Crop Pest Research Programme (CPRP) at MPFS/ICIPE, respectively, for the field experiments. The Hybrid 511 is susceptible but is a high yielding variety grown by many farmers in the country. ICZ3 (Reg. no. GP-246, PI 570679) maize germplasm was developed at ICIPE and has an appreciable level of tolerance to *C. partellus* infestations as a mode of resistance to this pest (Ajala and Saxena, 1994).

These maize varieties were planted according to recommended agronomic practices on plots of 6 m x 8 m size on a 0.25 ha field at MPFS/ICIPE. Spacings between rows and hills were 75 cm and 30 cm, respectively. Three seeds of each cultivar were sown in each hill to ensure adequate germination and thinned to one to maintain a minimum of 25 plants in an 8 m row before plants were artificially infested with *C. partellus* eggs. The field experiments were set following a randomized complete block design with four replications (Hicks, 1973; Snedecor and Cochran, 1978). Commercially available Diamonium phosphate (DAP) and Urea fertilizer at a rate of 300 kg/ha each were applied at planting and three weeks after crop emergence, respectively. Weeding was done manually with hoes as recommended.

2.2.3. Culture of *C. partellus* and artificial infestation

The experimental insects used were obtained from the Insect and Animal Breeding Unit (IABU)/MPFS/ICIPE. The culture of *C. partellus* was maintained on artificial diet developed by Ochieng *et al.* (1985). The rearing protocol included a variable number of adult male and female moths kept in rearing cages and allowed to mate. Glossy paper was placed inside rearing cages being supported by the sides of cages for oviposition. Egg batches laid on paper strips were kept in incubation chambers and allowed to develop to the blackhead stage which were used for field infestations. Maize plants in all plots were artificially infested with egg batches of *C. partellus* (about 30-40 blackhead stage eggs per plant) at three weeks after crop emergence. The egg batches were placed in the inner whorl leaves of plants using forceps late in the afternoon to reduce egg desiccation due to heat (Plate IX). This allowed the successful establishment (25.9% on Hybrdid 511 and 19.6% on ICZ3 during the long rains of 1993; 19.3% on Hybrid 511 and 17.2% on ICZ3 during the short rains of 1993-94) and colonization of first instar larvae of *C. partellus* on young maize plants by the time of treatment application (Appendices IV and IX).

2.2.4. Experiments on neem seed materials and chemical insecticide

Neem fruits of the 1993 and 1994 crops were collected from Mombassa, Kenya, during fruiting seasons. Depulped seeds were dried in the shade and ground manually with mortar and pestle to obtain neem seed powder which was used diluted with sawdust, or as aqueous suspension (neem shake) (Plates X and XI). Dipterex (Trichlorophon, 5% granular) at a rate of approximately 1g/plant for the control of stem borers was used as a check treatment along with neem seed formulations.

Neem seed powder (NSP) was applied at the rate of approximately 3 g/plant. This was done by taking a pinch of NSP using the thumb and three fingers and applied in the whorl of maize plants. The powder was mixed with equal amount of sawdust (w/w) and the mixture was applied at a rate of approximately 6 g/plant (a pinch of the mixture using the fingures and thumb as shown in Plate XII). Neem seed powder was also mixed with tap water and kept overnight, thoroughly stirring repeatedly at intervals of six hours. After 24 hours, the mixture was filtered with cheesecloth to obtain a 10% aqueous neem seed suspension (w/v) which was immediately sprayed at a rate of 500 l/ha. Dipterex was applied at a rate of approximately1 g/plant (a pinch of granules with the thumb and two fingers). The rate of application of neem seed products and insecticide was determined based on results of preliminary experiments conducted by the Neem Awareness Project, ICIPE (R. C. Saxena, 1993, unpublished). Untreated plots were used as controls. The treatments were applied one week after artificial infestation (four weeks after crop emergence) (Plates XIII and XIV). Treatments were applied in the funnel of the young maize plants late in the afternoon to minimize immediate evaporation and UV effect on the neem extracts.

2.2.5. Parameters obseved for crop damages and yield loss due to *C. partellus*

In all the field experiments, ten maize plants from each replicate were randomly selected at a weekly interval beginning from the day of application of treatments (i.e. four weeks after crop emergence) until harvest. One row at each side of the plots was left and not considered for sampling to minimize the border effect. Pre-marked inner rows in each treatment were retained for yield assessment. Plant height, leaf damage (on visual rating of 1-9 scale), percent stem tunneling, borer density, and grain yield at harvest were recorded and studied (Plates XV-XVII).

Plant growth was recorded by measuring the height of each plant at sampling and the averages for each treatment group were compared. Height of maize plants was measured up to the collar-leaf in plants that had not tasseled or up to the tip of the peduncle and the base of the tassel where plants had tasseled (Plate XVI). Leaf damage, based on a nine-point visual rating scale (1, slightly visible damage; 9 severe foliar damage) was recorded using the standardized *Chilo* leaf feeding scoring system (Dissemond and Weltzien, 1986; ICRISAT, 1990). Each plant in the sample was assessed individually and the mean score for the plot was calculated from the data recorded. Number of plants with deadheart were recorded as absolute counts showing the symptom in each plot and expressed in percentage as a proportion of the number of stands. Each maize plant in the sample was carefully dissected along the entire length including the peduncle and the length of tunnels produced due to larval feeding was recorded. Stem tunneling was expressed as a percentage of the total length of stem tunneled over plant height for each treatment.

The number of larvae, pupae, and pupal cases recovered from dissected plants in the sample in each treatment group were recorded at the time of measuring tunnel length and used to determine the level of infestation by *C. partellus*. The larvae and pupae were identified by comparison with standard collections. Recovered larvae were preserved in 70% ethanol in vials and kept for head capsule measurement. Pupae collected at sampling were kept in glass petri dishes in the laboratory and checked for the emergence of parasitoids. Recovered parasitoids from each treatment were collected in vials and identified at ICIPE.

Dried cobs of maize in each plot were collected and shelled at harvest. Grain weight (kg/plot) was taken using ordinary balances. Simultaneously, the grain moisture content was recorded with a Dickey-John® moisture tester. Grain yield per hectare was calculated using the grain weight and moisture content obtained for each plot as follows (Dent, 1991).

$$\text{Yield (t/ha)} = (1-\text{Mc}) \times \text{Gwt} \times \frac{10{,}000}{\text{Area}} \times \frac{1}{1000} \times \frac{100}{86}$$

Where Mc= % moisture content in decimals Gwt= grain weight in kg

Area= area of plot in m^2.

2.2.6. Statistical analysis of field data

All data on crop damages, stem borer density, and yield were analyzed after Arc sine or square-root transformations as specified for each variable. Treatment and cultivar effects and their interaction were sorted by plant age (weeks after crop emergence). Where the percentages were used, the data were transformed by using Arc sine transformation after adding 0.5 to each value. The data pertaining to the number of stem borers were transformed after adding 0.5 to each figure by square-root transformation. Unless otherwise stated, the data given in tables or used in figures are untransformed. The data were subjected to analysis of variance, and means were separated at $P=0.05$ by Duncan's multiple range test (SAS Institute, 1987; SPSS Inc., 1995) to determine significance among treatments, between cultivars, and treatment-cultivar interactions.

Plate IX. Artificial infestation of three weeks old maize plants with blackhead stage egg masses of *C. partellus*. Egg batches placed inside the whorls of young plants.

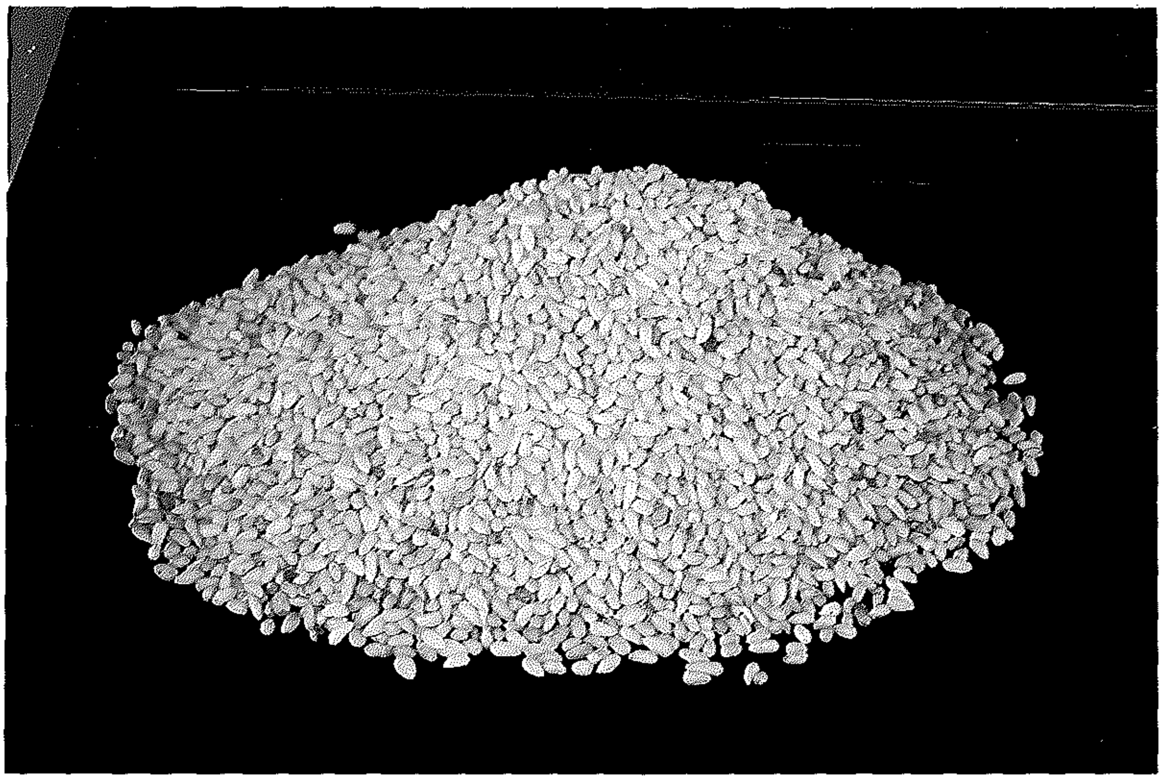

Plate X. Cleaned and dried neem seeds ready to be processed for field application as pest control material.

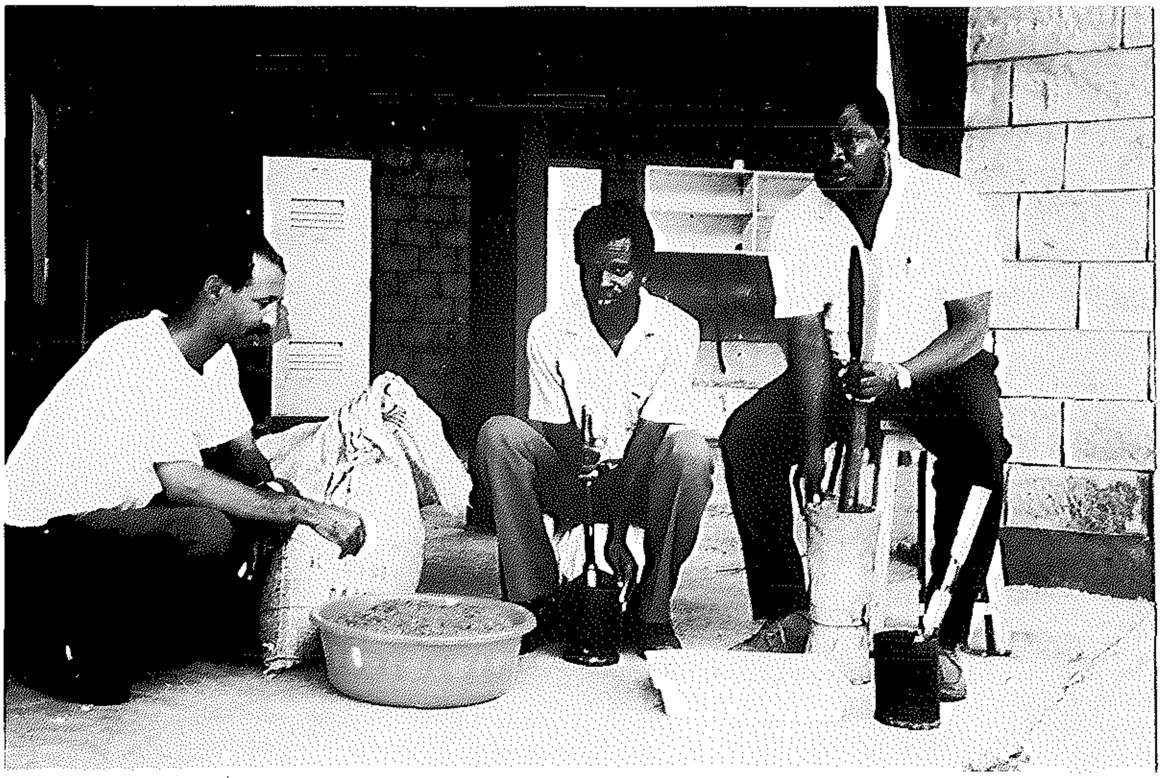

Plate XI. Dried neem seeds manually ground with mortar and pestle to obtain neem seed powder.

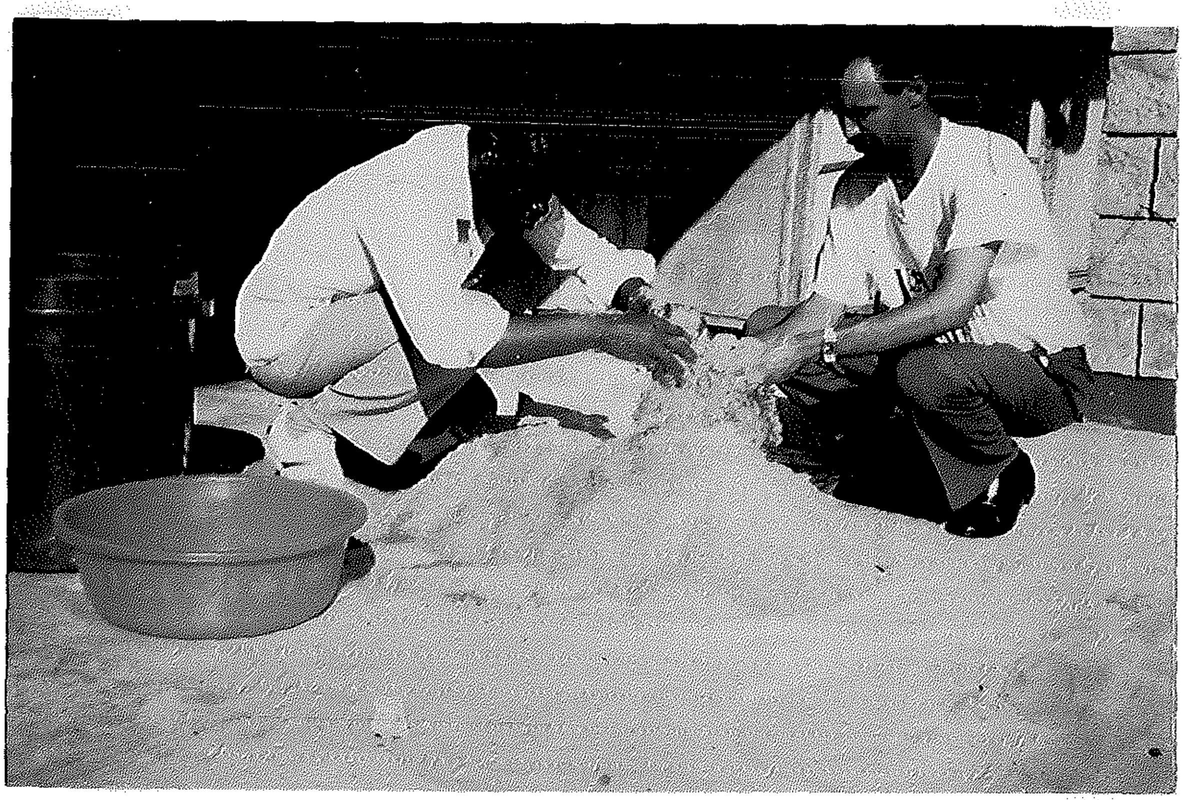

Plate XII. Neem seed powder mixed with sawdust.

plants

Plate XIII. Application of neem seed powder into the whorl of young maize plants artificially infested with *C. partellus*.

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