BIOLOGY AND CONTROL OF THE LESSER GRAIN BORER, *Rhizopertha dominica* Fabricius (Coleoptera: Bostrichidae) ON WHEAT (*Triticum aestivum* L).

BY

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A Thesis submitted to the Crop Protection Department, Faculty of Agriculutre, Ahmadu Bello University Zaria in partial fulfilment of the requirements for the degree of Master of Science (M.Sc.) Crop Protection.

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CERTIFICATION

This thesis entitled BIOLOGY AND CONTROL OF THE LESSER GRAIN BORER, RHIZOPERTHA DOMINICA FABRICIUS (COLEOPTERA: BOSTRICHIDAE) ON WHEAT (TRITICUM AESTIVUM L.) by ABDULLAHI, Jamilatu meets the regulations governing the degree of Master of Science of Ahmadu Bello University, Zaria, and is approved for its contribution to scientific knowledge and literary presentation.

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DECLARATION

I hereby declare that this thesis has been written by me and that it is a record of my own research work. It has not been presented before in any previous application for a higher degree. All borrowed ideas have been duly acknowledged by means of references.

Abdullahi, Jamilatu — Date: 1-6-94

The above declaration is confirmed

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DEDICATION

In the name of Allah the most high.

I dedicate this piece of work to my Son, Suleiman.

May you find knowledge and wisdom in your life.

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I am grateful to Allah subhanahu wata'ala who created man from but mere dust and said unto him Iqra (read!). May peace and blessings of Allah be on his holy Prophet (SAW), his companions, his wives (mothers of believers) and all believing men and women, Alhamdu Lillah.

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ABSTRACT

The life cycle, flight ability, host preference, micro-organisms associated with and chemical control of the lesser grain borer, Rhizopertha dominica F. was studied. On whole wheat, the life cycle took four weeks to complete but took five to six weeks on other test food materials. The adult insects were found to fly freely and measured 1.338-2.275mm in length. When the effect of R. dominica was compared on different host food materials, millet (Var. Sammil-1) was found to be the preferred host leading to more survivors during the development process, while wheat (Var. Samwhit-6) was suitable for shorter length of the life cycle. The micro-organisms Aspergillus niger. Rhizopus Spp.., Penicillium Spp. and an unidentified bacterium were found associated with the insect externally while Aspergillus Spp. and the same unidentified bacterium were found associated with the insect internally. The chemical insecticides Actellic 2% dust, Coopex 5% dust, Phostoxin tablets, lindane 5% dust and Quickphos tablets gave significantly high adult mortality three days after treatment than airtight and ventilated controls. All the chemicals suppressed progeny development and emergence after killing the parents with the exception of Actellic 2% dust.

CHAPTER 1:

1.1 PREAMBLE

INTRODUCTION: WHEAT AS A CROP

The wheat, Triticum aestivum (L.), plant is a member of the grass family, Gramineae, which comprises some 600 genera and more than 5000 species (Aykroyd and Doughty, 1970). While the Gramineae have great diversity, they show numerous similarities in the structure of the roots, stems and leaves. The principal cereals used by man - wheat, rice, maize, barley, oats, rye, sorghum, millet - are seeds of plants belonging to the grass family an important non-cereal member of this family is sugarcane, the stem, of which is the source of food. The word wheat is applied both to the plant and its edible seeds, and the words for the other cereals have the same dual significance.

1.2 HISTORICAL BACKGROUND OF WHEAT

Evidence of origins of wheat can be derived from archeological research (Riley, 1975), carbonized remains of wheat grains, and imprints of grains in

baked clay (Aykroyd and Doughty, 1970). Discoveries were made of wheat species in the Near East (Iran and Iraq) that are dated earlier than 5000 BC (8500-5000 BC) in sites around Ali Kosh and other

sites (Riley, 1975). Imprints of the grains have also been found in the famous neolithic site of Jarno in Northern Iraq, which has an estimated radiocarbon date of 6700 BC (Aykroyd and Doughty, 1970; Riley, 1975). Other regions in which wheat was found from archeological evidence include Palestine (7000 BC), Zagros (6750 - 5500 BC), Syria (5750 BC), Anatolia (7000 - 5000 BC), Greece (6200 - 5000 BC) and Bulgaria (5000 BC) (Riley, 1975).

1.3 TAXONOMY AND GENETICS OF THE WHEAT PLANT

All wheats whether wild or cultivated belong to the genus Triticum of which 14 species are commonly recognised. Bread wheat - Triticum aestivum SSP vulgare is the most widely distributed of all varieties (Spicer, 1975).

Modern taxonomy divides wheat into three groups in accordance with the number of chromosomes in their

reproductive cells (Spicer, 1975). Group I with a chromosome number of 14 (known as a diploid), includes the wild and cultivated 'Einkorn' wheats, T. aegilopoides and T. monococcum. Group II with a chromosome number of 28 (known as a tetraploid) comprises of the wild and cultivated 'Emmer' wheats, T. dicoccoides; Durum wheat; Abyssinian wheat; Rivet or cone wheat; Persian wheat; Polish wheat; and T. timopheevi. Group III, with a chromosome number of 42 (known as hexaploid) includes spelt wheat (T. spelta); Common or bread wheat (T. aestivum L.); Indian Dwarf wheat; and Macha wheat. These classifications are mainly, though not exclusively, based on morphological differences.

1.4 WHEAT PRODUCTION

On a world wide basis, wheat is the most important cereal with production figure of 254 million metric tonnes in 1965, 445 million metric tonnes in 1979 (Food and Agricultural Organization (FAO, 1980) and 535.3 million metric tonnes in 1989 (FAO, 1990). This shows an increase in production of 20.34 per cent in the ten years between 1979 and

1989. Wheat is followed only by paddy rice which had a production figure of 506.86 million metric tonnes in 1989. Where wheat represents 29% of total world cereal production, paddy rice represents 27%, maize 25% and sorghum only 3.17%.

The great wheat lands of the world are in the temperate climates mainly concentrated in the northern hemisphere. These regions are very favourable for production of wheat a cold season crop. Wheat is grown extensively between latitudes $60^{o}N$ and $40^{o}S$ with environmental requirements of 300-750mm rainfall of per year, and $5^{o}C$, $29^{o}C$ and $43^{o}C$ minimum, optimum and maximum temperatures, respectively, for growth.

In tropical Africa, the only areas where significant quantities of wheat are produced are the highland provinces of Ethiopia and Kenya. This is due to the cooler temperatures of highland regions which have advantages for this crop (Southworth and Johnston, 1976).

Wheat cultivation in Nigeria is not a new practice. Wheat has been under cultivation traditionally in the Sahel and Sudan zones of

northern Nigeria as early as 2000 BC (Olugbemi, 1980). It was grown on a very small scale as a minor crop on dry season irrigated gardens. It was only recently that the government decided to develop irrigation schemes in the far north of the country (between latitudes 12-14^{o}N) to boost the cultivation of wheat. Although wheat has been cultivated for a long time in Nigeria, the contribution to the Nigerian economy has been insuffficient until recently when government banned wheat importation in 1986. Before then wheat importation had been draining the country of much needed, hard-earned foreign exchange. Wheat importation rose rapidly from 407,500 tonnes in 1975 to 1.83 million tonnes in 1985 (National Farming Systems Research Network (NFSRN), 1990). This indicates a rise in importation of about five folds in just ten years.

Prior to 1986, farmers in the wheat growing areas had no incentive to increase their production at home because of the absence of a guaranteed market in the flour milling industry. With the Accelarated Wheat Production Programme (AWPP), the production went up to 140,000 tonnes in 1987/88, 492,826 tonnes

in 1988/89 and 550,000 tonnes in 1989/90 (NFSRN, 1990). With increase in wheat production, the number of flour mills increased from five to twenty in 1988 with a total capacity of 4 million tonnes per year.

Current land under cultivation in Nigeria is 250,000 hectares (Chiezey et al., 1990). Irrigation schemes have been established in the country for wheat cultivation. These include the Hadejia - Jama'are River Basin Development Authority (HJRBDA) in Kano State, Sokoto-Rima River Basin Development Authority (SRBDA) in Sokoto State and the Chad Basin Development Authority (CBDA) in Borno State. Many farmlands are being cultivated by individual farmers scattered around the northern parts of the country with the aid of the Ministries of Agriculture, farmers supply companies and the Agricultural Development Projects (ADP). Initially, the Institute for Agricultural Research (IAR), Ahmadu Bello University, Zaria, co-ordinated the wheat research programmes in the northern states of the country. Technologies developed by these researches are passed to the farmers to encourage them to increase their wheat production. This responsibility has recently

been passed on to the Lake Chad Research Institute.

1.5 AGRONOMY AND ECOLOGY OF WHEAT IN THE TROPICS

Temperature is the limiting factor for the growth of wheat in the tropical and sub-tropical regions. Because of its need for low temperature regimes, wheat is grown under irrigation during the harmattan period (November to February in Nigeria). Fortunately for Nigeria, the harmattan period during the dry season provides the initial cool favourable temperatures for the growth of the crop under irrigation. The factor which prevents the extension of the crop southwards in Nigeria is temperature.

Wheat yields have increased greatly in recent years. Improved soil fertility through commercial fertilizers has certainly helped. Essentially three elements (N.P.K) are required for fertilization. The wheat crop with its extensive fibrous root system can therefore absorb a substantial portion of the nitrates (from nitrogen fertilizers) in the soil. The crop is extremely sensitive to phosphorus deficiencies. It needs liberal quantities of phosphorus during the early stages of growth.

Although potassium is an essential nutrient for plant growth and development, wheat yield reductions due to lack of potassium have not been frequently recorded. Use of micronutrients especially magnesium increases wheat yields significantly (Azarema, 1983).

The greatest demand upon the soil of nitrogen by wheat is during the rapid growth stages of jointing and shooting. The wheat plant requires about 9.1 - 22.7 kg/ha phosphorus during the early stages of its growth.

For dwarf wheats the fertilizer requirement is as follows:

N = 100 - 120kg/ha

P = 50 - 60kg/ha

K = 40 kg/ha.

The environmental conditions required for the effective cultivation and growth of the wheat crop are:

i). A wide variety of well drained soils, but sandy loams that are mildly alkaline are preferred.

ii) Optimum temperature of 29^{O}C during growth

periods, temperatures below 5°C or above 43°C will prove lethal to the crop.

(iii) Rainfall requirement of 300-750mm/year.

(iv) An elevation of 240-310 metres above sea level.

1.6 WHEAT AS FOOD

Wheat is the most cultivated food plant (FAO, 1976). It is eaten in various forms by more than 1000 million human beings, and makes a larger contribution to the calories and protein available to man than any other food (Aykroyd and Doughty, 1970). It is significant that the FAO has chosen as its emblem an ear of wheat, surrounded by the letters of its name, with the latin inscription "Fiat panis" (Let there be bread") appearing below. No other food would be as appropriate as the emblem of an international organization concerned with food and agriculture.

Wheat compares well with other cereals in nutrient value. Hard wheat contains more protein than any other cereal except oats. Wheat in general has a relatively high content of thiamine and niacine. Like other cereals, it is poor in riboflavin and also in

calcium. It contains little fat which is confined to the embryo and is devoid of vitamin A. Wheat germ is also rich in vitamin E (Appendix I).

Generally, wheat contains less protein (10.5 - 13.8%) than other common foods such as legumes (18-26 percent protein), meat (12-20%), fish (16-20%), eggs (13%) and cheese (19-25%). Like other cereals, wheat is much richer in protein than various roots, tubers and starchy fruits which are staple foods in some parts of the world and contain not more than one to two percent of protein in the fresh state.

Wheat is the most preferred grain for food in the advanced countries. Apart from being a staple food, it is also the major ingredient in most breads, biscuits, semolinas, macaroni, noodles, crackers, cakes, buns, pastries, scones, breakfast cereals, beverages, porridge, couscous,chappatis, pancakes and many other foods around the world. Locally, wheat is used for making snacks such as "alkaki", 'Funkaso', 'Dublan', 'Talia,' 'Gireba', 'chinchin' and in many other foods. Most of these local snacks are prepared in the northern parts of Nigeria and are mostly used for special occasions such as naming and wedding

ceremonies.

1.7 INSECT PESTS AND DISEASES OF WHEAT

While in the field, wheat is liable to attack by insect pests and diseases. Insect pests recorded on the wheat crop include the green bug, Schizaphis graminum (Rond), the Hessian fly, Mayetiola destructor (Say), wheat stemfly, Meromyza americana Fitch., Termites, Sesamia spp., cutworms, Agrotis spp., brown wheat mites, Petrobia (P.) latens Mulla, grasshoppers, wheat aphids, Macrosiphum avenae (F.), wheat bulb-flies, Delia coactata (Fall.), wheat stem sawfly, Cephus cinctus Norton, army worms Spodoptera spp. and many minor insect pest. Diseases found in the field include the fungal diseases Black or stem rust (Puccinia graminis Pers. f. sp. tritici), brown or leaf rust (P. recondita), yellow or stripe rust (P. striiformis), blight (Alternaria triticina), foot and root rot (Drechslera rostrata, Fusarium equiseti), spot blotch (Drechslera sorokiniana), grain weathering (Fusarium semitectum, F. moniliforme, F. equisetiphoma sorghina, Drechslera sorokiniana) loose smut (ustilago nuda) and the sooty ear (Cladosporium herbarum, Alternaria sp.). Other

pathogens on wheat include Aspergillus spp., Chaetomium spp., Curvularia spp. other Fusarium spp., Mucor hiemalis, Rhizopus sp., Rhizoctonia sp. and many others. Nematode diseases found include the root knot nematodes, Meloidogyne incognita and M. javanica. All these diseases were isolated here in the Savannah and semi-arid areas of Nigeria (Emechebe et al, 1980.

While in storage wheat grains are attacked by storage insect pests such as Sitotroga cerealella Oliv., Oryzaephilus surinamensis L. Rhizopertha dominica (F.), Sitophilus oryzae L.,S granarius L., Tribolium castaneum Herbst., T. confusum J. du val and a host of others. The stored product insects lay their eggs on wheat in the field prior to harvest in the tropical and sub-tropical parts of the world (Cotton, 1963). When the threshed grain is stored in farm storage, the insects emerge as adults and cause further deterioration of stored produce by completing life cycles on the grain. The estimates for harvest-to-mouth losses vary between 15-30% (Hall, 1969). Loss in storage can also be due to bacteria, fungi, mites, rodents and moisture.

Apart from a few published works by Giles

(1965a, b; 1966a, b) and Howe (1952) and a few unpublished works in the Institute for Agricultural Research (IAR) Cropping Schemes Reports which deal mainly with the distribution and control of storage pests on sorghum and to a limited extent that of millet, there seems to be little information on the cereal storage entomology in the northern parts of Nigeria. However, this is being remedied by the IAR entomology staff and the Cereal Research Programme at the Institute are working towards filling these gaps.

Wheat is of special interest in this context because of its importance as a staple cereal food and more importantly because of its recent extensive cultivation under modern irrigation facilities in Kano, Kadawa, Kaduna, Borno, Yobe, Sokoto, Kebbi, Niger, Gongola, Taraba and Bauchi States due to the embargo placed on its importation by the Federal Military Government of Nigeria since 1986. Infact, it can be said that large scale cultivation of wheat in Nigeria is just taking off. With the encouragement of farmers co-operative societies, the Federal and State Ministries of Agriculture, farmers supply companies and the Agricultural Development Projects with loan

facility from the World Bank, the Federal Government has given much support to the cultivation of wheat in Nigeria. With increased cultivation, the demand for wheat will eventually be met with some surplus to store for use in times of scarcity and for use as seeds for the next cropping seasons. It is in view of this that it is important for researches to be undertaken so as to find the most convenient and economic method of storage of wheat. In order to control a pest, an adequate knowledge of its biology is very important so that the best method of control can be applied which will in the long run be both efficient and cost effective.

1.8 GENERAL OBJECTIVES OF THE STUDY

(a) To study the life cycle of R. dominica

(b) To study the flight ability of the insect which is important for dispersal.

(c) To study the host preference of the beetle in respect to common stored products in Samaru

(d) To study micro-organisms associated with the insect

(d) To study the effect of different chemicals on the

beetle.

(f) To study the ability of these chemicals to suppress further development of the beetle.

CHAPTER 2: LITERATURE REVIEW: RHIZOPERTHA DOMINICA

2.1 NOMENCLATURE, TAXONOMY AND DISTRIBUTION

The lesser grain borer, Rhizopertha dominica (Fabricius) (Coleoptera: Bostrichidae), is a major pest of stored cereals in the warmer parts of the world. Originally described from South America (Hill, 1983), it is now cosmopolitan in the tropics and sub-tropics. It can also be found in the temperate regions in warm situations e.g. warm warehouses (DEGESCH, 1977). Its recorded distribution stretches from Africa to the Middle East, and includes parts of Europe, Asia and Oceania (FAO, 1976) (Fig.1).

2.2 HOST RANGE

Crop in three families of plants are found to be seriously infested by this insect. These are the Graminae, Euphobiaceae and solanaceae. The Gramineae constitute about 90% of the crops to which damage is done (DEGESCH, 1977; Hill, 1983; Tropical Development Research Institute (TDRI), 1984; Osuji, 1985). Other families include Euphorbiaceae in which cassava (Tapioca) is attacked (Frappa, 1938; Pingale et al,

1956; Belloti and Schoonhoven, 1979; Hill, 1983; Zachner, 1930) and Solanaceae in which the Irish potato is attacked. All three families except for barley in the Gramineae are cultivated in Nigeria.

Rhizopertha dominica has also been found on some unidentified herbs (DEGESCH, 1977). R. dominica has been found to feed on yam Dioscoreaceae and yam products in Nigeria (Osuji, 1985); on sweet potato (Convolvulaceae) in Taiwan (Lin,1958); and on soyabeans and some pulses (Legunminoseae) in storage in the United States (Horton, 1982).

2.3 MODE OF DAMAGE

Both the adults and larvae of R. dominica feed on the host seed. The larvae and adults chew into grain, consuming both germ and endosperm, eating out the entire starchy interior and the seed coat in places, thereby leaving irregularly shaped holes. Large quantities of floury dust are produced. Heavily infested wheat has a characteristic sweetish musty odour (a honey - like smell) (DEGESCH, 1977; TDRI, 1984; Osuji, 1985). It was shown that more extensive

egg laying must be preceded by a period of increased feeding (Golebiowska, 1968). This observation agrees with an earlier one by Lepesme (1944) who reported that the females are particularly voracious feeders before egg laying. The feeding activity of the adult creates a lot of duct and grain debris which includes the frass of the insect.

The young larvae feed on the grain debris left over by the adults, it is only after the second ecdysis that they are able to bite into undamaged kernels (Golebiowska, 1968; TDRI, 1984). Feeding activity of the beetle adults and larvae causes reduction in weight, nutritive value and germination of seeds (Parkin, 1956; Howe, 1965; Adeyemi, 1968; Hall, 1970; Ahmed, 1978; Campbell and Sinha, 1976; Hill, 1983; Osuji, 1985). In respect of human health, Bernton and Brown (1967) obtained positive skin reactions in patients to a group of storage insect pests including R. dominica. It is found that commodities infested with R. dominica rarely become mouldy (TDRI, 1984).



Fig. 1 World distribution of Rhizopertha dominica. (After Hill (1983))

To aid in their feeding activity, R. dominica, like other coleopterans, contains certain symbiotic micro-organisms usually yeasts, Actinomyces or bacteria (Richards and Davies, 1976) which may often be transmitted from one generation to the next through the egg. The function of these organisms is to digest lignin which is found in some of the food they feed on. These symbionts can be eliminated at 38^{O}C (Huger, 1954). A laboratory investigation on the effects of feeding by six species of stored-product coleopterans, including R. dominica, on the chemical composition of wheat grains showed that all these pests reduced starch content in addition to other important nutrients (Krzymanska and Golebiowska, 1987). This could lead to possible downgrading of foodstuff and total loss of profit to the farmer.

2.4 DESCRIPTION, LIFE CYCLE, ECOLOGY AND BEHAVIOUR

The adult beetle of Rhizopertha dominica is 2-3mm long, red-brown to black-brown in colour, with a cylinderical slim body. The pronotum is rounded at the front where there is a transverse row of teeth. Centrally and posteriorly, there are flattened

tubercles. The scutellum is almost square. The elytra have rows of punctures and short setae that curve posteriorly. Apically the elytra are gently convex. Each antenna has ten segments. The three last segments of the antenna form a club. The hoodshaped neck shield conceals the head.

The larvae are white and parallel sided, i.e., they do not taper. The legs are somehow more prominent than in the Sitophilus spp. and they move faster than the larvae of weevils. The head capsule is rather small relative to the size of the body. The first instar larva is distinctive in having a median posterior spine. The pupa is white and its entire development is inside the grain kernel.

The sexing of R. dominica has always posed problems. Potter (1935) showed that the genital papillae of the pupae exhibited constant differences in each sex, but adults could not be separated externally. Halstead (1963) repeated Potter's observations. However, Stemly and Wilbur (1966) and Ghopade and Thyagarajan (1980) found that the fifth abdominal sternum of the male possess a transverse, rather shallow punctate groove of variable

development. This is present at least on one side, generally on both sides of the midventral line. This sort of groove is never present in the female in which the sternum is more convex than in the male. The sex of the beetles is confirmed by dissection and examination of the genitalia. The observation could be made under the microscope with a magnification of 30.

A female lays 300 - 500 eggs loosely amongst the grain (TDRI, 1984; Osuji, 1985). In contrast with Sitophilus spp, females of R. dominica lay eggs either outside or between the grains (Golebiowska, 1968; TDRI, 1984). If the kernels are cracked however, the female lays her eggs only in such cracks (Grombie, 1945). Adults mate soon after emergence and under favourable conditions, oviposition may continue for up to four months. Larval development occurs more rapidly on whole grains than on flour. On a whole wheat at the optimum temperature of 34^{o}C and 70% r.h.,larvae undergo 3-5 moults and develop to pupal stage in about 17 days (Howe, 1950). R. dominica is exceptional in being able to develop on food of very low moisture content (m.c.). At 34^{o}C development is

possible on grain with a m.c. as low as 9% although under these conditions there is 98% larval mortality, mostly at the first instar. On wheat at the same temperature but with a 14% m.c.,mortality is only 22% (TDRI, 1984). The minimum temperature for development is partly dependent on the food m.c., being 18^{o}C at 11-14% m.c., but rather higher, 22^{o}C, when the m.c. drops to 10%. The maximum temperature has been recorded as 38.2^{o}C. The pupal stage, at 34^{o}C and 70% r.h. lasts for approximately 3 days.

The first and second instar larvae are very susceptible to physical damage during handling of the grain (FAO, 1976). The developmental period even for individuals from eggs laid on the same day is very variable. On the average, during its growth at a temperature of 28^{o}C ± 1 and 75% r.h., a larva can consume 12mg (9 - 16mg) of grain; leaving 7mg (5-19mg) of grain dust at the same time (Golebiowska, 1968). The insect has about 4-5 instars. A freshly emerged beetle weighs 1.4035 ± 0.015mg.

The temperature threshold for development of R. dominica is 17.2, 18.2, 16.9 and 17.2°C for egg, larval, pupal and total development, respectively

(El-Refai, 1987). The thermal constants for these stages were 79.5 ± 0.02, 256.07 ± 11.6, 55.64 ± 1.5 and 422.43 ± 9.8 day - degrees C, respectively.

El-Refai (1987) also found that the composition of the population in terms of instars were as follows: eggs and larvae form the greatest part (over 90%), pupae form about 5% and adults about 3.6%. The percentage mortality was 46.67 for eggs, 38.83 for larvae, 4.17 for pupae and 10.6 for adults, indicating that only the early stages suffer high mortality. This observation was made earlier by TORI, (1984). At a temperature of 28^{o}C the embryo of R. dominica takes four to eight days to develop (Howe, 1950; Golebiowska, 1962; 1968). It is only after the second ecdysis that the larvae are able to bite into undamaged grain. The food consumed by a larva daily and in its entire life is 31.8% and 11.6 times its body weight respectively (Golebiowska, 1968). The temperature threshold for development is about 18^{o}C (Hill, 1983).

Both the adults and larvae of R. dominica are capable of boring into, and feeding on a wide range of commodities. The species is especially important

as a pest of whole cereals, including even rough rice which is resistant to the attack of most storage pests. On emergence the larvae which are scarabaeiform will make use of even minute husk defects to bore into the grain (Potter, 1935).

Small populations of R. dominica have been reported on the field in cereals, but infestation is mostly post-harvest. The insects bore into wooden structures of stores which ensures continuous infestation if the store is not properly treated before storage of food starts. The adults and larvae of R.dominica are generally inconspicous in stores as they spend most of their time in tunnels in the grain thus making the study of its life cycle difficult without destroying the grain kernels.

Commodities attacked by R. dominica rarely becomes mouldy (TDRI, 1984); it would seem that this species does not raise the moisture content to the same extent as Sitophilus spp. which may cause an increase of 5-6% (Birch, 1945).

2.5 CHOICE OF OVIPOSITION SITE

Laboratory tests were carried out by Laubman

(1956) to determine the type of oviposition site preferred by females of R. dominica. Preliminary tests showed that more eggs were laid on maize than on other grains and that this was probably due to the fact that maize seeds were not only the largest seeds used but also the only ones with prominent glumes, which provide the crevices favourable for oviposition. On wheat seeds, most eggs were laid in the raphe, which was part of the grain affording the deepest crevices. On whole grains the eggs are laid loosely amongst the grain (TDRI, 1984; Osuji, 1985). The females prefer to lay their eggs in crevices or on rough surfaces of a seed. If the kernels are cracked, however, the female lays her eggs only in such cracks (Crombie, 1945).

2.6 EFFECT OF VARIETY ON INFESTATION LEVEL

The fecundity and subsequent development of storage insect pests is higher on some varieties than in others. Amos et al. (1986) showed that the fecundity of the stored grain insects Sitophilus Spp., R. dominica and T. castaneum when compared on 32 varieties of wheat was lower on some varieties than others. Notably the lowest fecundity for

Sitophilus spp. and R. dominica was on the experimental variety DX6148. Fecundity of the insects and their subsequent development was high on many registered varieties, notably Egret, Zenith, Summit, Pinnacle, Olympic, Kalkee and Kewell. R. dominica was found to develop on milled but not highly polished rice.

2.7 ABUNDANCE RELATIVE TO OTHER STORAGE INSECT PESTS

Imura (1981) surveyed the abundance of stored product pests in a barley mill in Saitama (Japan). Insects were extracted from samples using a modified Tullgren funnel. Out of 24 species obtained, the most abundant in a decreasing order were Tribolium confusum, Sitophilus oryzae, Ephestia kuehniella and Rhizopertha dominica. The relative abundance of the storage insects at the barley mill was compared with that at a flour mill, a feed mill and farm granaries using Morisitas index of similarity, and it was found that the fauna from the barley mill was very similar to that of the flour mills but different from that of the feed mill and farm granaries. The erratic seasonal change of species diversity (Brillouin's

index) in the mill was caused by T. castaneum.

Surveys in Idaho since 1978 indicated that the most common insects during storage in order of abundance were T. castaneum (forming 60% of the total population) followed by Oryzaephilus. surinamensis (28%) and R. dominica (4%) (Sandvol et al, 1983).

During a world survey by the FAO in the 1970s,it was shown that R. dominica ranks third in importance to S. oryzae and Sitotroga cerealella on wheat. Whereas R. dominica was associated with the warmer, drier wheat areas of the world like Australia, Pakistan and India, O. surinamensis which also ranked third in the survey was found to be restricted largely to the cooler wheat-producing areas such as in Europe. In export trade, R. dominica was found to be more significant than O.surinamensis.

The abundance of R. dominica relative to other storage insect pests varies both with location and the food product. It is of major importance in Australia, Columbia, Egypt, Ethiopia, India, Iraq, Israel, Libya and Sudan, while it is either of moderate, minor or rare occurence in Afghanistan, Algeria, Argentina, Canada, China, Cyprus,

Czechoslovakia, Denmark, Netherlands, Italy, Kenya, Lebanon, Nigeria, Norway, Poland, Singapore, South Africa, Switzerland and the United Kingdom (FAO, 1976). Considering how foodstuff is handled without grading and quarantine in Nigeria, R. dominica could well turn out to be a major pest of stored products.

R. dominica is one of the three key pre-storage and storage pests in Nigeria often causing heavy damage in the farmer's granaries and in warehouses (Caswell, 1962). Its ability to attack grains which are too dry for most other storage pests and its tolerance to very low humidity regimes of up to a minimum of 25% makes this insect an extremely important pest of stored grains especially in northern Nigeria where about seven months of dry season are experienced annually.

2.8 EFFECT OF INSECT FEEDING ON FOOD QUALITY

Feeding in all categories of food materials causes loss in weight, quality and market value of the food material (Parkin, 1956; Campbell and Sinha, 1976; Hills, 1983; Osuji, 1985). Destroyed grains generate heat more quickly than it can escape, the

temperature of the produce rises and may reach 42-46^{o}C (Howe, 1965). Such high temperatures cause moisture migration in stored produce leading to spoilage and accelarates chemical degradation especially destruction of vitamins. Losses of 10% or more in developing countries have frequently been reported (FAO, 1976). Insect pests are the cause of loss of buffer stocks of food stuffs which are used to guard against irregularities in production due to vagaries of climate, thus creating circumstances in which storage losses can be potentially greater. Insect pests also contaminate stored food products thus causing loss in monetary value of the product. Such contamination has become unacceptable in international trade. The result of insect feeding on stored foodstuff is thus not only a significant drain on buffer stock food supplies, but also possible damage to export earnings from the agricultural produce. They have also been found to cause allergic reactions on patients with asthma.

2.9 FLIGHT ABILITY

Rhizopertha dominica can fly freely and will do

so at temperatures above 25^{o}C (FAO, 1976). It cannot, however, cling readily to many surfaces when flying comes to rest by colliding with an object and falling to the surface below. When placed at the top of grain towers filled with wheat grains (1.7-2.6m high), less than 1.0% were found below 127cm four months later (Keever, 1983). This is attributable to the fact that the insect is rather slow of movement in nature. The insects have been found to bore into the wooden structures of stores, this can result in heavy attack and considerable damage to grains in such stores.

2.10 VITAMIN REQUIREMENTS: REARING ON ARTIFICIAL DIET

The effect of various vitamins of the B-Complex on the growth and survival of R. dominica was studied by Anand and Pant (1989). The insect was reared on diet pellets or wheat grains. The percentage adults developing in diets lacking any of the essential vitamins was low. Diets lacking P-amino benzoic acid or folic acid were significantly superior to a diet with all vitamins. When different concentrations of vitamins were tested, it was found that 25-35% of adults could develop in a diet without vitamins. The

best growth was obtained in a diet containing 15% vitamin solution.

2.11 GENETICS OF R. DOMINICA

The Karyotype of R. dominica is 8AA + XY (Smith and Bnower, 1974) but there is only one mutant available, black (b) body colour, a semi dominant autosomal fully penetrant but apparently sharing some lethal effects in the homozygous state (Dyte and Blackman, 1965; Champ and Genn, 1971). Champ and Genn (1971) also described a fused antenna mutant that had poor penetrance. These genes govern the inheritance of resistance in this insect e.g malathion-specific resistance appears to be partially dominant and linked with b.

2.12 NATURAL ENEMIES OF R. DOMINICA

Several Hymenoptera have been found to infest insects in storage. Among those found on R. dominica include Lariophagus distinguendus (Foster) (Kaschef, 1959); TDRI, 1984), Chaetopsila elegans (Westwood) and Anistopteromalus calandrae (Howard) (TDRI, 1984). Another parasistoid found to be feeding on the egg is Tyrogluphus arinae (Lin, 1958). Streptomycin produces

aposymbiosis.

2.13 CONTROL OF R. DOMINICA

2.13.1 Non-Chemical Control

A number of experiments on the non-chemical control of R. dominica have been carried out around the world. This is as a result of the fact that the use of chemical agents is greatly discouraged and move has been made towards finding alternative methods of control which will either minimize or completely eradicate the use of chemicals in food storage.

The non-chemical methods of control include manipulation of the environment (temperatures and hermitic control), use of radiation, use of juvenile hormones and their analogues and also use of various plant extracts.

2.13.1.1 Temperature Control

2.13.1.1.1 Heat Treatment

High temperatures if properly manipulated can be used in control of storage insect pests without damaging the grain. Claflin et al. (1986) carried out

an experiment in which batches of wheat infested with all stages of R. dominica were heated in a 300mm diameter spouted bed fitted with a draft tube to control grain and air flow. This apparatus combines features of pneumatic packed bed systems. For a 16kg batch of wheat spouted with 0.07kgS^{-1} of air, the time to achieve 99.9% mortality (LT99.9) decreased from 13.6 to 2.6 minutes as inlet air temperature was increased from 80-180^{o}C. Bed temperatures corresponding to LT99.9 were in the range of 60-66^{o}C depending on operating conditions. Some mechanical kill was also detected. Thermal contact efficiencies varied from 45-85% and were sensitive to operating and design parameters.

2.13.1.1.2 Cold Treatment

The proportion of R. dominica that survived cold treatment in a high density experiment decreased from 33-50% or 4-16% for 13 weeks exposure to 13.5 or 9^{o}C respectively, to 2.4% or less for exposures of 52 weeks (Evans, 1987). The proportion of R. dominica surviving cold treatment for 13 and 26 weeks was greater than in the high density experiment. Survival

after exposure of 39 or 52 weeks was generally zero up to 30 per cent) mortality of the adults within 8 hours of eclosion. The 20 Krad dose caused high mortality of adults from irradiated pupae and of irradiated adults within 3-5 weeks. Complete sterility, as evidenced by the lack of F1 generation, was induced in pupae by a dose of 14 Krad and in adults by 11.5 Krad.

In an earlier experiment using radiation, Watters and MacQueen (1967) irradiated adults of five species of stored product insects in a mobile Cobalt-to irradiator at doses of 6250 to 150,000 rad. R. dominica achieved total mortality after 3 weeks or irradiation with 150,000 rad.

2.13.1.2 GROWTH REGULATORS, JUVENILE HORMONES AND THEIR ANALOGUES

Insect growth regulators (IGRs) and juvenile hormone analogues (JHAs) have been used for the control of adults and juvenile stages of R. dominica. An added advantage of this kind of treatment is the ovicidal effects of the IGRs. Insect growth regulators BAYSIR 8514 (1-4-trifluoromethoxyphenyl) -3- (2-chlorobenzoyl) Urea), difluorobenzuron,

methoprene and MV - 678 (2-methoxy 9-(p-isopropylphenyl) -2,6- dimethylnonane), applied at 5ppm to wheat flour or grain were evaluated against O. surinamensis, T. castaneum, R. dominica and S. oryzae by Mian and Mulla (1981). BAYSIR 8514 and difluorobenzuron were highly active against the eggs and younger larvae of R. dominica. Methoprene, besides its ovicidal action against O. surinamensis and R. dominica, caused substantial mortality in the full grown larvae of the three species. BAYSIR 8514 and methoprene also affected subsequent progeny production of parent adults pre-exposed to IGR-treated food for 2 weeks. MV 678 appeared to be the least active compound.

In a related experiment by Mkhize (1988) on the juvenile hormone analogues (JHAS), JHA1 (6,7 - epoxy - 3, 7 - dimethyldec - 2 - enyl - 6 - ethyl - 3 - pyridyl ether), JHAII (3,7 - dimethyl-undec - 2, 6 - dienyl 6 - ethyl - 3 - pyridyl ether), MV - 678 and R - 20458 (CE) - 3 - {- 5 - (4 - ethylphenoxy) - 3 - methylacetone solution were applied to insect diets at 10ppm (V/V), and their effects on species of stored product beetles observed. The bostrichid R.

dominica completely failed to reproduce in a medium treated with JHAI. JHAII, MV-678 and R - 20458 affected the reproduction of R. dominica to varying extents, with MV - 678 being the least potent juvenile hormone analogue. This observation agrees with that of Mian and Mulla (1982).

2.13.1.3 Plant Extracts

The toxic effects of plant extracts or plant products in controlling stored product insects has been a subject that has attracted a considerable amount of interest. For example the use of wood ash is by no means a new practice (Viado, 1959). Ajayi et al., (1987) used wood ash, chilli (Capsicum annum), palm oil and dried leaves and twigs of Hyptis spicigera in Nigeria to control the insect. The toxic effects of the vapours of Indian Acorus calamus rhizomes on adults of several stored-product insect pests was studied at 30°C and 55% r.h. by El-Nahal et al.,(1989). Rhizopertha dominica was controlled at a dosage higher than the other insects and the period of exposure appeared to be the most important factor affecting the efficiency of these vapours.

The repellency of parts of three plants, the rhizomes of tumeric as well as the leaves of neem (Azadirachta Indica) and fenugreek,to adults of T. castaneum, S. granarius and R. dominica was studied by Gilani and Su (1983) in Pakistan. Tumeric was most effective as a plant powder and also as a solvent extract. In all three plant materials, the petroleum ether extract of fenugreek was the least effective while the petroleum ether extract of neem was the most effective against R. dominica. Effect of Embelin, a benzoquinone isolated from the berries of Embelia ribes, against R. dominica was compared and also chloranil at concentrations of 0.01125m with 0.025% (W/W) respectively in wheat. Embelin and chloranil at 0.025 and 0.05% gave mortality of 71 and 68%, respectively. When compared with dichlone at 0.025%, it significantly reduced the production of progeny by R. dominica (Chander and Ahmed, 1987). Eucalyptus oil prevented infestation of R. dominica in rice (Dakshinamurthy, 1988).

2.13.2 Chemical Control of Rhizopertha dominica

The use of chemical agents or insecticides is by

no means a new practice. Pyrethrum (a plant) has been used for the control of storage insect pests since 1828 (Hassell, 1969). Although the use of chemicals for control of insect pests is not greatly encouraged, current storage systems and technology dictate that control of these pests be based largely on use of chemical pesticides (FAO, 1976). There are comparatively few materials that are safe for use in the control of pests of foodstuffs in storage. However, for the recommended chemicals, if the correct method and dosage of application is used judiciously, little or no damage will be done to man, his foodstuff, livestock and his environment.

Chemicals used comprise essentially of a limited range of persistent insecticides and non persistent fumigants. These few materials have been used widely and intensively and it is probable that the present requirements of freedom from insects would have been unattainable if these materials had not been available.

A number of chemicals have been used for the control of storage insect pests in different parts of the world by various workers. The effectiveness of a

number of insecticides, formulations and methods of application in protecting grain was studied in Egypt by Kamel and Farm, (1962) on wheat in burlap bags under store room conditions. The insects present were Sitophilus oryzae, R. dominica and Tribolium confusum, and the insecticides tested were the desiccant Silica aerogels SG69 (with 82% of the aggregates 0.1 - 3.2m in diameter), Dri - Die (which is similar but includes 4.7% ammonium fluosilicate) and Dione (49.5% Dri-Die, 0.1% pyrethrins, 1.0% piperonyl butoxide, 1.9% petroleum base oil and 47.5% inert ingredients), a dust of 1.0% malathion in wheat flour and katelsons (84% rock phosphate and 16% ground sulphur). Dri-Die or SG68 at 0.16% by weight or Dione at 0.08 - 0.16% by weight gave protection for one year and kept insect damage to a minimum. These dusts and the malathion at 8 parts malathion also recommended were all superior to Katelsons at the recommended dose of 1.0%. Malathion applied to the wheat as the dust or as a spray at 7.6 and 11.4 ppm gave virtually similar results under similar conditions, but the dust applied at higher rates to the outside, and only 0.8% of the grains were

infested a year after treatment. None of the materials or methods of application entirely prevented infestation.

The use of chemical protectants for stored food stuff against storage insect pests may not prevent infestation but may delay it by a few weeks by which time the grain may have been put to use. Highland (1983) working on the adults of the cigarette beetle, Lasioderma serricorne, and the lesser grain borer, R. dominica, placed in food with small multi-wall paper bags coated with permethrin or pyrethrins synergized with piperonyl butoxide, showed that the two insects penetrated out of the bags within two weeks. Larvae of R. dominica on the other hand took 10 weeks to penetrate into treated bags as compared to the one week taken by the larvae to penetrate untreated bags.

Fumigants such as phosphine and methyl bromide have been used by various workers for the control of storage insect pests. For example the Food and Agricultural Organisation (FAO) of the United Nations in 1972 and 1973 organised the collection from all over the world eight species of stored product beetles (Anon,1973; 1975; Champ and Dyte, 1976).

These insects were sent to Slough in the United Kingdom, where they were reared, and adults of the various populations were exposed to the commonly used contact insecticides and also to phosphine and methyl bromide. The toxicities at 25^{o}C and 70% relative humidity of methyl bromide at about 4mg/litre were determined for large populations, including all developmental stages of a number of strains of seven species of stored product beetles from 29 countries including Nigeria for a range of exposure periods (Hole, 1981). The species tested included Oryzaephilus surinamensis, Rhizopertha dominica, Sitophilus granarius, S. oryzae, Tribolium castaneum and T. confusum. In several of the species, there was some correlation between the tolerance of the immature stages and of adults for both fumigants. Many strains were tolerant to both fumigants.

Sometimes for fumigants to be more effective,they are used in conjunction with some natural gases. Kashi (1981) tested the effects of phosphine and methyl bromide on the adults of the stored product insects, T. castaneum, T. confusum, R. dominica, S. oryzae and S. granarius in atmospheres

of air or nitrogen. Although the two Sitophilus species survived concentrations of phosphine of up to 80mg litre^{-1} for 24 hours in normal (air) or nitrogen atmospheres, T. castaneum, T. confusum and R. dominica could not tolerate more than 0.2g phosphine litre^{-1} in air for 12 hours. They could however, tolerate up to 10mg phosphine litre^{-1} in nitrogen for that period. This shows that phosphine is more effective in the normal atmosphere than in a nitrogen atmosphere.

A commercial method of applying mixtures of methyl bromide and carbon dioxide to wheat silos against pests of grain was developed in Victoria, Australia (Williams et al., 1985). A gas mixture containing carbon dioxide is piped to the base of the silo, where methyl bromide is bled into the gas stream. This achieved killing of all stages of R. dominica and other insects at one third of the minimum dose of methyl bromide recommended in a trial in 2000-t wheat silos.

When doses and exposure periods of fumigants are increased, their penetration is also increased. Studies on the effectiveness of ethylene dibromide

and carbon bisulphide alone or together against adults of R. dominica, I. castaneum and Trogoderma granarium in 2.438m wheat column showed deeper penetration by increasing the doses and exposure time (Sandhu and Sohi, 1969). Deeper penetration is also more at higher than medium or low temperatures.

Many more insecticides have been used against R. dominica all over the world. Fenitrothion has been used for control of stored product insects by various workers. Duplicate experiments on bulk stored sorghum in South and Central Queensland, Australia by Bengston et al. (1983) showed that fenitrothion at 12mg/kg and Pirimiphos-methyl at 4mg/kg plus carbaryl at 8mg/kg controlled typical malathion-resistant strains of some insects including R. dominica. Chloropyriphos - methyl at 10mg/kg plus piperonyl butoxide at 12mg/kg and fenitrothion at 12mg plus (IR) - phenothrin at 1.0mg/kg also controlled storage insects including R. dominica.

Chemical assays established that the residues and breakdown of the grain protectants on sorghum conformed to the general pattern for other cereal grains, residues from the above were below the

individual maximum limits recommended by the Codex Alimentarius Commission. In another work by the Food and Agricultural Organization (1976) on comparative laboratory trial with insecticides under tropical conditions using 18 insecticides against Cryptolestes ferrugineus, O. surinamensis, R. dominica, T. castaneum and T. granarium on stored sorghum grains the best results against all species tested with fenitrothion at 10, 1(jodphenphos) at 20 and entrimphos at 15mg/kg. Pyrethroids have also been found to control two strains of R. dominica (one susceptible, one organophosphate resistant) in silo trials (Ardley, 1976; Elliott et al. 1978).

In an experiment by Bengston et al. (1983) using organophosphorothioates and synergised synthetic pyrethroids in duplicate field trials in commercial silos on bulk wheat in New South Wales and Queensland, laboratory bioassays using malathion-resistant strains of insects were carried out on samples of treated grains at intervals for over nine months. These established that all treatments were generally effective. Deltamethrin at 2mg/kg,

fenitrothion at 12mg/kg plus piperonyl butoxide at 8 mg/kg, fenitrothion at 2mg/kg plus piperonyl butoxide at 8mg/kg and pirimiphos - methyl at 4mg/kg plus permethrin at 1mg/kg plus piperonyl butoxide at 8mg/kg controlled common field strains of S. oryzae and R. dominica.

Some of the chemicals used for stored grains are also used for the treatment of storage structures before placement of grains. Permethrin, deltamethrin and fenvelerate have been applied to blocks of concrete, galvanized iron and wood which are commonly used in the construction of silos and other facilities for stored grain (Williams, et al.,1983). Before then fenitrothion had been used for treating storage structures before placement of grains (FAO, 1976). This helps in controlling any insect including R. dominica which may likely infest otherwise uninfested grains.

Laboratory tests method to determine efficacy of dust, spray and aerosol preparation for control of insect pests have been made. Preparations containing DDT, Lindane, bendiocarb, diazinon, fenitrothion, chlorpyriphos and phoxim were generally found to be

effective against larvae and adults of Attagenus woodroffei, R. dominica, T. confusum, T. destructor and O. surinamensis (Ruovinen and Ekbom, 1982). Preparations of bromophos fenchlorphos and malathion were effective on most species while the effect of pyrethrin varied according to the preparation.

The effectiveness of mechanical aerosols containing eleven insecticides on S granarius, S oryzae. T castaneum, R. dominica, O. surinamensis and reptolestes ferrugineus in empty warehouses was studied by Tsvetkov et al. (1983) in Bulgaria. The most effective preparations on these pests were based on dichlorvos (Nuvan, DDVP and Vapona) at dosages of 265 - 300 mg/m^3 and with an exposure period of 48 hours. Emulsifiable concentrate formulations of phoxim (Baythion), fenitrothion (Agria 1050) and etrimphos (Satisfar) were also highly effective at dosage of 300 mg/m^3 space and 48 hours exposure periods. Pirimiphos-methyl was also effective.

Trimethacarb, a carbamate, has been used as a grain protectant of soft red winter wheat against

four species of stored product insects T. confusum, Sitotroga cerealella, R. dominica and S. oryzae (Halliday, 1987). Methyl iodide (meI) is used as a highly toxic fumigant against several species of insect pests including R. dominica (Lindgren, 1938; Ferguson and Pirie, 1948; Balock, 1951; Burditt et al. 1963). MeI shows promise as an effective fumigant in that it controls several species of stored product insects although in general it is less toxic than methyl bromide (Lindgren et al.1954; Bang and Telford, 1966). The added advantage with meI is that is liquid hence it is easy to handle.

2.14 PESTICIDE PERSISTENCE AND RESIDUES

Pesticide persistence, though a desirable property for long term control, can cause harm to man and the environment and may lead to the development of resistance in otherwise susceptible pest species. Yadav (1988) conducted an experiment using deltamethrin in godowns of the Food Corporation of India using stacks of bagged rice and wheat grain. Insecticide deposits of 10 and 20 mg/m^2 were produced on the stack surface of jute and floors of alleyways,

and discs of jute and polythene collected and used in laboratory assays of persistence against the stored product pests S oryzae , Callosobruchus chinensis, T. castaneum, R.dominica and T. granarium showed toxicity to beetles and persisted for 120 - 170 days on the jute surface. Protection was afforded against coleoptera for six months of storage in winter and summer and residues were below detection levels in cereal grains.

Alarmingly high phosphine concentrations were measured above the headspace of ships holds during an in-transit shipboard fumigation of wheat with phosphine (Wohlgemuth, 1989). Bioassays of the stored product insect pests S. granarius O.surinamensis,T. confusum ,Ephestia elutella and R. dominica showed the evolution and distribution of the gas 15m deep. Vilakshi et al. (1982) tested ten insecticides and discovered that the residues of isofenphos, fenitrothion, fenthion and phoxim had the maximum toxicity and persistence when sprayed as emulsions on cement surfaces to adults of R. dominica and T. castaneum. These residues could be harmful to

man and his enivironment.

2.15 RESISTANCE TO PESTICIDE IN RHIZOPERTHA DOMINICA

Pest resistance is the ability of a strain of apest species to tolerate doses of a toxicant which would prove lethal to a majority of individuals in a normal population of the same species. Resistance develop over a period of time not on the spur of the moment. Many factors influence the development of resistance in insects. Laboratory studies in the United Kingdom demonstrated that considerable resistance to phosphine in Sitophilus oryzae, R. dominica and Cryptolestes spp. had developed in Bangladesh (Halliday et al. 1983). This had been caused by persistent fumigation of bagged grain without ensuring that adequate concentration-time products of phosphine were achieved to ensure effective control of all species of pests.

Sometimes resistance could be due to the ability of the resistant strain of the pest to take up the insecticide and metabolize it into a non-toxic

product. Resistant strains of R. dominica had been used to observe the mode of control by radio-labelled phosphine and its effect on metabolism of the insect. The uptake of radio labelled phosphine (36P) by the resistant strain was much reduced compared to that of the susceptible strain. The production of metabolites was qualitatively the same in both strains though the resistant insects metabolized a higher percentage of the absorbed dose (Price, 1981).

Fumigation is the most widely used method of control of R.dominica on a world wide basis (FAO, 1976). This is a direct reflection of the greater importance of this insect pest in grain held in storage for a considerable period period, when fumigation is the most satisfactory and often the only practicable method of control.

2.15.1 Resistance to Different Groups of Insecticides

The problem of resistance in most cases is caused by the person(s) applying the chemical. In most cases the operators lack the technical knowhow and in other cases the chemicals are applied either when it is not necessary or at higher doses than is

actually required for the control. With these came the attendant problem of development of resistance at one time or the other to the different chemicals. If not for these problems there is virtually no scientific evidence that properly used and approved pesticides present any health hazard (Berry, 1990) much less the development of resistance to the different chemicals.

2.15.1.1 Lindane Resistance

Lindane is rarely used for the control of R. dominica though there would be contact indirectly in general use of lindane as a hygiene treatment. Thus the occurrence is not of particular importance (FAO, 1976). However, Lindane resistance was more widespread than malathion resistance occurring in 41 of 51 countries surveyed by the FAO in the 1970's.Resistance occurred in 91 of the 137 strains tested. Dyte et al. (1975) reported two of eight strains resistant to lindane in the United Kingdom.

2.15.1.2 Malathion Resistance

The only report of insect resistance to

malathion before 1974 concerned interceptions at Avonmouth, England. Of three strains of R. dominica in maize ex-South Africa, Cocoa exGhana and wheat residues in a ship, all were resistant to malathion and lindane (Dyte et al. 1973). The strain from South Africa was not resistant to malathion synergized with triphenyl phosphate (Dyte and Wildey, 1976).

In Australia where malathion has been admixed with wheat immediately after harvest, control of R. dominica has always been marginal. In March 1971 in New South Wales, Greening et al. (1975) reported collecting a strain from the terminal elevators at Sidney which was resistant to malathion (x9) using impregnated paper tests. Subsequently during 1971/72, these same authors detected malathion resistance in 17 grain storages in country centres of New South Wales (52 localities sampled). In 1972/73, malathion resistance was recorded from 16 of 25 wheat and barley storages in country centres and again at both terminal elevators. By 1973/74, four only of 21 centres sampled yielded susceptible strains. Dyte et al. (1975) in a survey of the pesticide resistance status of storage pests in the United Kingdom

reported resistance in two out of seven strains. These resistances were imported as R. dominica would not normally be expected to occur commonly in England. In a study by Navarro et al. (1976) in Israel R. dominica was found to be resistant to malathion (x9). By using triphenyl phosphate (TPP), an inhibitor of carboxyestarase, it was shown that in R. dominica the resistance is a malathion-specific type. In the U.S.A, out of 13 strains of R. dominica, 11 strains showed malathion resistance (Haliscak and Beeman, 1983).

The cause of wide spread malathion resistance can be attributed to the fact that when it was found that many of the organophosphorus compounds are very toxic to mammals, including man, research was therefore directed towards finding compounds that are highly toxic to insects but which are of low mammalian toxicity. Such a chemical was malathion which was introduced in 1950 by the American Cyanamid company. Malathion became an outstandingly successful insecticide, and probably the most widely used organophosphorus compound at the time.

2.15.1.3 Dichlorvos Resistance

Dichlorvos resistance has been recorded along with that of malathion. This could be because of the range of organophosphates in use, dichlorvos was the next most commonly used material after malathion (FAO, 1976). Greening et al. (1975) while collecting and diagonising malathion resistance at the terminal elevators, found R. dominica resistant to dichlorvos (x10) using the same impregnated papers. In New South Wales, dichlorvos resistance was recorded in 12 storages out of 33 sampled, eight additional records of dichlorvos resistance were listed from bulk grain storages and a poultry farm. This worsening of the problem was accentuated in April 1973 when a strain with x65 resistance to malathion and x16 resistance to dichlorvos was found.

2.15.1.4 Methyl Bromide Resistance

Methyl bromide has been widely, and in some countries intensively, used for control of R. dominica. The scale and often inefficiency of many of these fumigations should have created conditions favourable for the development of resistance.

However, its correct use needs greater level of expertise than most other pest control methods used in stored products. The greatest deficiency was not in its application operation itself, but hygiene and stock management negligence which resulted in reinfestation so that frequent fumigation was necessary. Although no resistance to methyl bromide has been reported in R. dominica in the FAO survey, however, if the above problem is not tackled resistance to the chemical could develop over time.

2.15.1.5 Phosphine Resistance

The situation with phosphine resistance in R. dominica is completely different from that with methylbromide. Twenty two strains of the 92 tested were shown to have abnormal tolerance to phosphine and many of these were shown to satisfy such criteria of true resistance as heritability and intensification of the resistance with selective breeding from survivors (FAO, 1976).

The highest levels of resistance were recorded from India. They concerned the Bombay area of Maharashta state and to a lesser extent the area about Delhi. Another report of phosphine resistance

in R. dominica was from bagged wheat and barley in the port silos in Keelung, China (Taiwan). Halliday et al. (1983) reported phosphine resistance in R. dominica from Bangladesh.

Phosphine resistance comparable to that of India was recorded from Guyana and Libya. Other areas include Buenos Aires, Argentina and Bangui (Central African Republic). Some tolerance was also recorded from many parts of Australia (FAO, 1976).

In surveys on the incidence and levels of resistance to phosphine in Coleoptera in stored grain in the developing countries throughout the world, resistance was detected in strains of R. dominica among other storage insect pests by Taylor and Halliday (1986). These strains were collected in one or more countries including Bangladesh, Brazil, Mali, Nepal, Pakistan and Sri Lanka.

It is generally observed that the dosage of fumigant required to kill eggs and pupae of beetles is greater than that needed to kill all adults (Brown, 1959; Howe and Hole, 1976; Lindgren and Vincent, 1966). Bell et al. (1979) observed resistance in both eggs and adult strains of R. dominica.

A common feature of all these outbreaks of phosphine resistance is their association with use of Phosphine under conditions that conflict with the accepted principles of fumigation and the known properties of phosphine. With this in mind and considering the way Nigerians carelessly handle agricultural chemicals, it will not come as a surprise if resistant strains of all known storage insect pests in the country are already showing some degree of resistance to the commonly used insecticides.

In the FAO report, resistance has been recorded to the many of the insecticides tested in the Lagos area of Nigeria in not only R. dominica but also in most of the other insects placed under investigation. It is possible that between 1976 and 1992 the problem may have escalated and possibly no record is available to show this trend. This is an area that needs to be explored.

2.16 REMARKS

In this study, the length of the life cycle, flight ability, host preference, micro-organisms

associated with, chemical control and the ability of the chemical to suppress development and emergence of new adult R. dominica were studied.

The present study aims to shed more light on what is already known about this important primary insect pest of stored products in the tropics and sub-tropics.

CHAPTER 3: GENERAL MATERIALS AND METHODS

3.1 MAINTENANCE OF RHIZOPERTHA DOMINICA CULTURE

Mass culture of R. dominica was maintained by obtaining the identified insects from naturally infested wheat at the Storage Entomology Laboratory, Crop Protection Department, Institute for Agricultural Research (IAR), Samaru, Zaria.

For the purpose of this experiment, each unit was a 1.5L Ravenhead Kilner jar with a cover fitted with baft over wire mesh (1.0mm mesh) which allowed aeration but precluded entry or exit of insects. Five hundred grams of prefumigated wheat, variety samwhit-6 (Pavon F.76), was weighed using a Mettler balance (PE 200) into each of three Kilner jars. Fifty randomly selected adult R. dominica were picked out using an aspirator from a culture already present in the laboratory, introduced into each jar and left under open laboratory conditions to await the emergence of fresh adults.

3.2 SOURCE OF INSECT FOOD MATERIALS

The wheat used for the experiments was the

hexaploid bread or common wheat Triticum aestivum L, variety samwhit - 6. The wheat was obtained from two sources, one from the Seed Multiplication Unit of the Institute (IAR) and the other from the Kadawa Irrigation Research Station in Kano State. Wheat from both sources were from the 1989/90 wheat cropping season.

Other test food materials used were cassava (Manihot esculenta Crantz) an unidentified variety obtained from the open market place in Sabon Gari Zaria), groundnut (Arachis hypogaea (L.), variety Samnut-18), maize (Zea mays L., an unidentified white hybrid variety); millet (Pennisetum typhoides (Burm) Stapf and Hubbard: variety Sammil-1, sorghum (Sorghum bicolor (L.) Moench) variety Samsorg - 20); and cowpea (Vigna unguiculata (L) Walp, variety sampea - 3). All these test food materials except cassava, were obtained from the Seed Multiplication Unit of the IAR and were produced in the 1989/90 cropping year.

3.3 SAMPLING

Sampling was done by emptying grains into an extraction dish assembly consisting of a sieve of

2.0mm mesh (with a cover to prevent spillage) placed over a 0.7mm mesh sieve which in turn was placed over a collection dish. On gentle shaking of the dish assembly, both insects and grain dust fell through the 2.0mm mesh sieve leaving the grain behind. The 0.7mm mesh sieve did not allow the insects through but allowed dust created by the feeding activity of the insects to pass through it.

Dead beetles were then removed from the 0.7mm mesh sieve and counted, newly emerged insects were either used for the experiments or for setting up new cultures while the rest were returned into the old culture. The insects were always transferred using an aspirator.

Data on daily temperatures, relative humidities and rainfall for the period of the experiments were obtained from the meterological station located at the IAR.

3.4 AGE STANDARDIZATION OF R. DOMINICA

Age was standardized by collecting adults that emerged from the culture within the same short range of time; Zero to 24 hour old R. dominica were used.

Uniform oviposition periods were allowed to standardize the ages of the eggs.

3.5 MOISTURE CONTENT

The moisture content of the food materials was determined by the oven dry method both prior to and at the end of the experiment. For this, sufficient quantity of each food material was ground using a mechanical blender. The ground material was then placed in pre-weighed aluminium tins in three replicates. Initial weight of the tin and sample was recorded and the tin containing the sample was placed in a Gallenkamp oven running at $105^{O}C$ for four hours after which the oven was switched off and allowed to cool for ten minutes.

Percentage loss in moisture content (m.c.) in each replicate was determined using the following calculations:

$$\% \text{ m.c.} = \frac{\text{initial sample weight - final sample weight x 100}}{\text{initial sample weight.}}$$

3.6 DESIGN AND ANALYSIS

The completely randomized design (CRD) was used

for all the experiments. The bottles were arranged on a flat level table where they could receive approximately the same amount of ventilation and light. Data from replicated trials were analysed using the one-way analysis of variance and differences between means were compared using the least significance different test (LSD) at the 5% level of probability (P = 0.05).

CHAPTER 4: LIFE CYCLE STUDIES

4.1 INTRODUCTION

The adult *R. dominica* is 2.0 - 3.0mm long, reddish brown to dark brown in colour, with a cylinderical slim body. It has a rounded pronotum at the front where there is a traverse row of teeth. The larvae are white and parallel sided while the pupae which also white undertakes its entire development inside the kernel.

In its lifetime, a female adult is capable of laying 300-500 eggs. These are laid loosely amongst the grain or in cracks if present on the grain kernels (Golebiowska, 1962; 1968; Hill, 1983; Osuji, 1985; TDRI, 1986). On whole wheat, at the optimum temperature of 23°C and 70% relative humidity, larvae undergo three to five moults and develop to pupal stage in about 17 days (Howe, 1950; TDRI, 1986). Observations by various workers on the development of *R. dominica* have shown that the length of the developmental stages are dependent on temperature and relative humidity of the environment and partly on

the moisture content of the food material. Rhizopertha dominica is exceptional in being able to develop on food with very low moisture content, though this may result in high larval mortality (TDRI, 1986). The adult beetle has been found to fly freely at temperatures above 25°C but cannot cling readily to many surfaces (FAO, 1976).

The aim of this experiment was to study the length of the life cycle of R. dominica from the time of introduction of the newly emerged adults into whole wheat (var. Samwhit-6) to the time of emergence of the F1 adults. The average length of the strain of the adult used in this experiment was studied, the response to touch, flight ability, type of immature stages ane type of damage done to wheat grain were also studied.

4.2 MATERIALS AND METHODS

4.2.1 Setting up of the Experiment

Fifty gram lots of well formed prefumigated wheat grains (Samwhit - 6) were each placed in a 500ml Kilner jar with a cover of baft over 1.0mm wire mesh. A battery of twenty jars were used in two sets

of ten each.

Five day-old adult R. dominica were placed in each Kilner jar. The grain and insects in ten of the Kilner jars were left undisturbed for two weeks after which ten grains from each of the ten Kilner jars were randomly extracted at forty eight hour intervals for eight days. The grains were soaked in ten Petri dishes of water for ten minutes to soften the wheat kernels. The water was then drained and the individual grains were cracked at the raphe to divide the grain into two halves using a small penknife. This procedure was done to observe the size, shape and colour of the immature stages and also to observe how and where they are located in the kernels. The observation was made under the microscope with a calibrated field of view at 10 x magnification. After eight days the rest of the grains in the ten jars were left undisturbed to await adult emergence.

The grain and insects in the second set of ten Kilner jars were left undisturbed for three weeks before being sampled for adult emergence. Sampling for adult emergence was done at weekly intervals for twelve weeks after which the experiment was

terminated. Readings for each of the replicates were taken and the mean weekly readings were plotted in a graph.

This experiment was repeated using ten day-old adult R. dominica. A battery of twenty was used in two sets of ten each.

The grain and insects in the twenty Kilner jars were left undisturbed for 48 hours after which ten grains from each of the twenty Kilner jars were randomly extracted at 48 hour intervals. These grains were then stained with iodine Bp solution obtained from the pharmacy shop. The stained grains were placed under the microscope at a magnification of 10 x to observe any eggs laid and the number, size and shape. The grain were then washed using clean water from the tap, each ten set was then placed in individual Petri dishes soaked for 15 minutes to soften the kernels. The water was then drained after the 15 minutes and individual kernels were cracked at the raphe to divide the grain into two halves using a small clean pen knife. Using a clean compass needle under a stereo microscope, the divided kernels were

gently picked to remove the surface softened endosperm and observe any presence of immature stages embedded in the kernel. The removed endosperm and kernels were then observed under the microscope at a magnification of 10 x to clarify observations. This procedure was carried out at 48 hour intervals for six weeks during which time new adults were expected to have emerged.

The size of the adult R. dominica was determined by assessing 100 adult dead beetles selected randomly from the original culture and observed under the microscope at 4 x magnification. The length of the head from the mouth parts to the end of the head where it joins the thorax and of the rest of the body to the caudal end were measured using a calibrated slide mounted on the microscope. The measurements were made in microns and converted first to µm by multiplying by 12.5 (since the eyepiece of the microscope used was X4). The larva was measured at the same magnification and converted to obtain mm.

The flight ability of R. dominica was studied by allowing 10 adult insects to roam freely on a white

table and to fly freely in an empty room which was later sprayed with Pirimiphos-methyl (Actellic 25 Ec) at the recommended dilution of 100ml. Actellic to 20L water using a CP15 Hand operated knapsack sprayer. Weather parameters for the period of the experiment were obtained from the Samaru Meteoroligical Station which was about 500m from the building where the experiment was conducted.

The moisture content (m.c.) of the wheat was taken at the beginning of the experiment and also at each weekly recording of the adult emergence.

The speed of movement of R. dominica, its response to touch and its ability to cling to a surface were observed on a formica topped table. Each insect was allowed to walk freely. It was then touched with a pencil and upon its recovery to touch, attempt was made to pick it up using an aspirator. The insects were then allowed to continue roaming on the white table, were then toppled on their backs and picked up again with the aspirator. This procedure was repeated five times using ten different adults randomly selected from the original culture set for the experiment.

On termination of the life cycle experiment, the number of damaged kernels in each 50g lot was removed, counted and weighed. To roughly estimate the mean number and weight of the damaged kernels, ten 50g lots of whole, undamaged kernels were counted to estimate the average number of kernels that were likely to have been used in the original experiment.

The nature and smell of the dust created by the feeding activity of the insects were studied by observation through the author's natural senses of touch, sight and smell.

4.2.2 Data Analysis

The standard error of the mean for the 100 of dead adult R. dominica was determined for each part of the body measured using the following formulae:

$$\text{Standard error of the mean } SE\bar{x} = \frac{\sigma}{\sqrt{n-1}}$$

where σ = Standard deviation

n = total number of insects in sample

$$\text{Standard deviation } \sigma = \sqrt{\frac{\Sigma x^2}{n}}$$

where x = Size of the part of the body measured.

4.3 RESULTS

4.3.1 The Immature Stage

Of all the four hundred kernels of wheat cracked, only one contained a larva in it. The larva was found deeply embedded on one side of the endosperm of the grain. The larva was whitish with a small dark brown head capsule. The total body length was found to be 0.65mm while the head capsule was found to be 0.13mm in length. The larva was scarabaeiform i.e C-shaped in side view, it was found to be dead and dried up, thus making the attempt at preparation in xylene and absolute alcohol to clear the tissues for photography unsuccessful. This measurement was for the dry larva.

When the experiment was repeated, despite the larger number of adults, no immature stages were observed. Also no eggs were observed on the grains studied.

4.3.2 The Adult

Adult *R. dominica* started emerging from the

fourth week after introducing the day-old adults. Mean temperature for the week preceding the emergence was 29^{o}C and the mean relative humidity was 23% (Appendix XI). Two adults emerged during that fourth week, one each from replicates 4 and 6 (Fig.2 and Appendix III). The mean weekly adult emergence increased from the seventh week to a peak of 2.0 in the tenth week (Fig.2). Adult emergence decreased during the eleventh and twelfth weeks, rose in the thirteenth week and decreased in the fourteenth and fifteenth week. During the period of emergence both the temperatures and relative humidities fluctuated. The visual pattern of adult emergence was similar to the fluctuations in relative humidity so that one increased or decreased with the other.

The colour of the newly emerged adult ranged from reddish brown to dark brown (Plate 1). The total length of the body of the adult ranged from 1.338 to 2.375mm (Appendix I), the mean from head to the caudal end was 1.687 ± 0.017mm mean length from the beginning of the thorax to the caudal end was 1.146 ± 0.094, the mean width of the body at the 3rd

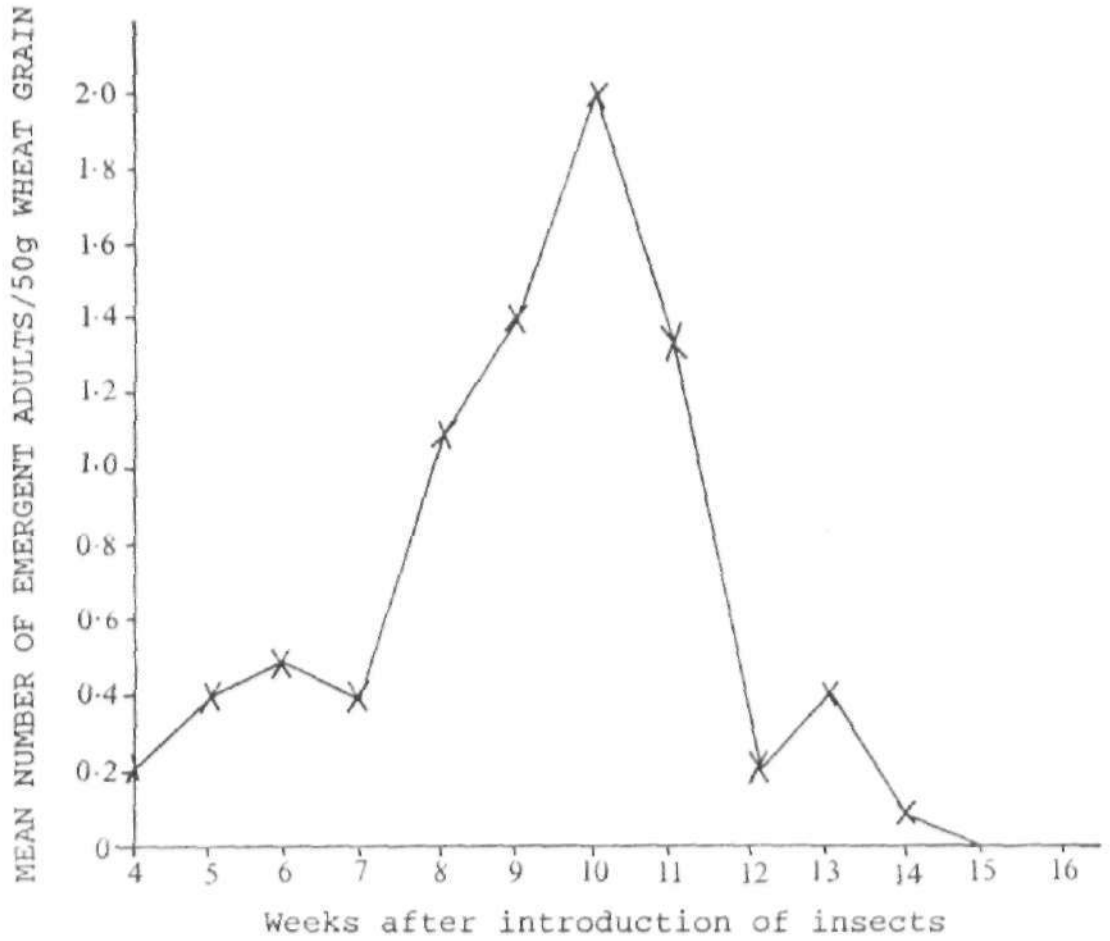


Fig. 2. Mean weekly emergence of R. dominica on Samwhit-6 from the fourth week of introduction into the grain

abdominal segment was 0.610 ± 0.017mm. The width of the head at its widest point was 0.053 ±0.020mm (Table 1 and Appendix X). When the insect clung to the flat surface of a table, it held firmly to the table and was difficult to pick up with an aspirator. It was, however, easy to pick up the adult when it was turned on its back.

The adult insect was found to be very sluggish of movement and could feign death for a long time when disturbed or touched with a finger or a pencil.

In heavy infestations, a lot of light brown dust was created. The dust had a sweet honey-like odour. Even when the wheat was heavily infested, it was found that only a few kernels were bitten into and completely hollowed out while most of the wheat grains were left completely untouched. Out of 1000 whole grains (≡ 35.54g), only 9.2g was found damaged which is equivalent to 25.9% infestation.

The insects flew around the room when left alone but moved in no specific direction except upwards initially and then randomly around the room. The m.c of the grain was 10.2% at each weekly recording of

the life cycle experiment.

When the experiment was repeated, no eggs, immature stages or adults were observed after the sixth week when the experiment was terminated. On the contrary, only three adults each in batteries 1, 5 and 7 survived while 5 adults each survived in batteries 2 and 10 and one in battery 3. The rest of the batteries all had dead adults by the third week of the experiment and no new adults emerged in all the 20 batteries.

TABLE 1: Body measurements of *R. dominica* Adults

BODY PART MEASURED	(mm) (n=100) MEAN ± SΣ
1. Head length	0.532 ± 0.017
2. Head width at widest part	0.537 ± 0.020
3. Length from thorax to caudal end	1.146 ± 0.094
4. Body width at the centre of the abdomen	0.610 ± 0.017
5. Body length from the head to the caudal end	1.678 ± 0.096

TABLE 2: Weight of ten lots of 100 grains of whole and damaged wheat

	Wheat grains, g	
LOT	UNDAMAGED	DAMAGED
1	3.70	1.0
2	3.70	0.7
3	3.45	0.9
4	3.50	1.3
5	3.33	0.6
6	3.45	0.8
7	3.81	1.0
8	3.48	1.1
9	3.74	0.9
10	3.38	0.9
$\bar{x}$	3.554	0.92

4.4 DISCUSSION

Positive visual correlation of the patterns of adult emergence and relative humidity might influence emergence of filial R *dominica*. This however, does not agree with an earlier observation by TDRI (1984) where temperature was considered the more important parameter for adult development and subsequent emergence. The length of the life cycle was found to be four weeks which agrees with earlier observation (Howe, 1950; Golebioska, 1962; 1968; FAO, 1976; Hill, 1983; Osuji, 1985, TDRI, 1986).

The insect was found to cause heavy damage to wheat which resulted in light brown dust with a honey-like odour. However, even in this heavy infestations only a few kernels were found to be infested. This could be as a result of the fact that only the second instar larvae can bite and bore into an undamaged grain (Golebiowska, 1968). Possibly, the first few larvae that emerged bore into grains and subsequent larvae only use the cracks created by the first set of larvae. This is however inconclusive and is open to further investigation.

The insects flew freely at temperatures of

27.9^{O}C and above. This agrees with the observation by TDRI (1984). This may be a good method of dispersal for the insects. The insects were found to cling to the white table and were hard to pick using an aspirator, this contrasted to an earlier observation (FAO, 1976) and may be due to the fact that the surface being smooth might have provided the cohesion for ready clinging of the insect. The absence of eggs immature stages and adults and the non emergence of adults in the repeated experiment may be due to the regularity with lwhich sampling was done as R. dominica die when subjected to constant agitation (FAO, 1976).



PLATE 1: A group of adult R dominica showing variation in size and colour.

CHAPTER 5: HOST RANGE STUDIES

5.1 INTRODUCTION

Rhizopertha dominica is a primary pest of cereal grains and other seeds. It also feeds on dried potatoes, tapioca (cassava) and some unidentified herbs (Zachner, 1930; Frappa, 1938; Pingale et al., 1956; DEGESCH, 1977; Belloti and Schoonhoven, 1979; Hill, 1983; TDRI, 1984; Osuji, 1985). In Nigeria, R. dominica has been reported on yam and yam products (Osuji, 1985) whereas in Taiwan, it was found feeding on sweet potato (Lin, 1958). The record of its feeding activity on the Leguminoseae is sketchy. However, Horton (1982) reported it in bins where soyabeans and some pulses were stored in the United States.

When placed on different hosts, the R. dominica has been found to prefer feeding on some to others. Feeding preference has been shown for grains with prominent glumes; Laubman (1956) found eggs were laid in the raphe if present. The eggs are rarely seen as they are either laid loosely amongst the grains or in cracks if present on the grains (Crombie, 1945; TDRI, 1984, Osuji, 1985). Its feeding activity creates a

lot of dust, grain debris and frass. The insect is exceptional in being able to feed on food with low moisture content (Howe, 1950; TDRI, 1984). The young larvae feed on the grain debris left over by the adults, and it is only after the second ecdysis that they are able to bite into undamaged kernels (Golebiowska, 1968).

The aim of this study was to observe and record a list of the alternative hosts of R. dominica among the most commonly stored food materials in Nigeria. It was also aimed to find out the mode of damage done to each of these food materials and to determine the effect of their feeding activity on weight loss by the grain.

5.2 MATERIALS AND METHODS

5.2.1 Setting up of the experiment

Two hundred and fifty grams of each of the pre fumigated test materials were weighed using a mettler balance (PE200) and placed in Kilner jars (1500mls) each covered with baft over wire mesh (1.0mm mesh). The trial materials used were wheat (Var. Samwhit-6), sorghum (Samsorg-20) millet, (Sammil-1), maize (white hybrid variety), cowpea (var. Sampea-3), groundnut (Var Samnut-18) and dry chips of an unidentified

variety of cassava which is commonly used in the Zaria area.

Ten newly emerged adult R. dominica were placed in each of the jars with test materials. The treatments were replicated three times using the completely randomized design. The jars were placed on a flat bench in the Storage Entomology Laboratory where the treatments received uniform light and aeration.

The moisture content of each of the test materials was taken before and at the end of the experiment using the oven dry method. The treatments were left undisturbed for the first three weeks after which the parent adults were removed completely before sampling. Percentage number of damaged grains was estimated as: $\frac{\text{Number of damaged grains}}{\text{Total number of grains}} \times 100$

5.2.2 Sampling

5.2.2.1 Progeny Emergence and Weight Loss

Insect sampling was done as described in section 3.3. The dish assembly described was used for all the trial materials except millet where the 2.0mm mesh sieve was substituted with a 1.0mm mesh sieve due to the small size of the grains. Dead beetles were

counted and removed while live adults were counted and returned to their respective jars along with the test material and the dust. This procedure enabled the estimation of the extent to which the original ten beetles and their subsequent progenies could survive and continue feeding on each of the test materials. This experiment was conducted over eight weeks starting from 28 May 1991 and ending on 23rd July 1991. The final weight and moisture content was taken for each test material after removing the insects and the dust created by their activity.

Progeny emergence assessment started from the third week and continued at weekly intervals for six weeks.

The adult insects were not sexed as this may involve killing the insects before observing the fifth abdominal sternum. Random selectionn of the insect was done to ensure a 1:1 ratio of males to females.

5.2.2.2 Damage Assessment

The number of damaged grains from 100g of each of the test grains were removed, counted and weighed

to estimate the percentage weight loss for all test materials except cassava chips.

By weighing 100g lots of whole undamaged grains and counting the number of grains in each lot, the mean number of grains per 100g of each test material was determined. This procedure enabled the determination of the expected weight of the damaged grains had they remained undamaged and hence allowed estimation of weight loss for each grain. This procedure was not suitable for cassava chips because the chips were not of uniform size therefore damage assessment for cassava was made only on weight loss.

5.2.3 Data Analysis

Data from replicated trials were analysed using the one-way analysis of variance and differences between means were determined by the least significant difference test (LSD) at the 5% level of probability ($P = 0.05$). The spread about the mean for each set of unreplicated data was determined by computing the standard errors (see Appendix VIIIA).

5.3 RESULTS

None of the test materials except wheat showed any adult emergence by the fourth week (Appendix IV).

During the fifth week, wheat, millet, sorghum and groundnut had adult emergence in at least one of their replicates, while cassava and maize continued to show no adult emergence in any of the replicates. During the sixth week, all the test materials showed adult emergence in at least one of the replicates. In the case of wheat, millet and maize, there was increase in numbers of emerged adults between the sixth and eighth week when the experiment was terminated. The results show significantly higher progeny emergence from millet Sammil-1 than all the other test materials ($P < 0.5$) (Table 3). The remaining test materials had similar adult emergence ($P=0.05$).

At the end of eight weeks when the experiment was terminated, wheat, sorghum, cowpea and maize showed an increase in weight of 5.0, 8.3, 18.3 and 8.3g, respectively, representing weight increases of 2.0, 3.32, 7.32 and 3.32%, respectively. Groundnut and cassava, on the other hand, showed a decrease in weight of 18.33 and 8.3g, respectively, representing losses in weight of 7.332 and 3.332%, respectively. Millet showed neither increase nor decrease in weight

although it had the highest adult emergence (Tables 3 and 5). In each test material, the damaged grain were found to be completely hollowed out and lots of dust was created.

When compared statistically using the one-way analysis of variance, the decrease in weight in groundnut was singificantly lower than all the other food materials which compared favourably with its high percentage loss of 7.332% which was higher than the loss in weight shown by cassava. The loss weight in groundnut was followed by that in cassava which was not significantly different from millet which did not show any appreciable loss in weight. Millet was also not significantly different from wheat, maize and sorghum even though the latter three test materials showed increase in weight.

Cowpea showed a significantly higher increase in weight $P<0.05$), whereas cassava and millet were not significantly different from one another ($P>0.05$).

All trial materials except cassava and groundnut showed increase in moisture content eight weeks after introducing R. dominica (Table 7). The letter two

test materials also showed loss in weight at the end of the experiment. The percentage moisture content of the other test materials showed different levels of increase.

The insect was observed to infest and hollow out only a few grains even in very heavy infestations.For example, out of 100g of wheat grains (representing 2966 grains, 1.17g were infested representing 1.17% infestation by weight (Table 5). Millet which had the highest number of emerging beetles had, out of 7398 grains (100g) only 214 hollowed grains (1.6g) representing 1.6% infestation.

Mean weekly emergence data showed that wheat produced three newly emerged adults by the fourth week (week 1 of Appendix IV), while wheat, groundnut, maize, millet, sorghum, cowpea and cassava produced 6.3, 3.3, 0, 1.67, 5.0, 1.3 and 0 newly emerged adults, respectively (Fig 3 and Appendix IV). Of all the trial materials, only maize, millet and cassava showed progressive increase in number of adults to the eighth week when the experiment was terminated (Fig.3). The other test host materials showed fluctuations in the mean number of emerged adults

over the five weeks that emergence was recorded.

TABLE 3: Host preference of R. dominica for common food materials in Samaru

	Food material	Mean number of emerged adults/250g
1.	Wheat (var.SAMWHIT -6)	48.0[a]
2.	Cassava chips (dry)	5.33[a]
3.	Maize (white hybrid)	50.33[a]
4.	Millet (var.SAMMIL-1)	148.33[b]
5.	Sorghum (var.samsorg-20)	13.0[a]
6.	Cowpea (var.SAMPEA-3)	5.33[a]
7.	Groundnut (Var.SAMNUT-18)	5.66[a]
	± SED	29.68
	LSD	63.67

TABLE 4: Damage by R. dominica to 100g of various food materials

Food Material	Total Number of GRAINS/100g	DAMAGED GRAINS NUMBER	DAMAGED GRAINS WEIGHT g	DAMAGED GRAINS % WEIGHT
Wheat	2966	47	1.17	1.17
Groundnut	408	14	4.26	4.26
Maize	486	48	8.53	8.53
Millet	7398	214	1.6	1.6
Sorghum	6358	30	0.87	0.87
Cowpea	640	6	0.65	0.65

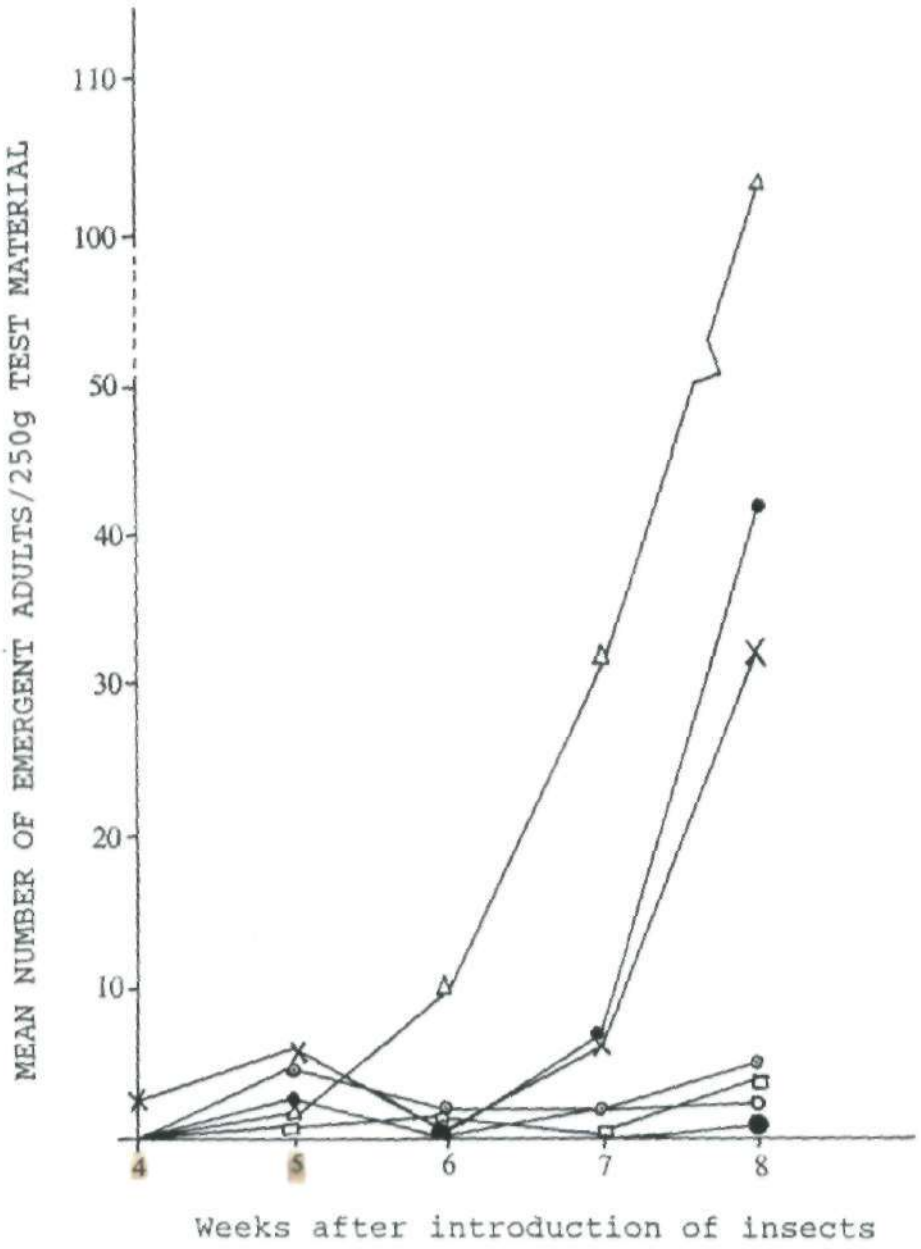


Fig. 3 Curves of R. dominica adult emergence on different hosts

KEY

X WHEAT	⊙ SORGHUM
O CASSAVA	□ COWPEA
• MAIZE	● GROUNDNUT
Δ MILLET	

TABLE 5: Weight of test host materials before and after exposure to *R. dominica*

	Host material	Mean weight(g) Initial	Final	Change in Weight g	%
A.	Wheat (SAMWHIT-6)	250	255.0c	+5.0	+2.0
B.	Groundnut(SAMNUT-18)	250	237.69a	-18.33	-7.332
C.	Maize (while hybrid)	250	258.3c	+8.3	+3.32
D.	Millet (SAMMIL-1)	250	250.0bc	0	0
E.	Sorghum (SAMSORG-20)	250	258.3c	+8.3	+3.32
F.	Cowpea (SAMPEA-3)	250	268.3d	+18.3	+7.32
G.	Cassava Chips	250	241.67b	-8.33	-3.332
	± SED		4.385		
	LSD		9.41		

TABLE 6: Moisture content of test host materials at the beginning and at the end of the experiment on host range of *R. dominica*

	Host material	% Moisture Content Initial	Final	Moisture gain or loss
1.	Wheat (SAMWHIT-6)	8.39	11.62	3.21
2.	groundnut (SAMNUT-18)	7.25	6.23	-1.02
3.	Maize (White hybrid)	6.62	11.63	5.01
4.	Millet (SAMMIL-1)	8.02	12.22	4.20
5.	Sorghum (SAMSORG-20)	8.82	11.72	2.90
6.	Cowpea (SAMPEA-3)	7.5	12.76	5.26
7.	Cassava (chips)	12.72	12.22	-0.55

TABLE 7: Amount of dry matter present out of 250g test host materials before and eight week's after introducing 10 Adult R. dominica

Host material	Dry matter weight, g		
	Initial	Final	Loss of dry matter
Wheat Samwhit-6	229.025	220.95	8.075
Groundnut Samnut-18	231.875	234.425	-2.55
Maize White hybrid	233.455	220.925	12.525
Millet Sammil-1	249.5	219.45	30.05
Sorghum Samsorg-20	227.955	220.7	7.25
Cowpea Sampea-3	231.25	218.1	13.15
Cassava chips	218.2	219.45	-1.25

5.4 DISCUSSIONS

All test materials were found to be suitable to varying degrees as host for R. dominica since development to adult stage was completed on all test materials which shows that in the absence of cereals, these other stored crops could be hosts to the insect (Plates 2,3,4 and 5).

R dominica, however showed preference for millet. Thus the experiment has shown that millet (var. ex-Borno sammil-1) is a better bost of R. dominica than wheat (Var.Pavon F.76 (Samwhit-6), cassava chips, maize (white hybrid), sorghum (var. SSV6 (L. 187) (samsorg - 20), cowpea (Var. IAR341-1 alias sampea-3) and groundnut. This is however, predicted on the assumption that a similar sex ratio had been achieved in random selection for all treatments.

Few grains were damaged possibly because the insects are only able to bite into whole grains at the second instar larval stage (Golebiowska, 1968) and only those that survived to that stage would be able

to infest the grain. Also, the females prefer to lay eggs in Cracks or crevices (TDRI, 1984; Dsuji, 1985) created either by mechanical means or by the feeding of the insects. Thus it is possible that the insects continued to feed and develop on the few grains that were first bitten into by the first set of second instar larvae.

Mejule (1978) asserted that stored agricultural products are hygroscopic by nature was confirmed in the present experiment for wheat, millet, sorghum, maize and cowpea whose moisture content increased over the period of the experiment. The moisture content increase were responsible for their increase in weight as there was loss in dry matter equivalent to 8.075, 30.05, 7.25, 12.52 and 13.15g respectively, for these food materials (Tables 5,6 and 7). Cassava and groundnut, however, showed decrease in weight despite both showing increase in dry matter equivalent to 1.25 and 2.55g respectively. The loss of weight in cassava may be attributed to the large quantity of dust created and the increase in dry matter shown in both could be due to loss in moisture content during the course of the

experiments. It is however not clear why there was loss in moisture content in both the cassava and the groundnut.

More grains of maize were hallowed out than all the other food materials. This could be due to the prominent glumes which provide the crevices favourable for oviposition (Laubman, 1956).



PLATE 2: Wheat (Samwhit-6) showing the infested (left) and uninfested (right) grains.



PLATE 3: Dry cassava chips (left) and sorghum (right) (Samsorg-20) infested by R. dominica.

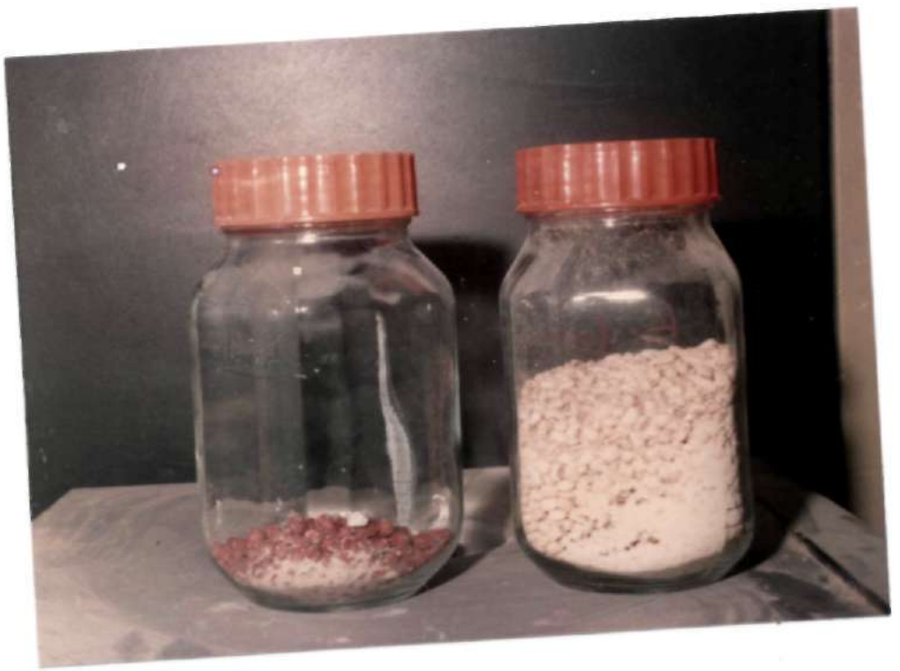


PLATE 4: Groundnut, var.Samnut-18 (left), and cowpea, var.Sampea-3 (right), infested by R.dominica



PLATE 5: Millet, var.Sammil-1 (left) and maize, white hybrid var. (right) infested by R.dominica.

CHAPTER 6: MICRO-ORGANISMS ASSOCIATED WITH R. DOMINICA

6.1 INTRODUCTION

Rhizopertha dominica, like other coleopterans, has been shown to contain certain micro-organisms in their gut. Some of these micro-organisms, usually yeasts, Actinomyces or bacteria, are symbionts which help in digestion of the beetle's food (Richards and Davies, 1976). These symbiotic micro-organisms may be transmistted from one generation to the next through the egg. Another micro-organism found associated with R. dominica is Streptomyces which produces aposymbiosis.

The aim of this study was to observe and identify the micro-organisms associated with R. dominica both internally and externally and to find out the kind of association they might possibly have with the insect.

6.2 MATERIALS AND METHODS

6.2.1 Setting up of the Experiment

Five whole and five crushed adult R.dominica were each plated on three Petri dishes of pectin

dextrose agar (PDA) for bacterial micro-organisms and pectin dextrose agar with streptomycin (PDAS) for fungal micro-organisms. The streptomycin suppresses the growth of bacteria.

Plating was done in a microflow isolation hood. Before plating the insects, the room was first sprayed with a dilute solution of izal using a CP13 knapsack sprayer to avoid contamination from micro-organisms that may already be present in the room. The room was then left for 30 minutes after spraying before bringing in the insects for plating. The floor of the isolation hood was then cleaned using a clean cotton pad soaked in ethanol by rubbing the floor all over for three minutes. It was then left to dry off for about two minutes. The fan of the hood was turned on to drive out any in-coming contaminants while the fluorescent lamp was turned on for clear viewing of the procedure.

The insects were prepared for plating by washing in 5% sodium hypochlorite solution for five minutes. They were then washed in distilled water to remove the sodium hypochlorite solution. The distilled water was then drained and the insects taken into the micro

flow. Tweezers cleaned in ethanol, heated red hot and then allowed to cool were used to pick up the insects which were then placed whole on the agar plates in the isolation hood. Five individual insects were placed at about 3.0cm from each other in three Petri dishes of PDA or PDAS. Sterilized tweezers were used to crush the insects or also to pick up their pieces which were then plated. The plates were then placed in a cool incubator running at $32^{o}C$ and observed daily until growth colonies were formed. The plates were incubated for five days.

6.2.2 Sampling

When micobial growth was observed, the Petri dishes were then removed from the incubator and taken to the Pathology laboratory for identification. The individual growths were identified visually and examined then mounted on slides to confirm or disprove the visual observation. Since no visible contamination was observed, the individual growths were picked up with sterile needles and placed on a drop of lactophenol blue. The needle was used to spread the mixture to prevent clustering of the

micro-organisms. Lactophenol blue was used to stain the fungal micro-organisms as well as to clearly distinguish the different fungal hyphae to be identified. The slides were then mounted on the microscope and observed at a magnification of x40 for more conclusive identification.

6.3 RESULTS

No growth or colony was observed until the fifth day. The following fungi were identified:

(a) On whole adult *R dominica*:

(i) *Aspergillus niger*, (A yeast belonging to the group Ascomycotina)

(ii) *Penicillium* spp. (A yeast)

(iii) *Rhizopus* spp (class: Mucorales)

(B) On crushed adult *R dominica*:

(i) *Aspergillus* sp.

On all PDA plates, some unidentified bacterial colonies were observed. They were, however, suspected to belong to the genus *Pseudomonas* but this was not confirmed.

6.4 DISCUSSION

The micro-organisms associated with R. dominica may be living innocuous or symbiotic lives since no death had been observed during the period of the experiment due to their activities. The micro-organisms present internally may be responsible for digesting some food materials in the insect gut, possibly lignin as shown by Huger (1954) and Richards and Davies (1976). These micro-organisms include yeasts, Actinomyces and bacteria.

The external micro-organisms may not have an active role on R. dominica. They may just be living on the insect or they could have been picked up from the food materials since they were from the cultures that were made from the original culture present in the laboratory, or possibly the surface sterilization may not have been very effective in eradicating the external micro-organisms.

CHAPTER 7: CHEMICAL CONTROL OF R. dominica ON WHEAT

7.1 INTRODUCTION

The use of chemical agents as insecticides is an old practice. For example, pyrethrum has been used for the control of storage insect pests since 1828 (Hassel, 1969). Environmentalists and other concerned bodies have been crying against the use of chemical agents especially in storage where the food is almost always consumed directly. However, current storage systems and technology dictate that the control of these pests be based largely on the use of chemical pesticides (FAO, 1986). In a country like Nigeria, where not much knowledge has yet accumulated on the use of alternative methods of control, the use of chemical agents will still continue for sometime to come. Although there are comparatively few materials that are safe for use in the control of pests of foodstuffs in storage,, wWhere the correct amount is judiciously applied as recommended, little or no damage will be done to man, his property and his environment. Chemical agents to date give the fastest and most dramatic and spectacular control of insect pests in storage.

The aim of this experiment was to compare the efficacy of a novel pesticide available on the Nigerian market with previously recommended insecticides for control of R. dominica on stored wheat and to elucidate the effect of the chemicals on adult emergence and hence development of the insect.

7.2 MATERIALS AND METHODS

7.2.1 Setting up of the Experiment

Two hundred and fifty grams of pre-fumigated wheat (var.Samwhit-6) was placed in each of 21 kilner jars (1500ml). The layout was a completely randomized design. The seven treatments were replicated three times. The chemicals used were applied at the dosage recommended by their manufacturers. The treatments were as follows:

0.25g Actellic 2% dust (pirimiphos-methyl), an organophosphorus compound with both contact and fumigant action;

0.25g Coopex 5% dust (permethrin) a novel pyrethroid with contact action;

0.25g lindane 5% dust (gamma-benzene hexachloride - BHC) which acts both as a contact and a stomach poison;

0.05g Phostoxin tablet (aluminium phosphide) with fumigant action following sublimation to the poisonous gas, phosphine;

0.05g Quickphos tablet (aluminium phosphide) with similar fumigant action as phostoxin

a control with no insecticide but ventilated;

a control with no insecticide but airtight.

The dusts were thoroughly mixed with the grain by shaking the jars vigorously for five minutes. Each jar was then left for ten minutes before introducing 10 R. dominica adults. However, with Quickphos and Phostoxin the same number of insects were first introduced into the jars before placing Quickphos and Phostoxin. Quickphos and Phostoxin were placed in donation envelopes (8.7 x 6.9cm) after weighing the tablets. The envelopes with the tablets were then placed into the jars which were capped immediately with glass covers and rubber bands to create on airtight condition. The same kind of cover was used for the airtight control. In the dust treatments and the ventilated control treatment, the jars were capped using a cover of baft over wire mesh (1.0mm).

The treatments were arranged on a flat table

where they received uniform ventilation and light. While the dusts and the two controls were kept in the laboratory, the fumigant treatments were kept outside in the corridor for three days in a covered plastic container usually used for fumigating grains. This procedure was to avoid gas escaping and affecting the results of the other experiments.

7.2.2 Sampling

Sampling was done by emptying the grains into an extraction dish assembly as described in section 3.3. Samples were taken daily from the first 24 hours for the dusts and ventilated control, while sampling for the fumigants and airtight control were taken beginning from the third day. After the third day, all readings were taken at weekly intervals for all treatments until the emergence of new adults. Dead adults were counted and removed while the live ones were returned to their respective jars along with the chemicals. Numbers of dead and live bettles were recorded separately at each sampling. Sampling was done twelve times.

7.2.3 Data Analysis

Data from replicated trials were analysed by the one-way analysis of variance and differences between means were determined by the least significant difference test at 5% level of probability (P=0.05). Analysis was done for data on mortality at 3 days, 7 days and 21 days post treatment. Three days was selected because an effective chemical should give a significant control by the third day.

7.3 RESULTS

By the third day of treatment with chemical insecticides, all chemical treatments had significantly higher beetle mortality than the two control treatments (P=0.05) but were not significantly different from each other. The airtight control also had significantly higher mortality than

TABLE 8: Effect of different chemicals on mortality of*R. dominica*, 1991

Treatment	Mean Number of Dead Adults/10 adults		
	3 days	7 days	21 days
Actellic	10.0[c]	10.0[b]	10.0[b]
Coopex	10.0[c]	10.0[b]	10.0[b]
Lindane	9.67[c]	10.0[b]	10.0[b]
Phostoxin	10.0[c]	10.0[b]	10.0[b]
Quickphos	10.0[c]	10.0[b]	10.0[b]
Airtight control	2.0[b]	5.67[a]	9.0[b]
Control	1.0[a]	4.33[a]	6.0[a]
± SED	0.642	1.49	0.69
LSD	1.38	3.196	1.48

TABLE 9: Mean weekly emergence of adult R. dominica from the fourth week of treatment with different chemicals

Mean No. of emerged adults/treatment

Treatment	Weeks 4	5	6	7	8	9	Σ	$\bar{x}$
Actellic	0.33	0	0.33	0	0	0	0.66	0.11
Coopex	0	0	0	0	0	0	0	0
Lindane	0	0	0	0	0	0	0	0
Phostoxin	0	0	0	0	0	0	0	0
Quickphos	0	0	0	0	0	0	0	0
Airtight control	0	0	0.33	0.1	0.67	0	1.1	0.18
Control	0.33	3.0	5.67	4.33	0.67	2.67	16.67	2.78

the ventilated control (Table 8). The chemical treatments all gave 100% control by the third day except lindane which gave 96.7% control. The airtight and ventilated control had 2.0 and 1.0% mortality, respectively. By the seventh day of treatment, lindane had also given 100% control and beetle mortality in the airtight (56.7%) and ventilated (43.3%) controls were statistically comparable. On the twenty first day of treatment, all chemical treatments and the airtight control were significantly superior ($P<0.05$) to the ventilated control. Mortality in the airtight treatment had reached 90% while it was 60% in the ventilated control.

From the fourth week, some adult emergence had been recorded in some of the treatments (Appendix VII). A mean of 0.33 adults was recorded to have emerged on the fourth week from the Actellic treatment. At the sixth week, a mean of 0.33 adult emergence was also recorded from the same treatment. None of the other chemical treatments recorded any adult emergence at that stage (Table 9). The airtight control gave a total mean adult emergence of 1.1 between the sixth and eighth week of treatment. The ventilated control gave a

total adult mean emergence of 16.67 from the fourth to the ninth week when the experiment was terminated.

7.4 DISCUSSION

It would appear from the results that the chemical insecticides Actellic, Coopex, Phostoxin,Quickphos and lindane are effective for the control of R. dominica after three days. The chemical treatments are far more superior to airtight and ventilated controls whilte the airtight control was significantly more superior to the ventilated control.

Where all the other chemicals suppressed the development process of the beetles after killing the parents, Actellic however, did not succeed in suppressing the progeny emergence. This may suggest the lack of ovicidal property on the part of the chemical which may also suggest that the chemical is not suitable for long term control of R. dominica.

8.0 GENERAL DISCUSSION

The present study has shown that the lesser grain borer, Rhizopertha dominica, can complete its life cycle on stored wheat (var. Samwhit-6), groundnut (var. Samnut-18), millet (var. Sammil-1), sorghum (var. Samsorg - 20), cowpea (var. Sampea-3), white hybrid maize and dry cassava chips. This is an indication that it is a primary pest on these stored food materials of which Sammil-1 appeared to be a better host with higher adult progeny emergence than any of the other test food materials. However, the life cycle of the insect took four weeks to complete on whole wheat but longer (five to six weeks) on other test materials. This would suggest that wheat was a more efficient food source for development of R. dominica but millet, although less efficient, led to more survivors during the development process. The pattern of adult emergence was different for all the test food materials. Although more adults emerged on millet, more holes were observed on maize than all the other test food materials. This may be not only due to its prominent glumes but also due to its large size as the hollowed out grain of maize provided the

crevices which were used for hiding by the adult beetles. This agreed with earlier observations (Howe, 1950; Golebiowska, 1962, 1968; Hill, 1983; TDRI, 1984; Osuji, 1985) where R. dominica were shown to prefer crevices for hiding and oviposition. The length of the adult beetle on a culture of Samwhit-6 was found to be 1.338-2.375mm which is smaller than the size given by other workers on different host materials, On observations by these workers, the adult size was given as 2-3mm in length (DEGESCH, 1977;, Hill, 1983; TDRI, 1984; Osuji, 1985). However, the small size of the head capsule of the larva (0.13 mm) relative to the body (0.65mm) agreed with the report by TDRI (1984).

The small size of the adult insect in the stock of culture used for this study, may suggest that smaller strains of R. dominica are found around the Zaria area.

In very heavy infestations on all the grains used for the present study, only a few grains were observed to be bitten into and hallowed out while the

rest of the grain remained completely untouched. This could be due to a number of reasons. First, the females prefer to lay their eggs in cracks and crevices created either by mechanical means or by the feeding of the insects (Crombie, 1945) and the larvae are only able to bite into whole grains at the second instar stage (Golebiowska, 1968; TDRI, 1984). It is then possible that subsequent larvae bored only into cracks created by the first set of larvae since no damaged grains were used in the experiments. Another underlying reason could be hormones secreted by the first set of larvae or some other kariomones (Uvah, personal communication) which triggered a response in subsequently developing larvae to bore into only such kernels. This is however a subject that needs to be further investigated.

The ability of R. dominica to fly freely would presumably ensure its dispersal to nearby farms, storage bins and buildings. The adult insect had been found in the present study to be associated with both external and internal micro-organisms. The external micro-organisms, A niger, Penicillium spp. an

unidentified bacterium and Rhizopus spp., appear to live an innocuous life on the insect while the internal micro-organism, Aspergillus spp and the bacterium, may be responsible for the digestion of certain food materials like lignin in the gut of the insect as indicated by Richards and Davies (1976).

All the chemicals tested in the present experiment gave superior adult mortality of R. dominica within three days than airtight and ventilated controls. This result is similar to that of previous workers who used some of these chemicals (FAO, 1976;Hill, 1983)

Inspite of the effectiveness of Actellic dust in killing the parent insects, it did not suppress development leading to some adult emergence. The novel insecticide coopex compared favourably with the other chemical insecticides by giving significant control of adults within three days and also by suppressing the emergence of new adult R. dominica this may suggest an ovicidal property in this new insecticide.

9.0 SUMMARY AND CONCLUSIONS

Experiments were conducted to determine the length of the life cycle, flight ability, adult body measurements, larval body measurements, host preference range, associated micro-organisms and chemical control of R. dominica. It was found that on whole wheat, the life cycle took four weeks to complete but longer on other food materials (five to six weeks) and that the adult could fly freely. The length of the adult insect was found to be 1.338-2.375mm which was smaller than was found by previous workers. The larva was found to be 0.65mm in length while the head capsule of the larva was found to be 0.13mm which agreed with the report by TDRI (1984).

Of the different host materials, wheat (var. Samwhit-6) was found to be the most efficient host for development and progeny adults started emerging four weeks after introducing the parent adult. Millet (var. Sammil-1) on the other hand, although less efficient led to more survivors (a mean of 104.3 adults compared to 31.67 survivors on wheat. In all test materials, only a few kernels (e.g 47

our of 2966 of wheat; 214 out of 7398 and 30 out of 6358 grains of sorghum representing 100g) were found to be infested even in very heavy infestations.

The micro-organisms associated with R. dominica included A niger, Penicillium spp., Rhizopus spp. and an unidentified colony of bacteria externally and Aspergillus spp. and the same type of unidentified bacterial colony internally.

The chemicals, Actellic 2% dust, Coopex 5% dust, lindane 5% dust, Phostoxin and Quickphos tablets gave significantly higher adult mortality of R. dominica ($P<0.05$) compared to airtight and ventilated controls after three days of application of the treatments. All the chemical treatments depressed numbers of emerged R. dominica adult progeny with the exception of Actellic which, although killed the parent adults, did not suppress the subsequent development and emergence of adult progeny. Airtight control will however be more practical economically.

It may be concluded from this study that the strains of adult R. dominica used in this experiment are smaller than those studied by other workers. However, this may be due to the source of the stock culture. The life cycle may take four to six weeks to complete depending on the host on which the insect is feeding. Millet (Sammil-1) was found to be preferred for development and fast multiplication which may suggest that the grain may have the required nutrients for fast development of the insect, although it did not provide the crevices and cracks needed for oviposition by the female.

Of the micro-organisms associated with R. dominica, the bacterium and Aspergillus spp. may play some significant role having been implicated in the digestion of the food of the insect. All the chemicals tested were effective for the efficient control of R. dominica infestation with the exception of Actellic 2% dust which did not succeed in suppressing development of the insect after killing the parents. This may also infer a lack of ovicidal action on the part of this chemical. The new

insecticide, Coopex, compared favourably with the other insecticides for the control of R. dominica.

This work is by no means exhaustive. Being that little work has been done on this important pest of stored products which attacks a wide range of food products ranging from cereals, legumes, oil seeds and stem propagated crops and possibly root crops, more work should be geared towards finding out more on the biology and the different methods of controlling it.

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APPENDIX 1: Calorie and nutrient content of wheat and other cereals per 100g

Source: FAO(1970).

CEREAL	WATER	CALORIES	PROTEIN*	FAT	TOTAL CARBOHYDRATE INCL.FIBR.	CALCIUM	IRON	THIAMINE	RIBOFLAVUBE	NICOTINIC ACID
	Grammes			Grammes				Milligrammes		
Wheat (hard)	12	332	13.8	2.0	70	37	4.1	0.45	0.13	5.4
Wheat (soft)	12	333	10.5	1.9	74	35	3.9	0.38	0.08	4.3
Rice	**13**	**357**	7.5	1.8	77	15	1.4	0.33	0.05	4.6
Maize	13	356	9.5	4.3	73	10	2.3	0.45	0.11	2.0
Barley	12	332	11.0	1.8	73	33	3.6	0.46	0.12	5.5
Rye	12	319	11.0	1.9	73	38	3.7	0.41	0.16	1.3
Oats	9	388	11.2	7.5	70	60	5.0	0.50	0.15	1.0
Sorghum	12	355	9.7	3.4	73	32	4.5	0.50	0.12	3.5
Finger millet	12	336	5.68	1.5	78	350	5.0	0.30	0.10	1.4
Bulrush millet	12	363	10.3	5.0	71	25	3.0	0.30	0.15	2.0

*Protein content has been calculated by nitrogen x 5.83.

APPENDIX II: Body Measurements mm adult 100 Rhizopertha dominica F taken under the microscope (x4) in mm.

INSECT NO.	BODY LENGTH	BODY WIDTH	HEAD LENGTH	HEAD WIDTH
1	1.125	0.625	0.625	0.563
2	1.375	0.500	0.625	0.425
3	1.188	0.625	0.563	0.563
4	1.125	0.625	0.500	0.500
5	1.125	0.625	0.563	0.500
6	1.188	0.625	0.500	0.500
7	1.125	0.583	0.500	0.500
8	1.188	0.625	0.563	0.563
9	1.125	0.625	0.500	0.575
10	1.000	0.625	0.438	0.500
11	1.375	0.688	0.688	0.625
12	1.125	0.563	0.500	0.500
13	1.125	0.563	0.500	0.563
14	1.063	0.563	0.500	0.500
15	1.100	0.588	0.500	0.500
16	1.063	0.625	0.500	0.563
17	0.900	0.500	0.438	0.475
18	1.063	0.563	0.500	0.500
19	1.125	0.575	0.625	0.525
20	1.500	0.750	0.813	0.688

INSECT NO.	BODY LENGTH	BODY WIDTH	HEAD LENGTH	HEAD WIDTH
21	1.188	0.625	0.563	0.563
22	1.963	0.625	0.500	0.563
23	1.063	0.563	0.438	0.500
24	1.125	0.563	0.500	0.500
25	1.188	0.625	0.563	0.563
26	1.538	0.775	0.750	0.688
27	1.188	0.563	0.563	0.538
28	1.125	0.625	0.563	0.563
29	1.438	0.688	0.688	0.563
30	1.125	0.625	0.563	0.500
31	1.063	0.600	0.500	0.500
32	1.125	0.563	0.500	0.500
33	1.125	0.625	0.500	0.563
34	1.125	0.625	0.563	0.563
35	1.125	0.625	0.500	0.500
36	1.063	0.588	0.500	0.500
37	1.063	0.563	0.500	0.500
38	1.063	0.563	0.500	0.500
39	1.063	0.588	0.563	0.538
40	1.000	0.563	0.438	0.500
41	1.063	0.563	0.563	0.538
42	1.188	0.625	0.500	0.525

INSECT NO.	BODY LENGTH	BODY WIDTH	HEAD LENGTH	HEAD WIDTH
43	1.125	0.600	0.563	0.563
44	1.125	0.563	0.500	0.500
45	1.250	0.625	0.625	0.563
46	1.125	0.588	0.500	0.525
47	1.063	0.625	0.500	0.500
48	1.563	0.750	0.750	0.650
49	1.250	0.625	0.563	0.500
50	1.038	0.625	0.563	0.563
51	1.250	0.563	0.625	0.500
52	0.938	0.500	0.500	0.413
53	1.250	0.625	0.538	0.500
54	1.125	0.600	0.500	0.525
55	1.188	0.600	0.563	0.563
56	1.125	0.563	0.430	0.563
57	1.250	0.625	0.500	0.563
58	1.625	0.750	0.750	0.688
59	1.125	0.588	0.500	0.538
60	1.125	0.563	0.563	0.500
61	0.913	0.500	0.438	0.475
62	1.250	0.625	0.500	0.563
63	1.100	0.688	0.500	0.563
64	0.013	0.563	0.500	0.500

INSECT NO.	BODY LENGTH	BODY WIDTH	HEAD LENGTH	HEAD WIDTH
65	1.188	0.688	0.500	0.563
66	1.125	0.600	0.475	0.563
67	1.125	0.588	0.500	0.538
68	1.063	0.625	0.563	0.563
69	0.963	0.500	0.475	0.438
70	1.125	0.625	0.475	0.563
71	1.188	0.625	0.563	0.563
72	1.963	0.525	0.438	0.500
73	1.125	0.625	0.500	0.538
74	1.188	0.600	0.500	0.500
75	1.188	0.625	0.563	0.563
76	1.000	0.625	0.563	0.500
77	1.125	0.563	0.500	0.500
78	1.250	0.625	0.500	0.500
79	1.000	0.625	0.438	0.563
80	1.000	0.563	0.500	0.563
81	1.188	0.625	0.438	0.563
82	1.188	0.625	0.438	0.563
83	1.125	0.625	0.500	0.563
84	1.063	0.625	0.500	0.500
85	1.188	0.625	0.563	0.500
86	1.188	0.625	0.563	0.563

87	1.188	0.625	0.563	0.563
88	1.188	0.688	0.563	0.563
89	0.873	0.625	0.500	0.563
90	1.063	0.500	0.500	0.475
91	1.188	0.625	0.500	0.563
92	1.313	0.625	0.563	0.563
93	1.250	0.688	0.500	0.625
94	1.100	0.625	0.500	0.563
95	0.938	0.600	0.500	0.500
96	1.125	0.538	0.438	0.600
97	1.563	0.625	0.688	0.500
98	1.163	0.750	0.550	0.563
99	0.913	0.625	0.500	0.500
100	1.188	0.625	0.563	0.563

MEAN LENGTH OF THORAX AND ABDOMEN = 1.146mm

MEAN BODY WIDTH AT THE THIRD ABDOMINAL SEGMENT = 0.610mm

MEAN HEAD LENGTH = 0.532mm

MEAN HEAD WIDTH AT ITS WIDEST PART = 0.537mm

MEAN TOTAL BODY LENGTH=MEAN HEAD LENGTH +
MEAN LENGTH OF THORAX AND ABDOMEN = 1.678mm

:. TOTAL BODY LENGTH OF R DOMINICA = 1.678±0.096mm

APPENDIX III: Weekly emergence of *R. dominica* adults on Samwhit-6 from the fourth week of introduction of adult beetles emerged Adults/250 wheat.

	REPLICATES											
WEEK	1	2	3	4	5	6	7	8	9	10	Σ	$\bar{x}$
1	-	-	-	1	-	1	-	-	-	-	2	0.2
2	-	1	-	1	1	-	-	-	-	1	4	0.4
3	1	1	-	-	1	-	1	-	1	-	5	0.5
4	1	1	-	-	-	1	1	-	-	-	4	0.4
5	1	-	1	2	1	2	-	1	1	1	11	1.1
6	1	1	2	3	1	2	1	-	1	2	14	1.4
7	2	3	2	3	2	1	1	1	3	2	20	2.0
8	2	1	1	3	2	1	-	1	1	1	13	1.3
9	-	-	1	-	-	1	-	-	-	-	2	0.2
10	1	1	-	1	-	-	-	-	-	1	4	0.4
11	-	-	1	-	-	-	-	-	-	-	-	-
Σ	9	9	8	14	8	9	4	3	7	8	80	
$\bar{x}$	0.81	0.81	0.67	1.27	0.67	0.81	0.36	0.27	0.64	0.67	7.3	

APPENDIX IV: Weekly emergence of R. dominica progeny from different host materials

	WHEAT (PAYOH F.70) SAMMAIT-6			GROUNDNUT (RRM) SAMNUT-18			MAIZE WHITE			MILLET (Ex.Borno) SAMMIL-1			SORGHUM (L.187) SAMSORG-20			COWPEA SAMPEA-3			CASSAVA CHIPS		
	REPLICATIONS																				
WEEKS*	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
4	2	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	16	3	0	10	0	0	0	0	0	2	3	0	8	6	1	4	0	0	0	0	0
6	0	0	4	0	0	0	2	0	0	5	5	21	0	5	2	1	1	0	0	0	1
7	7	6	4	0	0	1	10	5	7	31	10	55	0	3	4	1	0	0	0	6	1
8	27	30	38	0	1	3	42	33	52	79	55	149	0	7	8	2	9	0	3	3	3
TOTAL	52	44	48	10	1	4	54	38	59	117	73	225	8	21	15	8	10	0	3	9	5

* Weeks after introducing parent adults.

APPENDIX V: MEAN WEEKLY EMERGENCE OF *R. dominica* ON DIFFERENT HOSTS EMERGED ADULTS/250G TEST HOST MATERIALS

NO. ADULTS/250g

Week	Wheat	Groundnut	Maize	Millet	Sorghum	Cowpea	Cassava
1	3.0	0	0	0	0	0	0
2	6.3	3.3	0	1.67	5.0	1.3	0
3	1.3	0	0.67	10.3	2.3	0.67	0.3
4	5.67	0.3	7.3	32.0	2.3	0.3	2.3
5	31.67	1.3	42.3	104.3	5.3	3.67	3.0

APPENDIX VI: Daily mortality rate of the 10 adult R. dominica introduced into wheat protected with insecticides

	ACTELLIC			CDOPEX			PHOSTOXIN			QUICKPHOS			LINDANE			AIRTIGHT CONTROL			VENTILATED CONTROL		
	REPLICATIONS																				
DAY	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
1	9	6	7	6	7	5	0	0	0	0	0	0	5	6	6	0	0	0	0	1	0
2	1	4	3	4	3	5	0	0	0	0	0	0	2	2	3	0	0	0	1	0	1
3	0	0	0	0	0	0	10	10	10	10	10	10	3	0	1	3	3	0	1	0	2
7	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	4	2	5	3	3	2
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4	3	4	1	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	4	3
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	2
TOTAL	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10

APPENDIX VII: Weekly emergence of adult R. dominica after treatment with different chemicals

	ACTELLIC			COOPEX			PHOSTOXIN			QUICKPHOS			LINDANE			AIRTIGHT CONTROL			VENTILATED CONTROL		
	REPLICATIONS																				
WEEK	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	2	1
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	11	3	3
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	5	5	3
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	1
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	1
TOTAL	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	2	26	12	9

APPENDIX VIII A: Analysis of Variance for Host Range Study for Number of Adult R. dominica Emerged for Five weeks After Emergence of the First Set of Adults using CRD

	Number of Insects Emerged/Jar				
Treatment	REP.I	REPII	REP.III	TOTAL	MEAN
A. Wheat	52	44	48	144	48.0a
B. Cassava	3	9	4	16	5.33a
C. Maize	54	38	59	151	50.33a
D. Millet	117	73	255	445	148.33b
E. Sorghum	8	21	10	39	13.0
F. Cowpea	8	9	0	17	5.67
G. Groundnut	10	3	4	17	5.67a
Total	252	197	380	829	

$$CF = \frac{829^2}{21} = \frac{687241}{21}$$

$$= 32725.76$$

$$\text{Total SS} = 52^2 + 3^2 + 54^2 + 117^2 + 8^2 + 8^2 + 10^2 + 44^2 + 9^2 + 38^2 + 73^2 + 21^2 + 9^2 + 3^2 + 48^2 + 4^2 + 59^2 + 255^2 + 10^2 + 0^2 + 4^2 - 32725.76$$

$$= 99809 - 32725.76$$

$$= 67083.24$$

$$\text{Treatment SS} = \frac{144^2 + 16^2+151^2+445^2+39^2+17^2+17^2}{3} - 32725.76$$

$$= \frac{243917}{3} - 32725.76$$

$$= 81305.67 - 32725.76$$

$$= 48579.9$$

Error ss = 67083.24 - 48579.9

= 18503.34

ANOVA TABLE

Source	Df	ss	ms	F
Treatment(7-1) =	6	485579.9	8096.65	6.13*
Errof 7(3-1) =	14	18503.34	1321.67	
Total (7x3)-1 =	20	67083.24		

The computed F - value 6.13 at treatment degrees of freedom and 14 error degrees of freedom at the 5% level of probability (P = 0.05) is significantly higher than the tabulated F - value of 2.85, therefore the treatment is significant. It is then important to do the least significant difference test (LSD) to compare the means of the treatments.

$$\text{SED} = \sqrt{2\,\frac{EMS}{r}} = \sqrt{\frac{2 \times 1321.67}{3}}$$

$$= 29.68$$

LSD = t.05 x SED

= 2.145 x 29.68

= 63.67

Ranking of the means

F	B	G	E	A	C	D
5.33	5.67	5.67	13.0	48.0	50.33	148.33
					a	b

APPENDIX VIII: B: Analysis of Variance of weight change in 250g of test host materials after eight weeks of exposure to R. dominica

Treatment	REP.I	REPII	REP.III	Σ	x
A. Wheat	256	254	255	765	255^{c}
B. Groundnut	231	232	232	695	231.67^{a}
C. Maize	257.3	260	257.6	774.9	$258.3^{c}3$
D. Millet	250	245	255	750	250^{bc}
E. Sorghum	260.3	256.3	258.3	774.9	$258.3^{c}3$
F. Cowpea	260	275	272.45	807.45	$269.15^{d}3$
G. Cassava	230	247	248	725	$241.67^{b}3$
Total	1744.6	1769.75	1778.35	5292.25	

$$CF = \frac{5292.25^2}{25} = \frac{1333710}{}$$

$$\text{Total SS} = 256^2+254^2+255^2+231^2+232^2+257.3^2+10^2+232^2$$
$$+260^2 +257.6^2 +250^2+245^2+255^2 +260.3^2 + 256.3^2 + 258.3^2$$
$$+260^2 + 275^2 +272.45^2 +230^2 +247^2 + 248^2 - 1333710$$

$$= 3118.7$$

$$\text{Treatment SS} = \frac{765^2 +695^2+774.9^2+750^2+774.9^2+807.45^2+725^2}{3} - 133393$$

$$= 2720.1$$

$$\text{Error ss} = 398.6$$

ANOVA TABLE

Source	DF	SS	MS	F
Treatment(7-1) =	6	2720.1	453.35	15.92*
Error 7(3-1) =	14	396.65	28.47	
Total (7x3)-1 =	20	3118.7		

The computed F - value of 15.92 is higher than the tabulated F - value at 6 treatment degrees of freedom and 14 error degrees of freedom (2.85) at the 5% level of probability (P=0.05) thus making the treatment significant. The LSD test is important to compare the means.

$$SED = \sqrt{2}\,\frac{EMS}{r} = \sqrt{\frac{2 \times 28.47}{3}}$$

$$= 2.51$$

$$LSD = t.05 \times SED$$

$$= 2.145 \times 2.51$$

$$= 5.4$$

Ranking of the means

B	G	D	A	E	C	F
231.67	241.67	250.0	255.0	258.3	258.3	268.3
a	b	c				d

APPENDIX VIII C: Analysis of Variance for the No. of dead insect/jar 3 days post treatment of wheat grain with different insecticides

Number of Insects Dead/Jar

Treatment	REP.I	REPII	REP.III	TOTAL	MEAN
A. Actellic	10	10	10	30	10.0c
B. Coopex	10	10	10	30	10.0c
C. Phostoxin	10	10	10	30	10.0c
D. Quickphos	10	10	10	30	10.0c
E. Lindane	10	9	10	29	9.67c
F. airtight control	3	3	0	6	2.0b
G. Ventilated "	1	0	2	3	1.0a
Total	54	52	52	158	

ANOVA TABLE

Source	DF	SS	MS	F
Treatment(7-1) =	6	306.57	51.09	82.54*
Error 7(3-1) =	14	8.67	9.619	
Total (7x3)-1 =	20	315.24	15.76	

*The treatment is significant at P = 0.05

$$SED = \sqrt{\frac{2 \times 0619}{3}}$$

$$= 0.642$$

LSD = t.05 × SED

= 2.145 × 0.642

= 1.38 (approx.)

Ranking of the means

G	F	E	A	B	C	D
1.0	2.0	9.67	10.0	10.0	10.0	10.0
a	b	c				

APPENDIX VIII D: Analysis of Variance for No. of dead insects 7 days post chemical treatment

Number of Insects Dead/Jar

Treatment	REP.I	REPII	REP.III	TOTAL	MEAN
A. Actellic	10	10	10	30	10.0b
B. Coopex	10	10	10	30	10.0b
C. Phostoxin	10	10	10	30	10.0b
D. Quickphos	10	10	10	30	10.0b
E. Lindane	10	10	10	30	10b
F. airtight control	7	5	5	17	5.67a
G. Ventilated "	4	5	4	13	4.33a
Total	54	52	52	158	

ANOVA TABLE

Source	DF	SS	MS	F
Treatment(7-1) =	6	109.81	18.3	76.25*
Error 7(3-1) =	14	3.33	0.24	
Total (7x3)-1 =	20	113.14	5.66	

*F-value is significant at P = 0.05

$$SED = \sqrt{\frac{2 \times 3.33}{3}}$$

$$= 1.49$$

LSD = 2.145 x 1.49

= 3.196

Ranking of the means

G	F	A	B	C	D
4.33	5.67	10.00	10.0	10.0	10.0
	a	b			

APPENDIX VIII: E: Analysis of Variance for No of dead insects/jar 21 days post treatment with chemical insecticide

Number of Insects emerged/Jar

Treatment	REP.I	REPII	REP.III	TOTAL	MEAN
A.	10	10	10	30	10.0b
B.	10	10	10	30	10.0b
C.	10	10	10	30	10.0b
D.	10	10	10	30	10.0b
E.	10	9	10	30	10.0b
F.airtight Control	10	9	8	27	9.0b
G. Ventilated "	8	6	4	18	6.0a
Total	68	65	62	195	

ANOVA TABLE

Source	DF	SS	MS	F
Treatment(7-1) =	6	40.3	6.72	9.41*
Error 7(3-1) =	14	10.0	0.714	
Total (7x3)-1 =	20	50.34	2.515	

*F-value is significant at P = 0.05

$$SED = \sqrt{\frac{2 \times 0.714}{3}}$$

$$= 0.69$$

LSD = 2.145 x 0.69

= 1.48

Ranking of the means

G	F	A	B	C	D	E
6.0	9.0	10.00	10.0	10.0	10.0	10.0
a	b					

APPENDIX IX: Weather records for the period of Study (1991-92)

LATITUDE 11°N

LONGITUDE 07°N 38 E

DATE	JANUARY			FEBRUARY			MARCH		
	R.F.mm	ToC	% R.H.	R.F.mm	ToC	% R.H.	R.F.mm	ToC	% R.H
1	Nil	25	31	Nil	31	16	Nil	19	15
2	-	23	29	-	32	15	Trace	22	12
3	-	25	24	-	34	13	-	23	20
4	-	28	26	-	35	15	-	22	24
5	-	30	31	-	35	18	-	21	36
6	-	32	36	-	34	11	-	18	16
7	-	33	17	-	32	11	-	19	14
8	-	31	23	-	32	31	-	20	27
9	-	27	35	-	32	13	-	19	5
10	-	27	23	-	33	11	-	20	8
11	-	27	46	-	36	9	-	19	6
12	-	27	50	-	36	12	-	20	25
13	-	26	53	-	36	12	-	20	46
14	-	28	23	-	35	26	1.8	25	50
15	-	30	14	-	37	35	42.9	21	83
16	-	32	16	-	37	16	-	20	73
17	-	33	17	-	37	20	-	22	22
18	-	31	12	-	37	39	-	21	26

19	-	30	10	-	38	21	-	20	23
20	-	29	14	-	37	40	-	21	23
21	-	28	17	-	38	46	-	22	56
22	-	30	16	-	39	39	-	22	15
23	-	31	14	-	37	24	-	18	10
24	-	31	13	-	36	28	-	20	13
25	-	31	10	-	35	12	-	20	14
26	-	31	12	-	36	11	-	20	15
27	-	31	12	-	36	15	-	21	52
28	-	32	10	-	38	11	-	20	7
29	-	33	10	-			-	19	24
30	-	34	11	-	-	-	-	21	41
31	-	33	12	-	-	-	-	23	47
E	Nil	33	667	Nil	991.0	570	44.07	638	849
x	Nil	29.6	21.5	Nil	35.40	20.4	-	20.6	27.4

	APRIL			MAY			JUNE		
DATE	R.F.mm	ToC	% R.H.	R.F.mm	ToC	% R.H.	R.F.mm	ToC	% R.H.
1	Nil	39	47	19.5	34	66	Nil	30	82
2	-	37	54	-	30	76	-	31	81
3	11.0	37	62	-	32	63	-	31	78
4	-	37	72	2.8	32	73	-	33	79
5	-	36	59	-	33	75	-	31	78
6	-	34	62	-	32	75	16.5	31	73
7	-	36	62	-	35	65	-	30	72
8	-	36	35	9.0	35	71	-	31	77
9	-	35	61	5.7	33	78	-	31	84
10	-	34	9	-	32	71	5.6	31	77
11	-	35	21	14.0	33	67	-	28	75
12	-	36	12	7.7	31	77	-	30	77
13	-	35	44	0.9	31	73	-	31	74
14	8.7	35	11	5.0	32	68	3.8	29	80
15	-	30	76	4.7	29	84	-	30	82
16	-	36	58	-	30	84	1.2	29	88
17	-	36	56	-	30	81	0.4	28	91
18	-	36	63	18.7	30	78	-	31	75
19	-	35	54	11.2	29	82	-	31	69
20	-	36	50	0.9	30	88	2.1	30	73
21	-	37	56	12.8	28	73	-	29	80

22	Trace	36	61	-	27	88	Trace	29	84
23	-	37	60	6.3	30	72	-	30	66
24	-	37	61	24.0	28	84	4.5	31	67
25	6.0	36	62	11.0	29	78	3.5	31	73
26	-	32	77	3.4	30	76	4.8	28	87
27	5.3	36	63	52.5	31	80	11.0	29	84
28	11.1	33	74	28.8	28	88	33.6	30	87
29	5.7	33	71	-	30	84	-	31	81
30	Nil	35	71	-	30	84	Nil	29	77
31				4.1	31	85			
Σ	48.7	1063	1628	243	995	2382	87	904	2351
$\bar{x}$		35.4	54.3		30.8	76.8	-	30.1	78.3

	JULY			AUGUST			SEPTEMBER		
DATE	R.F.mm	ToC	% R.H.	R.F.mm	ToC	% R.H.	R.F.mm	ToC	% R.H.
1		28	74	0.6	29	85		30	75
2	-	29	78	9	29	91	4.3	31	77
3	26.6	28	88	9.7	25	83	0.9	31	73
4	-	24	67		28	83	0.2	29	80
5	-	28	79	-	27	95	14.6	29	78
6	-	29	81	25.7	29	76		30	76
7	8.8	28	86	5.7	26	83	-	31	72
8	8.8	29	82		29	82	-	31	77
9	12.2	28	82	TR	29	77	-	32	80
10	14.6	29	80	15.2	26	95		32	71
11	-	30	77	27.8	29	79	-	32	76
12	-	31	83	15.1	27	88	-	32	65
13	8.5	29	80	4.6	25	87	10.4	32	66
14	0.6	27	68		28	73		32	69
15	-	27	79	TR	30	82	-	31	68
16	2.3	28	83	26.6	30	78	12.8	31	71
17	6.6	28	73	1.0	27	87	1.9	29	85
18	3.5	30	69		27	83	-	31	71
19	1.2	26	89	28.1	29	84	-	32	73
20	TR	27	84		27	90		32	71
21	51.0	27	93		29	78	-	31	77

22		25	89	15.9	30	87	4.1	32	77
23	TR	28	76		30	82	-	32	76
24	1.2	29	79	43.7	29	83		32	68
25	30.0	30	83	33.7	27	87		32	75
26	-	27	79	15.5	28	83		32	69
27		28	79	10.6	29	83		32	61
28		28	79	33.0	29	85	0.5	33	68
29	10.5	29	80	-	26	95	-	32	77
30	3.2	28	89	-	28	83	1.5	31	68
31		29	83	5.9	25	91			
Σ	189.6	871	2491	329.0	866	261.8	51.2	939	2185
$\bar{x}$		28.1	80.3		27.9	84.4	-	31.3	72.87

	OCTOBER			NOVEMBER			DECEMBER		
DATE	R.F.mm	ToC	% R.H.	R.F.mm	ToC	% R.H.	R.F.mm	ToC	% R.H
1		33	63	Nil	33	30	Nil	30	20
2	-	31	68	-	33	19		30	20
3	25.6	31	69	-	33	25	-	32	19
4	-	31	68		32	19		32	17
5	3.1	31	77	-	31	25	-	33	15
6	-	32	63	-	31	23		34	12
7		31	80	-	31	19	-	34	15
8	-	31	77		31	20	-	33	18
9	-	32	85	-	31	26	-	31	24
10		32	81	-	30	15		31	21
11	-	33	61	-	29	22	-	30	19
12	-	32	72	-	30	22	-	30	16
13		32	66	-	31	22	-	30	18
14	TR	31	73		30	24		30	23
15	-	31	67		30	27	-	27	37
16		32	60	-	31	22	-	24	26
17		30	70		32	18		23	23
18		32	71		32	18	-	26	22
19		32	68		32	19	-	28	18
20		32	71		33	18		28	16
21		31	67		33	19	-	29	23

22		31	66		33	18		27	25
23		32	66		34	20	-	25	22
24		32	60		32	15		25	19
25		33	67		33	15		25	25
26	-	33	67					26	25
27		34	66					28	24
28		33	41					26	23
29		33	27					26	28
30		33	43					27	24
31		33	66					27	18
Σ	28.7	992	2046	Nil	791	520	Nil	887	655
$\bar{x}$		32.0	66.0		31.6	20.8	-	28.6	21.1

	JANUARY			FEBRUARY			MARCH		1992
DATE	R.F.mm	ToC	% R.H.	R.F.mm	ToC	% R.H.	R.F.mm	ToC	% R.H
1	Nil	24	24	Nil	33	16			
2	-	24	26	-	32	20			
3	-	20	30	-	32	17			
4	-	20	26	-	29	9			
5	-	19	28	-	28	34			
6	-	20	30	-	27	15			
7	-	23	23	-	29	14			
8	-	25	17	-	29	16			
9	-	25	21	-	29	6			
10	-	24	26	-	30	11			
11	-	23	27	-	31	13			
12	-	22	33	-	29	14			
13	-	25	22	-	29	10			
14	-	26	31	-	29	9			
15	-	25	15	-	29	11			
16	-	27	19	-	29	8			
17	-	27	22	-	30	7			
18	-	29	22	-	30	2			
19	-	28	16	-	29	11			
20	-	30	11	-	32	7			
21	-	31	16	-	33	7			

22	-	31	15	-	34	7
23	-	31	18	-	36	8
24	-	30	17	-	35	18
25	-	28	11	-	27	25
26	-	27	19	-	25	12
27	-	32	22	-	26	11
28	-	33	27	-	29	17
29	-	33	20	-	31	9
30	-	34	18			
31	-	32	16			
Σ	-	828	618	-	871	364
$\bar{x}$	-	27.7	21.5	-	30.0	12.6

APPENDIX X : mean weekly temperature and relative humidity readings for the period of life cycle experiment from the first week of adult R.dominica emergence

Week	Date	T°C	% RH.
1	21/12/91	39.0	23.0
2	28/12/91	26.0	23.28
3	4/01/92	24.0	28.43
4	11/01/92	22.7	28.30
5	18/01/92	25.9	23.43
6	25/01/92	29.86	14.85
7	1/02/92	32.0	21.29
8	8/02/92	29.43	12.86
9	15/02/92	31.0	7.0
10	29/02/92	29.86	14.29
11	29/02/92	31.0	9.0